AGRO - 507 (P)

Irrigation Agronomy:

Evapotranspiration (ET)

① Evapotranspiration (ET) is a term used to describe the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere. **Evaporation** accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. ③ **Transpiration** accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.

④ 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 ⑤ 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. ⑥ 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. In Figure 1 the partitioning of evapotranspiration into evaporation and transpiration is plotted in correspondence to leaf area per unit surface of soil below it. At sowing nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration.

⑦ The evapotranspiration rate is normally expressed in millimetres (mm) per unit time.

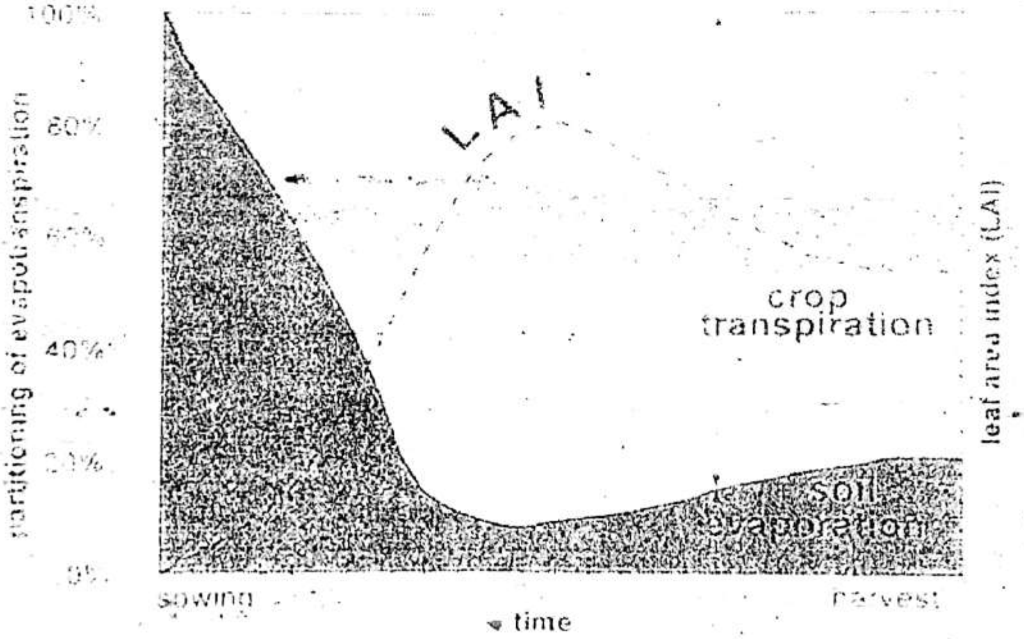

Fig 1: Partitioning of ET as affected by growth stages

Potential Evapotranspiration (PET) is a representation of the environmental demand for evapotranspiration and represents the ① evapotranspiration rate of a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile. It is a reflection of the energy available to evaporate water, and of the wind available to transport the water vapour from the ground up into the lower atmosphere. ② **Evapotranspiration** is said to equal **potential evapotranspiration** when there is ample water.

Potential evapotranspiration (PET) is the amount of water that could be evaporated and transpired if there was sufficient water available. This demand incorporates the energy available for evaporation and the ability of the lower atmosphere to transport evaporated moisture away from the land surface. (3) PET is higher in the summer, on less cloudy days, and closer to the equator, because of the higher levels of solar radiation that provides the energy for evaporation. PET is also higher on windy days because the evaporated moisture can be quickly moved from the ground of plants, allowing more evaporation to fill its place.

PET is expressed in terms of a depth of water, and can be graphed during the year. There is usually a pronounced peak in summer, which results from higher temperatures.

(4) Potential evapotranspiration is usually measured indirectly, from other climatic factors, but also depends on the surface type, such free water (for lakes and oceans), the soil type for bare soil, and the vegetation. (5) Often a value for the potential evapotranspiration is calculated at a nearby climate station on a reference surface, conventionally short grass. This value is called the **reference evapotranspiration** (ET_0) and can be converted to a **potential evapotranspiration** by multiplying with a **surface coefficient**. (6) In agriculture, this is called a **crop coefficient**. (7) The difference between potential evapotranspiration and precipitation is used in irrigation scheduling.

Evapotranspiration concepts

Distinctions are made (Figure 2) between reference crop evapotranspiration (ET_o), crop evapotranspiration under standard conditions (ET_c) and crop evapotranspiration under non-standard conditions ($ET_{c\ adj}$). ET_o is a climatic parameter expressing the evaporation power of the atmosphere. ET_c refers to the evapotranspiration from excellently managed, large, well-watered fields that achieve full production under the given climatic conditions. Due to sub-optimal crop management and environmental constraints that affect crop growth and limit evapotranspiration, ET_c under non-standard conditions generally requires a correction.

1. Reference crop evapotranspiration (ET_o)

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ET_o. The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as potential ET is strongly discouraged due to ambiguities in their definitions.

The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. It obviates the (2) need to define a separate ET level for each crop and stage of growth.
(3) ET_o values measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface.
(4) The only factors affecting ET_o are climatic parameters. Consequently, ET_o is a climatic parameter and can be computed from weather data. ET_o 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.

2. Crop evapotranspiration under standard conditions (ET_c) (1)

The crop evapotranspiration under standard conditions, denoted as ET_c, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions.

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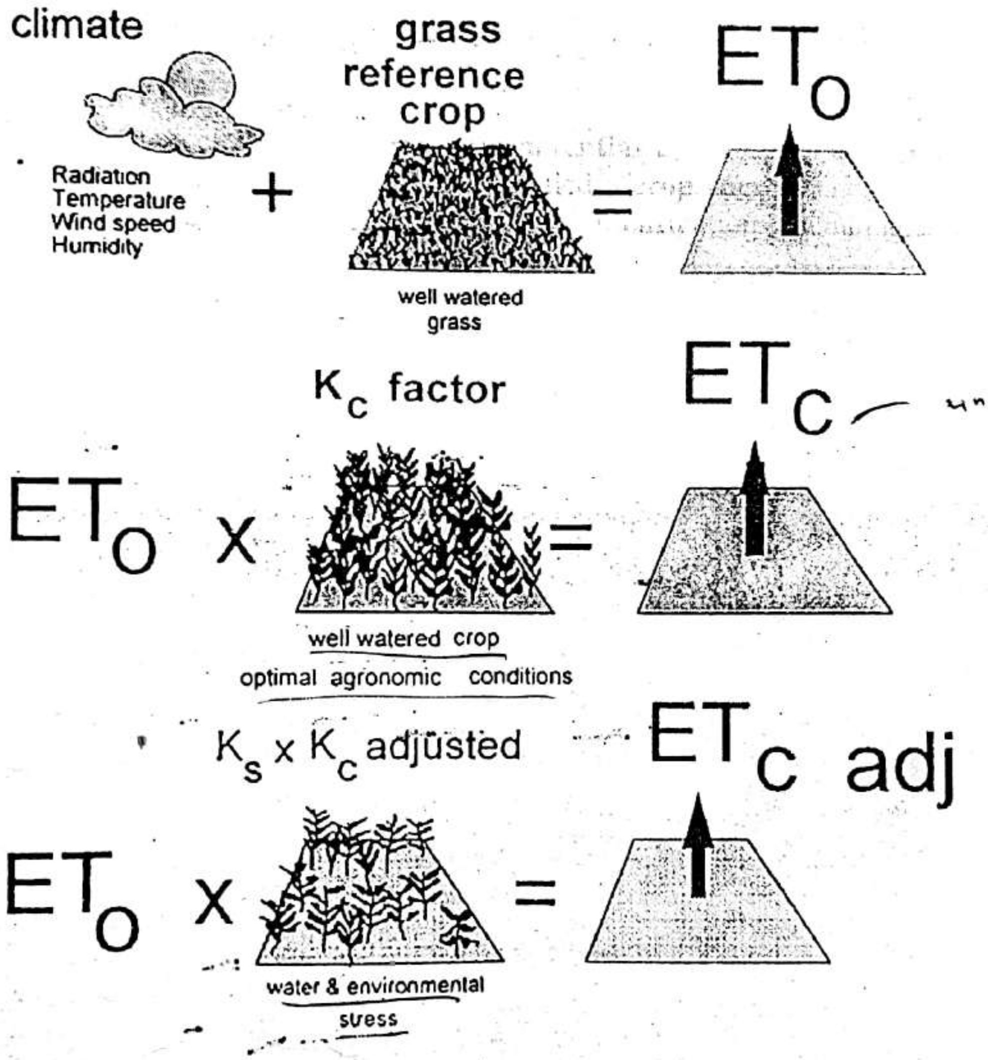
3. Crop evapotranspiration under non-standard conditions ($ET_{c\ adj}$) ①

The crop evapotranspiration under non-standard conditions ($ET_{c\ adj}$) is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions. ② When cultivating crops in fields, the real crop evapotranspiration may deviate from ET_c due to non-optimal conditions such as the presence of pests and diseases, soil salinity, low soil fertility, water shortage or waterlogging. ③ This may result in scanty plant growth, low plant density and may reduce the evapotranspiration rate below ET_c.



under standard condition

→ Under non-standard condition

Fig 2. Reference (ET_o), crop evapotranspiration under standard (ET_c) and non-standard conditions ($ET_{c\ adj}$)

Three major steps involved in estimation of ET are:

1. Estimation of PET or reference ET (ET_0)
2. Converting ET_0 to ET_c by multiplying it by K_c (Crop Coefficient) of the crop under study
3. Making appropriate adjustments to location specific crop environment

Input Data Required for Estimating ETo:

Different methods of estimating ETo require different input data of climate (meteorological / climatological data)

e.g. Blanney Criddle method require ① temperature, and ② day length etc.

Climatological Nomanclature:

① - Temparature (T)

Hot : $T_{mean} > 30°C$

Cool : $T_{mean} < 15°C$

$$T_{mean} = \frac{T_{max} + T_{min}}{2}$$

② - Humidity (Relative Humidity = RH):

It is measured throgh ① Hygrograph or ② wet & dry bulb thermometer.

① RH_{min} (minimum RH). It is the lowest humidity during day time & is reached usually at 2:00 pm to 4:00 pm. when it is read at 12:00 pm, subtract 5-10 for humid climate, " " " upto 30 " desert "

It is considered :- Low = < 20% &
Medium = 20-50%
High = > 50%

{ A climate having < 20% RH_{min} is considered dry climate & > 70% is considered humid climate

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ⅱ RH_{mean} (nearer mean R.H.) :

It is the average of max. & min R.H. or

$$RH_{mean} = \frac{RH_{max} + RH_{min}}{2}$$

If it is < 40% = Low
- 40-$\overset{55}{45}$% = Medium to low
- 55-70% = Medium to high
- > 70% = High

ⅲ RH_{max} (max R.H.)

It is usually reached before sunrise ✓

RH_{max} = 90-100% in humid Climate

= 80-100% in Semi-arid climate (where T_{min} is 20-25 °C lower than T_{max})

= 25-40% in arid areas (where T_{min} is 15 °C lower than T_{max})

Sunshine : It is the proportion of bright sunshine hrs to total day length

3- Radiation (Ra) :

Sunshine	
Sunshine	n/N
Low	< 0.6
medium	0.6 – 08
High	> 0.8

where, n = daily actual bright sunshine hrs

N = daily max possible " "

- If n/N = 08 it is considered that there was near bright sunshine all the day.

n/N = 0.6 – 08 " " " 40% of the day time remained full cloudy or 70% of " " " " partial cloudy

4- Wind (Wind Velocity) :

Indication	$m s^{-1}$	Wind Velocity $km\ day^{-1}$	Classification
leaves start rustling	< 2	< 175	Light
Twigs move, paper blowing away, leaf flies	2 – 5	175 – 425	Moderate
Small branches move, dust raises	5 – 8	425 – 700	strong
Small trees start moving	> 8	> 700	Very strong (storm)

{Latitude of Fsd = 31°25' N
{Longitude " " = 73°5' E }

{Lat of Pak = 23-34° N
{Long. of Pak = 70° E

Lat of Sgd = 32°5' 1" N → 32°05' N
Long of " = 72°40' 16" E → 72°67' E

Determination of Crop water Requirements:

Methods for crop water requirements are used owing to the difficulty of obtaining accurate field measurements. ① Testing the accuracy of these methods under a new set of conditions is laborious(i), time consuming(ii) & costly(iii), yet ② crop water requirement data are frequently needed for irrigation planning/scheduling(ii). To meet this requirement, guidelines are presented to calculate the water requirements of crop under different climatic & agronomic conditions.

③ → Crop water Requirement is defined as the depth of water needed to meet the water loss through ET of a disease free crop, growing in field under non-restricting soil conditions (both soil water & fertility) & achieving full production potential under the given growing envmt. ④ To calculate ET of a crop, a three-stage procedure is recommended:

i) Estimation of PET or Reference crop ET (ET₀).
ii) Determination of crop Co-efficients (Kc).
iii) Making appropriate adjustments to location-specific crop environment.

→ **Effect of Climate on Crop water Requirement:**

① This is indicated by the reference crop ET which is defined as "the rate of ET from an extensive surface of (i) 8-15 cm tall green grass cover of uniform (ii) height, actively (iii) growing, completely (iv) shading the ground and not short of water (v)".

② All the methods are modified to calculate ET₀ using the mean daily climatic data for a period of a week or 10 days.

③ Primarily the choice of method must be based on the type (i) of climatic data available (ii) & on the accuracy (iii) required in determining water requirement.

④ → The modified Penman method offer the best results with min. possible errors i.e upto 10%.
⑤ The pan-evaporation method can be graded next. with possible error upto 15% depending upon the location of the pan ⑥ The radiation method involves a possible error of 20%. ⑦ Blanney Cridle method should only be applied in humid, windy, mid

latitude winter conditions. The margin of error in this method is upto (25%) under these conditions.

⑧ Thus Penman method is superior than other methods & therefore extensively used all over the world.

$EC \geq 4\ dS\ m^{-1}$

$SAR \geq 13\ (15)$

$ESP \geq 15$

Estimation of PET (ETo):

1. Blanney-Criddle Method:
2. Radiation method
3. Penman Method
4. Pan-evaporation method

① Blanney-Criddle Method:

This method is used for estimation of Reference Crop evapotranspiration

$$ETo = C\left[P(0.46\bar{T} + 8)\right]$$

where

ETo = reference evapotranspiration mm day^{-1} / mm month^{-1}

$\bar{T}$ = mean daily Temperature (°C) which is calculated as $\bar{T} = (T_{max} + T_{min})/2$

P = mean daily percentage of annual daytime hours based on the respective month & latitude (Consult table-I)

C = adjustment factor which depends upon RH_{min}, daytime wind velocity & ratio of n/N (Consult fig-I)

Example: Calculate ETo for wheat season (Nov to April).

(latitude of Fsd = 31°.25′N . Lat. of Pak = 26-35°N
" " Sgd = 32°.05′N . long. " " = 62-76°E

Wheat Season	T (°C)		
	Max	Min	Mean
Nov	28.3	11.3	19.8
Dec	23 4	6.3	14.9
Jan	18.0	5.5	11.8
Feb	20.9	7.2	14.1
March	27.4	12.5	20.0
Aprie	37.8	20.4	29.1

ver,
Lat. = 31°.25' N (Fsd)
= 32°.05' N (Sgd).

(i) In November:

Conditions for C factor

$T_{max} = 28.3\ °C$ — $R.H._{min}$ = medium

$T_{min} = 11.3\ °C$ — Wind velocity = light

$T_{mean} = 19.8\ °C$ — n/N ratio = Low (< 0.6)

$$P(0.46\bar{T} + 8) = \overset{\text{From table - 1}}{0.24}(0.46 \times 19.8 + 8)$$

$$= 4.11$$

By the value of $P(0.46\bar{T} + 8)$ and Climatic Conditions (RH_{min}, Sunshine (n/N), & daytime wind speed), ETo can be observed from Fig 1.

From Fig 1. in graph - VIII,

ETo = 2.8 mm/day (average per day).

ETo = 2.8 × 30 = 84 mm/month (for total month of Nov)

June, July, Aug, Sept = high Sunshine (upto 0.8)
Oct, Nov, Dec, Jan = Low " (upto 0.45)
Feb, March, April, May = Medium " (upto 0.7)

$ET_o = 2.8$ mm day^{-1} (Average daily ET_o for month of Nov)

$ET_o = 2.8 \times 30 = 84$ mm/month (ET_o for total month of Nov.)

ii) In December :-

→ $T_{max} = 23.4°C$

$T_{min} = 6.3°C$

$T_{mean} = 14.85°C$

→ Condition for C factor

- $R.H._{min}$ = High
- low n/N ratio
- low wind speed.

→ $P = 0.23$

→ $P(0.46\,\overline{T} + 8) = 0.23\,(0.46 \times 14.85 + 8)$
$= 3.41$

→ According to graph (IX),

$ET_o = 1.3$ mm day^{-1} (Average daily ET_o)

$ET_o = 1.3 \times 31 = 40.3$ mm/month (for total montl

iii) In January :-

→ $T_{max} = 18 °c$

$T_{min} = 5.5 °c$

$T_{mean} = 11.75 °c$

→ Conditions for 'c' factor

- R.H. = High
- Low n/N ratio
- Low wind speed.

→ $P = 0.24$

→ $P(0.46\bar{T} + 8) = 0.24(0.46 \times 11.75 + 8)$

$= 3.2172$

→ According to graph (IX),

$ET_0 = 1.0$ mm day^{-1} (Average daily ET_0)

$ET_0 = 1.0 \times 31 = 31.0$ mm/month (for total month)

iv) In February :-

→ $T_{max} = 20.9 °c$

$T_{min} = 7.2 °c$

$T_{mean} = 14.05 °c$

→ Conditions for 'C' factor.
- R.H. = High
- Medium n/N ratio
- Low wind speed

→ $P = 0.25$

→ $P(0.46\bar{T} + 8) = 0.25(0.46 \times 14.05 + 8)$
$= 3.616$

→ According to graph (VI),

$ET_0 = 1.9$ mm day^{-1} (average daily ET_0)

$ET_0 = 1.9 \times 29 = 55.1$ mm/month (for total month)

v) <u>In March :-</u>

→ $T_{max} = 27.4°C$
$T_{min} = 12.5°C$
$T_{mean} = 19.95°C$

→ Conditions for 'C' factor
- R.H. = Low
- Medium n/N ratio
- low wind speed

→ $P = 0.27$

→ $P(0.46\bar{T} + 8) = 0.27(0.46 \times 19.95 + 8) = 4.638$

→ According to graph (IV),

$ET_0 = 4.4$ mm day^{-1} (Average daily ET_0)
$ET_0 = 4.4 \times 31 = 136.4$ (for total month)

vi) In April :-

→ $T_{max} = 37.8\,^\circ C$
$T_{min} = 20.4\,^\circ C$
$T_{mean} = 29.1\,^\circ C$

→ conditions for 'C' factor
- R.H. = low
- Medium n/N ratio
- low wind speed

→ $P = 0.29$

→ $P(0.46\overline{T} + 8) = 0.29(0.46 \times 29.1 + 8)$
$= 6.202$

→ According to graph (IV),

$ET_0 = 6.8$ mm day^{-1} (Average daily ET_0)
$ET_0 = 6.8 \times 31 = 210.8$ mm/month (for total month)

$ET_0 = 6.8 \times 15 = 102$ mm/month (upto 15th April)

V7.

Crop Co-efficients (Kc) of Some Selected crops :-

Crop	Crop Development Stages					Total growing period
	Initial	crop development	mid season	late season.	At harvest.	
✓ Bean	0·3–0·4	0·65–0·75	0·95–1·05	0.9–0.95	0·85–0·95	0·85–0·9
✓ Cotton	0·4–0·5	0·7–0·8	1·05–1·25	0·8–0·9	0·65–0·7	0·8–0·9
G.nut	0·4–0·5	0·7–0·8	0·95–1·1	0·75–0·85	0·55–0·6	0·75–0·8
✓ Maize	0·3–0·5	0·7–0·9	1·05–1·2	1·0–1·15	0·95–1·1	0·8–0·95
Potato	0·4–0·5	0·7–0·8	1·05–1·2	0.85–0·95	0·7–0·75	0·75–9.0
✓ Rice	1·1–1·15	1·1–1·5	1·1–1·3	0·95–1·05	0·95–1·05	1·05–1·2
✓ Safflower	0·3–0·4	0·7–0·8	1·05–1·2	0·65–0·7	0·2–0·25	0·65–0·7
Sorghum	0·3–0·4	0.7–0·75	1·0–1·15	0·75–0·8	0·5–0·55	0·75–0·9
Sugar beat	0·4–0·5	0·75–0·85	1·05–1·2	0·9–1·0	0·6–0·7	0·8–0·9
✓ S. cane	0·4–0·5	0·75–1·0	1·0–1·3	0·75–0·8	0·5–0·6	0·85–1·05
✓ Sunflower	0·3–0·4	0·7–0·8	1·05–1·2	0·7–0·8	0·35–0·45	0·75–0·85
Tobacco	0·3–0·4	0·7–0·8	1·0–1·2	0·9–1·0	0·75–0·85	0·85–0·95
Tomato	0·4–0·5	0·7–0·8	1·05–1·25	0·8–0·95	0·6–0.65	0·75–0·9
✓ wheat	0·3–0·4	0·7–0·8	·05–1·2	0·65–0·75	0·2–0·25	0·8–0·9
✓ Alfalfa	0·3–0·4				1·05–1·2	0·85–1·05
Soybean	0·3–0·4	0·7–0·8	1·0–1·15	0·7–0·8	0·4–0·5	0·75–0·9

2) Radiation Method :- Date :- [redacted]

① → This method is an adaptation of Makkinic Formula (1957) ② This method is suggested for areas where available climatic data include air temp., sunshine hours, cloudiness or radiation, but not measured wind & humidity.
③ → This method is more reliable than Blaney-Criddle Method. Infact in equatorial zones, small islands or at high altitudes, radiation method is more reliable, even if sunshine data are not available.

Formula :- -

$$ET_0 = C(W \cdot R_s)$$

Where ET_0 = Reference ET for the period considered

R_s - Solar radiation in equivalent evaporation (mmday^{-1}) (from equation I)

W = weighting factor for the effect of radiation on ET_0, which depends on temp. & altitude (from table 4).

C = adjustment factor which depends on mean R.H. & daytime wind conditions (from fig. 2)

$$R_s = \left(0.25 + 0.50 \times \frac{n}{\underset{\text{(From table 3)}}{N}}\right) R_a \text{ ——— (I)}$$

where n/N = ratio b/w actual measured bright sunshine hrs & max. daylength hrs

- Ra = Extra terrestrial Radiation expressed in equivalent evaporation (mm/day) - Consult table 2

Example :-

	latitude	Altitude
Faisalabad	31° N	; 150 m
Sargodha	32°.05′ N	193 m

, n = 12 hrs

T_{mean} = 31.8 °C

R.H = Medium

wind speed = modrate (2-5m/s)

For July :-

→ Ra = 16.8 $mm\,day^{-1}$ (from the table 2)

N = 14 hrs (from table 3), n = 12 hrs.

$$R_s = \left(0.25 + 0.50 \times \frac{12}{14}\right) 16.8$$

R_s = 11.4 $mm\ day^{-1}$.

→ T_{mean} = 31.8 °C

W = 0.79 (from table 4)

→ $W \cdot R_s = 0.79 \times 11.4$

$= 9\ mm\,day^{-1}$ ✓

→ conditions for C - factor :-

R.H. = medium

wind speed moderate

→ ET_o = 8.5 $mm\,day^{-1}$ (from figure 2, block II)

B) calculation of ET_0 for each month of wheat Season (Nov. — April) By Radiation Method :-

$$ET_0 = C\,(W \cdot R_s)$$

Example (Fsd.) :-

Month	Bright Sunshine hrs. (n)	R.H mean
Nov	8	Medium
Dec	8	High
Jan	8	High
Feb	8.5	High
March	10	Medium
April	10.5	Low

i) In November :-

→ $R_a = 9.5$ mm day^{-1} (from table 2)

$N = 10.6$ hrs (from table 3)

$n = 8$ hrs

$$R_s = \left(0.25 + 0.50 \times \frac{8}{10.6}\right) \overset{\boxed{9.0}}{9.5}$$

$= 5.96$ mm day^{-1}

→ $T_{mean} = 19.8$ °C

$W = 0.67$ (from table 4)

→ $W \cdot R_s = 0.67 \times 5.96$

$= 3.99 \simeq 4$ mm day^{-1}

→ Conditions for "C" factor

R.H. = medium

wind speed = moderate

→ $ET_0 = 4$ mm/day. (block II)

ii) <u>In December</u> :-

→ $R_a = \overset{7.8}{8.3}$ mm day^{-1}

$N = 10.2$ hrs.

$n = 8.0$ hrs.

$$R_s = \left(0.25 + 0.50 \times \frac{8}{10.2}\right) \overset{7.8}{8.3}$$

$$= \underset{5.0}{5.33} \text{ mm day}^{-1}$$

→ $T_{mean} = 14.85°C$

$W = 0.62$

→ $W \cdot R_s = 0.62 \times 5.33 = \overset{3.05}{3.3}$ mm day^{-1}

→ Conditions for C factor :

R.H. = High

Wind Speed = moderate

→ $ET_0 = \overset{2.5}{\cancel{2.5}}\ 2.4$ mm day^{-1} (block IV)

iii) <u>In January</u> :-

→ $R_a = \overset{8.3}{8.8}$ mm day^{-1}

$N = 10.4$ hrs

$n = 8$ hrs

$$R_s = \left(0.25 + 0.50 \times \frac{8}{10.4}\right) \overset{8.3}{8.8}$$

$$\underset{5.26}{} \quad \underset{5.3}{}$$

$$= 5.58 = 5.6 \text{ mm day}^{-1}$$

→ $T_{mean} = 11.75\,^\circ C\ (11.8\,^\circ C) \simeq 12\,^\circ C$.

$W = \boxed{0.57}\ 0.58$

$3.05\ (3.1)$

→ $W \cdot R_s = 0.57 \times 5.6 = \boxed{3.2}$ mm day^{-1}

→ Conditions for C factor

R.H = high, wind speed = moderate

→ $ET_0 = \boxed{2.4}\ \boxed{\cancel{2.4}}\ \boxed{2.9}$ mm day^{-1} (block IV)

iv) <u>In February</u> :-

10.2

→ $R_a = \boxed{10.7}$ mm day^{-1}

$N = 11.1$ hrs.

$n = 8.5$ hrs.

$$R_s = \left(0.25 + 0.50 \times \frac{8.5}{11.1}\right) \overset{10.2}{\boxed{10.7}}$$

6.45

$R_s = \boxed{6.77}$ mm day^{-1}

→ $T_{mean} = 14.05\,^\circ C$

$W = \boxed{0.61}\ 0.61$

→ $W \cdot R_s = 0.61 \times 6.77$

$= \boxed{4.13}\ 3.93$ mm day^{-1}

→ Conditions for C factor

R.H = high

wind speed = moderate

→ $ET_0 = \boxed{3.1}\ 2.9$ mm day^{-1} (block IV)

v) <u>In March</u> :-

→ $R_a = \overset{12.8}{13.1}$ mm day^{-1}

$N = 12$ hrs

$n = 10$ hrs

$$R_S = \left(0.25 + 0.50 \times \frac{10}{12}\right)\left(\overset{12.8}{13.1}\right)$$

$$= \underset{8.53}{8.73} \text{ mm day}^{-1}$$

→ $T_{mean} = 19.95°C \simeq (20°C)$

$W = 0.68$

→ $W \cdot R_S = 0.68 \times \overset{8.53}{8.73}$ ✓

$= \underset{5.8}{5.936}$ mm day^{-1}

→ Conditions for C factor

R.H. = Medium

wind speed = Moderate

→ $E.T_0 = \overset{5.8}{5.9}$ mm day^{-1} (block II)

vi) <u>In April</u> :-

→ $R_a = \overset{15.0}{15.2}$ mm day^{-1}

$N = 12.9$ hrs

$n = 10.5$ hrs

$$R_S = \left(0.25 + 0.50 \times \frac{10.5}{12.9}\right)\left(\overset{15.0}{15.2}\right)$$

$R_s = \overset{9.85}{\boxed{9.98}}$ mm day^{-1}

→ $T_{mean} = 29.1\,^{\circ}C$

$W = 0.775$

→ $W \cdot R_s = 0.775 \times \overset{9.85}{\boxed{9.98}}$

$= \underset{7.58}{\boxed{7.73}}$ mm day^{-1}

→ Conditions for 'C' factor

R.H. = low

wind speed = Moderate ✓

→ From block (I)

$ET_0 = \overset{8.2}{\boxed{8.3}}$ mm day^{-1}

m. maqsd

[redacted]

3) Penman's Method (1948):-

①It is the most accurate method of determining reference ET (ET_0) which is also called PET.
②For areas where data on temp.(i), humidity(ii), wind(iii), sunshine duration(iv) or radiation measurements are available, Penman method (1948) is suggested compared to other methods.
③The original Penman (1948) equation predicts evaporation losses from an open water surface i-e Pan. The Penman equation consisted of two terms:-

① Energy Term (Radiation term)
② Aerodynamic Term related to wind & humidity

The relative importance of each term varies with climatic conditions. ①Under calm weather conditions, the Aerodynamic term becomes less important than Energy term. under such condition the original Penman equation using a crop-coefficient of 0.8 has been shown to predict ETo closely, not only in cool humid regions like England where it was originated, but also in very hot & semi-arid regions. ②It is under windy conditions & especially under more arid regions that Aerodynamic term becomes relatively more important. Thus errors can result in predicting ETo when using 0.8 factor. Therefore a slightly modified Penman equation is suggested to determine ETo involving a

revised wind function term.
The method being uses daily climatic data, since day & night weather conditions considerably affect the rate of ET

Formula :-

$$ET_o = C\left[\underbrace{W\cdot R_n}_{\text{radiation term}} + \underbrace{(1-W)\cdot f(u)\cdot(ea-ed)}_{\text{Aerodynamic term}}\right]$$

where

W = Temp. related & altitude weighting factor - Consult table-9
(weighting factor for effect of radiation on ET_o)

R_n = net radiation in equivalent evaporation (mm day^{-1}) ($R_n = R_{ns} - R_{nl}$)

1 - W = weighting factor for the effect of wind & humidity on ET_o (Consult table-8)

f(u) = wind related function → Table-7

ea - ed = Saturation vapour pressure deficit of the air (millibar) ← Table-5

ed = ea × R.H mean/100

C = adjustment factor compensate by day & night weather condition from (Table-16)

① The suggested wind function applies to the conditions found during summer with (i) moderate wind, (ii) R.H. of 75%, and day-night wind ratio of 1.5 - 2.0 (iii). For these conditions, no adjustment is required. ② However if 24 hrs wind totals are used, there will be:

$\left\{ \begin{array}{l} \frac{U_{day}}{U_{night}} \text{ high = underprediction so high value of c} \\ U_{day}/U_{night} \text{ low = overprediction so low value of c} \end{array} \right.$

a) an **underprediction** of ET_0 by 15-30% in areas where day time wind greatly exceeds night time wind and where R.H approaches 100%. and also radiation is high.

4) Conversely for areas experiencing moderate to strong winds, where night time humidity is low & radiation is also low, the equation will over-predict ET_0. This over prediction increases with decreasing ratio of $\frac{U_{day}}{U_{night}}$

Therefore under these conditions, adjustment factor (C) should be applied.

→ Vapour pressure deficit $(e_a - e_d)$:-
air humidity affects ET_0. Humidity is expressed as saturation v.p. deficit $(e_a - e_d)$.

→ wind Function $(f(u))$:-
The effect of wind on ET_0 is defined as :-

$$f(u) = 0.27\left(1 + \frac{u_2}{100}\right)$$

where u is 24 hrs wind run in km per day at reference height (2m)

→ Original Penman Formula :-

$$\underset{(ET_0)}{PET} = \underbrace{R_n \Delta/(\Delta+\gamma)}_{\text{Radiation}} + \underbrace{E_a \gamma/(\Delta+\gamma)}_{\text{wind portion}}$$

Example :- Calculate ETo by Penman method for the month of July for a location having 30°N latitude from following climatic data

Saturation v.p (ea) : v.p. of air at 100% R.H. is called Saturation v.p (ea

Actual v.p (ed) : v.p. of air at the actual R.H is called actual v.p.

VPD : Difference b/w ea & ed of air is called VPD. More its value is more will be the dryness in air & vice versa.

→ $T_{max} = 35°C$

$T_{min} = 22°C$

$T_{mean} = 28.5°C$

→ $R.H._{max} = 80\%$

$R.H_{min} = 30\%$

$R.H_{mean} = 55\%$ & $n = 11.5$

Wind speed at 2 m height = 232 km/day

$\frac{U_{day}}{U_{night}} = 1$

A- Determination of Aerodynamic term $\{ \overset{③}{(1-W)} \cdot \overset{②}{f(u)} \cdot \overset{①}{(ea - ed)} \}$

① → Saturation v.p. (e_a) at 28.5°C = 38.9 m.bar (Table-5)

actual " (e_d) " " $= e_a \times R.H_{mean} / 100$

ed at 100% R.H = 38.9 m bar

" " 55% " $= \frac{38.9}{100} \times 55$

$= 38.9 \times 55 / 100$

$= 21.4$ m.bar.

$e_a - e_d = 38.9 - 21.4$

$= 17.5$ m.bar.

② → wind run at 2 m height = u

~~(u = 250 km/day)~~

u = 232 Km/day

$f(u) = 0.27 \left(1 + \frac{u_2}{100}\right)$

$= 0.27 \left(1 + \frac{232}{100}\right)$

$= 0.90$

(or) $f(u) = 0.90$ (from table-7)

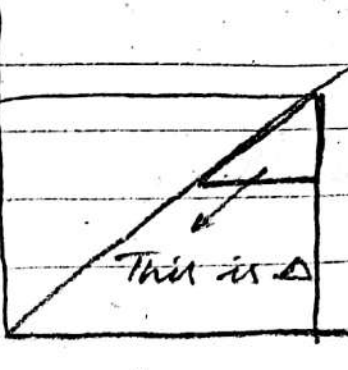
③ → (1 - W) is weighting factor for effect of wind and humidity on ETo (related to temp. & altitude)

Δ = rate of change of saturation v.P. with temp.

~~$W = \Delta / (\Delta + \gamma)$~~

In American literature
Δ is S.

γ = Psychrometric constant
its value is (0.66) m.bar.



0.66 m.bar = 66 Pascal) X

values of $(1-W)$ as related to Temp. & altitude is given in (table - 8)

Altitude = 95 m
T_{mean} = 28.5 °C

$(1-W)$ = 0.23 (in table 8)

Determination of radiation term $W \cdot R_n$ } → ① $W = 1 - 0.23 = 0.77$ or (from table - 9)
→ ② Net radiation (R_n):
in equivalent ET (mm day^{-1})

$R_n = R_{ns} - R_{nl}$

R_{nl} = net long wave radiation
R_{ns} = " short " "

→ Altitude = 95 m, Latitude = 30°N
T_{mean} = 28.5 °C
R.H.$_{mean}$ = 55%, ed = 21.4 m.bar

(from table (11)) → n = 11.5 hrs, N = 13.9 hrs } $n/N = \frac{11.5}{13.9} = 0.83$

$\rightarrow R_{ns} = (1-\alpha) R_s$ ↗ Extra-terrestrial radiation (Ra) expressed in equivalent evaporation (mm day^{-1}) from table-10.

$\rightarrow R_{ns} = \underbrace{(1-\alpha)\left(0.25 + 0.50 \frac{n}{N}\right)} R_a$

↳ It can be taken from table (12) or can be calculated as :

lat = 30°N ✓
Month = July

$\rightarrow R_a = 16.8$ mm day^{-1} (from table - 10)

✓ $R_S = \left(0.25 + 0.50 . \frac{n}{N}\right) R_a$

$= 11.2$ mm day^{-1} ✓

$\rightarrow R_{ns} = (1-\alpha) R_s$

$= (1 - 0.25)\, 11.2 = 8.4$ mm day^{-1} or (from table-12)

- From Table -

$(1-\alpha)\left(0.25 + 0.50 . \frac{n}{N}\right) = 0.50$

(as $n/N = 0.83$)

from Table-12

$R_{ns} = 0.50 \times 16.8 \rightarrow$ Table-10

$= 8.4$

α = radiation reflection co-efficient from crop surfaces its value is 0.25

$\rightarrow R_{nl} = f(T) . f(e_d) . f(n/N)$

$f(T) = 16.4$ (from table-13) ✓

$f(e_d) = 0.13$ (from table-14) ✓

$f(n/N) = 0.85$ (from table-15) ✓

$R_{nl} = 16.4 \times 0.13 \times 0.85$

$= 1.8$ mm day^{-1}

$\rightarrow R_n = R_{ns} - R_{nl}$

$= 8.4 - 1.8$

$= 6.6$ mm day^{-1} of ET_o

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$\rightarrow$ $C = 1.06$ (from $\overset{31\%}{\text{table}}$-16, using $\overset{80\%}{R.H._{max}}$, $\overset{11.2}{R_s}$, $U_{day}/U_{night} \overset{=1}{\text{ratio}}$ & U_{day} (m/sec), 2.68m/s

$$ET_o = C\left[W \cdot R_n + (1-W) \cdot f(u)(e_a - e_d)\right]$$

Value of W comes from table 9

$$= 1.06\left[0.77 \times 6.6 + 0.23 \times 0.90 \times 17.5\right]$$

$$= 1.06\left[5.082 + 3.6225\right]$$

$$= 9.22677 = 9.23 \text{ mm day}^{-1}$$

Data of monthly mean Temp, R.H. & wind Speed for the year [redacted] :-

uday U_2

Mouth	Tmean (°C)	R.H mean	R.H max.	wind Speed m/sec	wind Speed Km/day	m/N
January	12.85	90	95.7	1.9	164.16	5.4/10.4 = 0.52
February	16.8	66	75.8	2.27	196.32	6.6/11.1 = 0.60
March	21.0	44.4	50.6	2.62	226.08	8/12 = 0.67
April	28.45	30.2	34.7	2.56	220.8	9/12.9 = 0.70
May	33.3	31.6	37.1	3.18	274.56	9.5/13.6 = 0.70
June	33.8	32	38.6	3.85	332.64	10/14 = 0.71
July	33.65	44.3	54.5	4.27	369.12	8/13.9 = 0.58
August	32.9	49.5	55.6	3.72	321.6	8.32/13.2 = 0.63
Sept.	32.2	44	50.4	2.86	246.72	8.45/12.4 = 0.68
Oct.	29.35	44.6	53.9	1.79	154.56	8.7/11.5 = 0.76
Nov.	21.1	50.8	62.5	1.78	154.08	8.5/16.6 = 0.51
Dec.	15.85	60	78	1.36	117.6	8/10.2 = 0.78

Calculation of ET_o for each month of year [redacted] by Penman Method:-

1) For January :-

I) $T_{mean} = 12.85°c$ $R.H_{mean} = 90\%$

e_a at $12.85°c = 15$ m.bar. (Table-5)

e_d " " $= \dfrac{e_a \times R.H_{mean}}{100}$

$= \dfrac{15 \times 90}{100} = 13.5$ m.bar

$e_a - e_d = 15 - 13.5 = 1.5$ m.bar.

II) $u = 164.16$ km/day.

$f(u) = 0.27\left(1 + \dfrac{u}{100}\right)$

$= 0.27\left(1 + \dfrac{164.16}{100}\right) = 0.713$ km/day

III) Altitude = 150 m, $T_{mean} = 12.85°c$

$1 - W = 0.42$ (Table-8) ✓

$W = 0.58$ (Table-9)

IV) $T_{mean} = 12.85°c$, $R.H_{mean} = 90\%$

Altitude = 150m   latitude = 31°N

$e_d = 13.5$ m.bar $n/N = 0.52$

- $R_n = R_{ns} - R_{nl}$

$R_{ns} = (1 - \alpha) R_s$.

$R_a = 8.8$ mm/day (Table-10)

$R_s = \left(0.25 + 0.50 \frac{n}{N}\right) R_a$

$= (0.25 + 0.50 \times 0.52)\, 8.8$

$= 4.49$ mm/day.

→ $R_{ns} = (1 - \alpha) R_s$

$= (1 - 0.25)\, 4.49$

$= 3.37$ mm/day.

→ $R_{nl} = f(T) \cdot f(ed) \cdot f\left(\frac{n}{N}\right)$ — (from table 13, 14, 15)

$= 13.1 \times 0.18 \times 0.55$

$= 1.30$ mm day^{-1}.

→ $R_n = R_{ns} - R_{nl}$

$= 3.37 - 1.30 = 2.07$ mm day^{-1}

V) $R.H._{max} = 95.7\%$ $\qquad \frac{u_{day}}{u_{night}} = 2.0$ (1.9)

$R_s = 4.49$ mm/day

$u_{day} = 1.9$ m/sec. ✓ ~~[illegible]~~

$C = 0.89$ (from table-16)

$ET_o = C\left[W \cdot R_n + (1 - W) \cdot f(u) \cdot (e_a - e_d)\right]$

$= 0.89\,(0.58 \times 2.07 + 0.42 \times 0.713 \times 1.5)$

$= 0.89\,(1.20 + 0.449)$

$= 1.65$ mm/day.

$ET_o = 1.65 \times 31 = 51.12$ mm/month.

86400

2) For February :-

I) $T_{mean} = 16.8\,°C$ $\quad R.H_{mean} = 66\%$

e_a at 16.8 °c = 19.3 m.bar.

e_d " " $= \frac{e_a \times R.H_{mean}}{100}$

$= \frac{19.3 \times 66}{100} = 12.74$ m.bar.

$e_a - e_d = 6.56$ m.bar.

II) $u = 196.32$ km/day

$f(u) = 0.27\left(1 + \frac{196.32}{100}\right) = 0.8$

III) $1 - W = 0.35$

$W = 0.65$

IV) $R_a = 10.7$ mm/day.

$R_S = (0.25 + 0.50 \times 0.60)\,10.7 = 5.88$ mm/day.

$R_{ns} = (1 - 0.25)\,5.88 = 4.41$ "

$R_{nl} = 14 \times 0.195 \times 0.64 = 1.75$ "

→ $R_n = 4.41 - 1.75 = 2.66$ mm day^{-1}

R.Hmax = 75.8, [illegible], Rs = 5.88, u day = 196.32 km/day Rs = ✓

$\frac{196.32 \times 1000}{1 \times 3600 \times 24} = \boxed{2.27}$ m/sec

V) $C = 1.10$

$ET_0 = 1.10(0.65 \times 2.66 + 0.35 \times 0.8 \times 6.56)$

$= 3.92$ mm/day

$ET_0 = 3.92 \times 28 = 109.85$ mm/month

3) For March :-

I) $T_{mean} = 21°C$ $R.H_{mean} = 44.4\ \%$

e_a at 21°C = 24.9 m.bar

e_d " " $= \frac{e_a \times R.H}{100} = \frac{24.9 \times 44.4}{100} = 11.06$ m.ba

$e_a - e_d = 13.84$ m.bar.

II) $u = 226.08$ km/day.

$f(u) = 0.27\left(1 + \frac{226.08}{100}\right) = 0.88$

III) $1 - W = 0.305$

$W = 0.695$

IV) $Ra = 13.1\ mmday^{-1}$

$R_s = (0.25 + 0.50 \times 0.67)13.1$

$= 7.66\ mmday^{-1}$

$R_{ns} = (1 - 0.25)7.66 = 5.74\ mmday^{-1}$

$R_{nl} = 14.8 \times 0.205 \times 0.69 = 2.09\ mmday^{-1}$

$R_n = 5.74 - 2.09 = 3.65\ mmday^{-1}$

V) $C = 1.0$

$ET_o = 1.0(0.695 \times 3.65 + 0.305 \times 0.88 \times 13.84)$

$= 6.25\ mmday^{-1}$

$ET_o = 6.25 \times 31 = 193.79$ mm/month.

4) For April :- $ET_o = C[W \cdot R_n + (1-W) \cdot f(u) \cdot (e_a - e_d)]$

I) $T_{mean} = 28.45\ ^\circ C$ $R.H_{mean} = 30.2\ \%$

e_a at $28.45^\circ c = 38.9$ m.bar.

e_d " " " $= \frac{38.9 \times 30.2}{100} = 11.75$ m.bar.

$e_a - e_d = 27.15$ m.bar ✓

II) $u = 220.8$ km/day.

$f(u) = 0.27\left(1 + \frac{220.8}{100}\right) = 0.87$ ✓

III) $1 - W = 0.23$ ([illegible]) (Temp $= 28.5^\circ c$, Altitude $= 193$ m)

$W = 0.77$ (~~0.80~~)

IV) $R_a = 15.2$ mm day^{-1} (15.0 for SGD).

$R_s = (0.25 + 0.50 \times 0.70)\ 15.2$ (15.0 for SGD)

$= 9.12$ mm day^{-1} (9.0 for SGD)

$R_{ns} = (1 - 0.25)\ 9.12 = 6.84$ mm day^{-1} (6.75 for SGD)

$R_{nl} = 16.3 \times 0.19 \times 0.73 = 2.26$ "

$R_n = \overset{6.75}{6.84} - 2.26 = 4.58$ mm day^{-1} (4.49 mm day^{-1} (for SGD)

V) $C = 0.92$

$ET_o = 0.92(0.77 \times \overset{4.49}{4.58} + 0.23 \times 0.87 \times 27.15)$

$= 8.24$ mm day^{-1}.

$ET_o = 8.24 \times 30 = 247.28$ mm/month

5) For May :-

I) $T_{mean} = 33.3°C$, $R.H_{mean} = 31.6\%$

e_a at 33.3°C = 50.3 m.bar.

e_d " " $= \frac{50.3 \times 31.6}{100} = 15.89$ m.bar

$e_a - e_d = 50.3 - 15.9 = 34.4$ m.bar.

II) $u = 274.56$ km/day.

$f(u) = 0.27\left(1 + \frac{274.56}{100}\right) = 1.01$

III) $(1 - W) = 0.20$

$W = 0.80$

IV) $R_a = 16.5$ mmday^{-1}

$R_s = (0.25 + 0.50 \times 0.70)16.5 = 9.9$ mmday^{-1}

$R_{ns} = (1 - 0.25)9.9 = 7.42$ mmday^{-1}

$R_{nl} = 17.3 \times 0.16 \times 0.73 = 2.02$ mmday^{-1}

$R_n = 7.42 - 2.02 = 5.4$ mmday^{-1}

V) $C = 0.96$

$ET_o = 0.96(0.80 \times 5.4 + 0.20 \times 1.01 \times 34.4)$

$= 10.8$ mmday^{-1}

$ET_o : 10.8 \times 31 = 335.36$ mm/month.

6) For June :-

I) $T_{mean} = 33.8\,^{\circ}c$, $R.H_{mean} = 32\,\%$.

e_a at $33.8\,^{\circ}c = 53.2$ m.bar.

e_d " " $= \frac{53.2 \times 32}{100} = 17.02$ m.bar

$e_a - e_d = 36.18$ m.bar

II) $u = 332.64$ km/day.

$f(u) = 0.27\left(1 + \frac{332.64}{100}\right) = 1.17$

III) $(1-W) = 0.19$

$W = 0.81$

IV) $R_a = 17\ \text{mmday}^{-1}$

$R_s = (0.25 + 0.50 \times 0.71)17 = 10.3\ \text{mmday}^{-1}$

$R_{ns} = (1 - 0.25)10.3 = 7.71\ \text{mmday}^{-1}$

$R_{nl} = 17.7 \times 0.155 \times 0.73 = 2.003\ \text{mmday}^{-1}$

$\therefore R_n = 5.707\ \text{mmday}^{-1}$

V) $C = 0.97$

$ET_o = 0.97(0.81 \times 5.707 + 0.19 \times 1.17 \times 36.18)$

$= 12.28\ \text{mm day}^{-1}$

$ET_o = 12.28 \times 30 = 368.48$ mm/month

7) For July :-

I) $T_{mean} = 33.65°c$, $R.H_{mean} = 44.3\%$

e_a at $33.65°c = 53.2$ m.bar.

e_d " " $= \frac{53.2 \times 44.3}{100} = 23.57$ m.bar.

$e_a - e_d = 29.63$ m.bar.

II) $u = 369.12$ km/day.

$f(u) = 0.27 \left(1 + \frac{369.12}{100}\right) = 1.27$

III) $(1-W) = 0.19$

$W = 0.81$

IV) $Ra = 16.8$ mm day^{-1}

$R_s = (0.25 + 0.50 \times 0.58)\, 16.8 = 9.07$ mm day^{-1}

$R_{ns} = (1-0.25)\, 9.07 = 6.8$ "

$R_{nl} = 17.7 \times 0.12 \times 0.64 = 1.36$ "

$R_n = 5.44$ mm day^{-1}

V) $C = 0.97$

$ET_o = 0.97 (0.81 \times 5.44 + 0.19 \times 1.27 \times 29.63)$

$= 11.2$ mm day^{-1}

$ET_o = 11.2 \times 31 = 347.5$ mm/month

8) For August :-

I) $T_{mean} = 32.9\,°C$, $R.H_{mean} = 49.5\,\%$

e_a at 32.9 °c = 50.3 m.bar

e_d " " $= \frac{50.3 \times 49.5}{100} = 24.9$ m.bar.

$e_a - e_d = 25.4$ m.bar.

II) $u = 321.6$ km/day.

$f(u) = 0.27\left(1 + \frac{321.6}{100}\right) = 1.14$

III) $(1 - W) = 0.20$

$W = 0.80$

IV) $R_a = 15.7$ mm day^{-1}

$R_s = (0.25 + 0.50 \times 0.63)\,15.7 = 8.87$ mm day^{-1}

$R_{ns} = (1 - 0.25)\,8.87 = 6.65$ " "

$R_{nl} = 17.4 \times 0.12 \times 0.65 = 1.36$ " "

$R_n = 5.29$ mm day^{-1}

V) $C = 0.96$

$ETo = 0.96\,(0.80 \times 5.29 + 0.20 \times 1.14 \times 25.4)$

$= 5.56$ mm day^{-1}

$ETo = 5.56 \times 31$

$= 172.35$ mm/month

9) For Sept. :-

I) $T_{mean} = 32.2°c$ $R.H_{mean} = 44\%$

ea at 32.2°C = 47.6 m.bar.

ed " " $= \frac{47.6 \times 44}{100} = 20.9$ m.bar

ea - ed = 26.7 m.bar.

II) u = 246.72 km/day.

$f(u) = 0.27\left(1 + \frac{246.72}{100}\right) = 0.936$

III) $(1 - W) = 0.20$

$W = 0.80$

IV) $Ra = 13.9$ mmday^{-1}

$R_s = (0.25 + 0.50 \times 0.68)\,13.9 = 8.2$ mmday^{-1}

$R_{ns} = (1 - 0.25)\,8.2 = 6.15$ mmday^{-1}

$R_{nl} = 17.2 \times 0.14 \times 0.72 = 1.73$ " "

$R_n = 4.42$ mm day^{-1}

V) $C = 0.92$

$ET_o = 0.92(0.80 \times 4.92 + 0.20 \times 0.936 \times 26.7)$

$= 7.85$ mm day^{-1}

$ET_o = 235.5$ mm/month.

10) For october :-

I) $T_{mean} = 29.35°c$, $R.H_{mean} = 44.6\%$

ea at 29.35°c = 40.2 m.bar.

ed " " = $\frac{40.2 \times 44.6}{100} = 17.93$ m.bar.

$ea - ed = 22.3$ m.bar.

II) $u = 154.56$ Km/day.

$f(u) = 0.27\left(1 + \frac{154.56}{100}\right) = 0.69$

III) $(1-W) = 0.22$

$W = 0.78$

IV) $Ra = 11.6$ mmday^{-1}

$Rs = (0.25 + 0.50 \times 0.76)\, 11.6 = 7.3$ mmday^{-1}

$Rns = (1-0.25)\, 7.3 = 5.48$ "

$Rnl = 16.7 \times 0.15 \times 0.78 = 1.95$ "

$Rn = 3.53$ mmday^{-1}.

V) $C = 1.0$

$ET_o = 1(0.78 \times 3.53 + 0.22 \times 0.69 \times 22.3)$

$= 6.14$ mmday^{-1}

$ET_o = 6.14 \times 31 = 190.29$ mm/month.

11) For November :-

I) $T_{mean} = 21.1\,^{\circ}C$, $R.H_{mean} = 50.8\ \%$

e_a at $21.1^{\circ}C = 24.9$ m.bar.

e_d " " $= \frac{24.9 \times 50.8}{100} = 12.65$ m.bar.

$e_a - e_d = 12.25$ m.bar.

II) $U = 154.05$ km/day.

$f(u) = 0.27\left(1 + \frac{154.05}{100}\right) = 0.69$

III) $(1 - W) = 0.32$

$W = 0.69$

IV) $Ra = 9.5$ mmday^{-1}

$Rs = (0.25 + 0.50 \times 0.51)\,9.5 = 4.79$ mmday^{-1}

$R_{ns} = (1 - 0.25)\,4.79 = 3.59$ " "

$R_{nl} = 14.6 \times 0.19 \times 0.55 = 1.525$ " "

$R_n = 2.06$ mmday^{-1}

V) $C = 1.05$

$ET_o = 1.05\,(0.69 \times 2.06 + 0.32 \times 0.69 \times 12.25)$

$= 4.34$ mmday^{-1}

$ET_o = 4.34 \times 30 = 130.08$ mm/month

12) For December :-

I) $T_{mean} = 15.85°C$, $R.H_{mean} = 60\%$

e_a at 15.55°c = 18.2 m.bar.

e_d " " $= \frac{18.2 \times 60}{100} = 10.92$ m.bar.

$e_a - e_d = 7.28$ m.bar.

II) $u = 117.6$ km/day.

$f(u) = 0.27\left(1 + \frac{117.6}{100}\right) = 0.59$

III) $(1 - W) = 0.36$

$W = 0.64$

IV) $R_a = 8.3$ mm day^{-1}

$R_s = (0.25 + 0.50 \times 0.78)8.3 = 5.3$ mm day^{-1}

$R_{ns} = (1 - 0.25)5.3 = 3.98$ " "

$R_{nl} = 13.8 \times 0.21 \times 0.81 = 2.35$ " "

$R_n = 1.63$ mm day^{-1}

V) $C = 0.98$

$ET_o = 0.98(0.64 \times 1.63 + 0.36 \times 0.59 \times 7.28)$

$= 2.54$ mm day^{-1}

$ET_o = 2.54 \times 31 = 78.67$ mm/month

4) Pan Evaporation Method :-

① Evaporation pan provides a measurement of all the integrated effects of radiation, temp. wind & humidity on evaporation from a specific open water surface.

② (Evaporation from pan water surface is diff. from that of crop surface because water surface is not so rougher than crop surface)

③ Pan is actually "US Class A Pan" (the normal pan which is mostly used). But there are also other diff. types of Pans which differ in their suitability to diff. areas.

④ Class A Evaporation Pan is Circular (121 cm) (46.5 inches) in diameter & (25.5 cm) (10 inches) in depth. It is made of galvanized iron (22 guage). The pan is mounted on a wooden open frame with its bottom 15 cm above ground level. The soil is built up within 5 cm upto bottom of pan. The prerequisites are:-

⑤ ① - Pan of uniform level & it should be ② filled with water about 5 cm below rim & ③ water level in the Pan should not drop below 7.5 cm below the rim.

④ - water should be regularly renewed.

⑥ According to formula :-

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

where ; E_{pan} = mean daily value of Pan evaporation

K_p = Pan Coefficient.

⑦ K_p values are given in (table-18). K_p values relate to the pan located in an open field with no crops taller than $\boxed{1\,m}$ within upto $\boxed{50\,m}$ of the Pan. Grass cover should be frequently mowed.

e.g. For July,

$E_{pan} = 11.1$ mmday^{-1}

R.H. medium, wind moderate

$K_p = 0.75$

$ET_o = 0.75 \times 11.1$

$= 8.3$ mmday^{-1}

(40)

Water use Efficiency (W.U.E):- [redacted]

$$W.U.E. = \frac{\text{output}}{\text{input}}$$

There are 3 methods of calculating W.U.E.

1) Input W.U.E :-
It shows an absolute response.

$$W.U.E. = TDM / (I + R)$$
$$= G.Y / (I + R)$$

2) W.U.E based on ET :- It has more strong physiological basis than "input W.U.E".

$$W.U.E = TDM / ET_0$$
$$= G.Y / ET_0$$

3) $W.U.E_T$:- It is more physiological-relevant W.U.E. It makes use of V.P.D.

V.P.D. = $(e_s - e_a)$ of daytime

$$W = k \int T_a (e_s - e_a)\, dt$$

4) $W.U.E = TDM / T_a$ $T = 40-60\%$ of ET
$= G.Y. / T_a$

In I_0, $T = 60\%$ of ET
In $I_1, I_2 I_3$; $T = 50\%$ " "
In I_4, $T = 40\%$ " "

Mungbean Trial (1999) :- S.D. 3 Aug. H.D. 10 Oct.

	R1			R2			R3			R4		
Treat-ments	TDM kg/ha	G.Y (kg/ha)	ET (mm)	TDM (kg/ha)	G.Y (kg/ha)	ET (mm)	TDM (kg/ha)	G.Y (kg/ha)	ET (mm)	TDM (kg/ha)	G.Y (kg/ha)	ET (mm)
$V_1 I_0$	1833	477	189	2000	520	183	2167	563	219	1667	440	178
$V_1 I_1$	2333	740	193	2000	637	173	2504	797	211	2500	797	192
$V_1 I_2$	2500	697	231	2667	743	218	2333	650	263	2500	697	286
$V_1 I_3$	2416	710	268	2333	687	283	2500	737	288	2416	710	238
$V_1 I_4$	2750	870	197	2667	843	321	2833	897	253	2667	843	247
$V_2 I_0$	1667	507	213	1917	580	162	2000	613	152	1833	557	180
$V_2 I_1$	2000	577	150	2417	697	221	2000	573	183	2167	623	165
$V_2 I_2$	3000	600	207	2833	567	258	2333	667	252	2917	583	205
$V_2 I_3$	2500	623	216	2750	688	203	2667	667	211	2500	623	204
$V_2 I_4$	3667	1053	243	3333	957	236	3000	860	233	3167	910	279

Amount of irrigation & rainfall :-

I_0 = 74 mm (Control) rainfall = 74 mm

I_1 = 136 mm including rainfall

I_2 = 251 " " "

I_3 = 218 " " "

I_4 = 280 " " "

$ET_a = ET_o \times K_c$ Kc for mungbean: 0.85

(ET_r)

1) Calculation of Input W.U.E :-

Replication	Treatment.	W.U.E of TDM	W.U.E of G.Y.
		W.U.E = TDM/(I + R)	W.U.E = G.Y/(I + R)
R_1	$V_1 I_0$	1833/74 = 24.8	477/74 = 6.44
	$V_1 I_1$	2333/136 = 17.15	740/136 = 5.44
	$V_1 I_2$	2500/251 = 9.96	697/251 = 2.78
	$V_1 I_3$	2416/218 = 11.08	710/218 = 3.26
	$V_1 I_4$	2750/280 = 9.82	870/280 = 3.11
	$V_2 I_0$	1667/74 = 22.5	507/74 = 6.85
	$V_2 I_1$	2000/136 = 14.7	577/136 = 4.24
	$V_2 I_2$	3000/251 = 11.9	600/251 = 2.39
	$V_2 I_3$	2500/218 = 11.47	623/218 = 2.86
	$V_2 I_4$	3667/280 = 13.09	1053/280 = 3.76
R_2	$V_1 I_0$	2000/74 = 27.02	520/74 = 7.03
	$V_1 I_1$	2000/136 = 14.7	637/136 = 4.68
	$V_1 I_2$	2667/251 = 10.6	743/251 = 2.96
	$V_1 I_3$	2333/218 = 10.7	687/218 = 3.15
	$V_1 I_4$	2667/280 = 9.5	843/250 = 3.01
	$V_2 I_0$	1912/74 = 25.9	580/74 = 7.84
	$V_2 I_1$	2417/136 = 17.8	697/136 = 5.12
	$V_2 I_2$	2833/251 = 11.29	567/251 = 1.06
	$V_2 I_3$	2750/218 = 12.6	655/218 = 3.16
	$V_2 I_4$	3333/280 = 11.9	957/250 = 3.42

eplication	Treatment	W.U.E. of TDM	W.U.E of G.Y.
R_3	$V_1 I_0$	2167/74 = 29.3	563/74 = 7.61
	$V_1 I_1$	2500/136 = 18.38	797/136 = 5.86
	$V_1 I_2$	2333/251 = 9.29	650/251 = 2.59
	$V_1 I_3$	2500/218 = 11.47	737/218 = 3.38
	$V_1 I_4$	2833/280 = 10.12	897/280 = 3.20
	$V_2 I_0$	2000/74 = 27.03	613/74 = 8.28
	$V_2 I_1$	2000/136 = 14.7	573/136 = 15.92
	$V_2 I_2$	2333/251 = 9.29	667/251 = 2.66
	$V_2 I_3$	2667/218 = 12.23	667/218 = 3.06
	$V_2 I_4$	3000/280 = 10.71	860/280 = 3.07
R_4	$V_1 I_0$	1667/74 = 22.5	440/74 = 5.95
	$V_1 I_1$	2500/136 = 18.38	797/136 = 5.86
	$V_1 I_2$	2500/251 = 9.96	697/251 = 2.78
	$V_1 I_3$	2416/218 = 11.08	710/218 = 3.26
	$V_1 I_4$	2667/280 = 9.52	843/280 = 3.01
	$V_2 I_0$	1833/74 = 24.8	557/74 = 7.53
	$V_2 I_1$	2167/136 = 15.9	623/136 = 4.58
	$V_2 I_2$	2917/251 = 11.62	583/251 = 2.32
	$V_2 I_3$	2500/218 = 11.47	623/218 = 2.86
	$V_2 I_4$	3167/280 = 11.31	910/280 = 3.25

2) Calculation of ET-based W.U.E :-

Replications	Treatment	W.U.E of TOM	W.U.E of G.Y.
		W.U.E = TDM/ET	W.U.E. = G.Y/ET
R_1	V_1I_0	1833/160 = 11.46	477/160 = 2.98
	V_1I_1	2333/164 = 14.22	740/164 = 4.51
	V_1I_2	2500/196 = 12.75	697/196 = 3.56
	V_1I_3	2416/227 = 10.64	710/227 = 3.13
	V_1I_4	2750/167 = 16.47	870/167 = 5.21
	V_2I_0	1667/181 = 9.21	507/181 = 2.80
	V_2I_1	2000/127 = 15.75	577/127 = 4.54
	V_2I_2	3000/175 = 17.14	600/175 = 3.43
	V_2I_3	2500/183 = 13.66	623/183 = 3.40
	V_2I_4	3667/206 = 17.80	1053/206 = 5.11
R_2	V_1I_0	2000/155 = 12.9	520/155 = 3.35
	V_1I_1	2000/147 = 13.6	637/147 = 4.33
	V_1I_2	2667/185 = 14.4	743/185 = 4.02
	V_1I_3	2333/240 = 9.72	687/240 = 2.86
	V_1I_4	2667/272 = 9.80	843/272 = 3.09
	V_2I_0	1917/137 = 13.99	580/137 = 4.23
	V_2I_1	2417/187 = 12.9	697/187 = 3.73
	V_2I_2	2833/219 = 12.9	567/219 = 2.59
	V_2I_3	2750/172 = 15.9	685/172 = 4
	V_2I_4	3333/200 = 16.67	957/200 = 4.78

lication	Treatment	W.U.E of TDM	W.U.E of G.Y.
R_3	$V_1 I_0$	2167/186 = 11.65	563/186 = 3.03
	$V_1 I_1$	2500/179 = 13.97	797/179 = 4.45
	$V_1 I_2$	2333/223 = 10.46	650/223 = 2.9
	$V_1 I_3$	2500/244 = 10.24	737/244 = 3.02
	$V_1 I_4$	2833/215 = 13.18	897/215 = 4.17
	$V_2 I_0$	2000/129 = 15.5	613/129 = 4.75
	$V_2 I_1$	2000/155 = 12.9	572/155 = 3.69
	$V_2 I_2$	2333/214 = 10.9	667/214 = 3.12
	$V_2 I_3$	2667/179 = 14.89	667/179 = 3.73
	$V_2 I_4$	3000/198 = 15.15	860/198 = 4.34
R_4	$V_1 I_0$	1667/151 = 11.04	440/151 = 2.9
	$V_1 I_1$	2500/163 = 15.34	797/163 = 4.89
	$V_1 I_2$	2500/243 = 10.29	697/243 = 2.87
	$V_1 I_3$	2416/202 = 11.96	710/202 = 3.51
	$V_1 I_4$	2667/209 = 12.76	843/209 = 4.03
	$V_2 I_0$	1833/153 = 11.98	557/153 = 3.64
	$V_2 I_1$	2167/140 = 15.48	623/140 = 4.45
	$V_2 I_2$	2917/174 = 16.76	583/174 = 3.35
	$V_2 I_3$	2500/173 = 14.45	623/173 = 3.6
	$V_2 I_4$	3167/237 = 13.36	910/237 = 3.84

3) Calculation of T-based W.U.E :-

Replication	Treatment	W.U.E of TDM W.U.E = TDM / T_a	W.U.E of G.Y W.U.E. = G.Y. / T_a
R_1	V_1I_0	1833/96 = 19.09	477/96 = 4.97
	V_1I_1	2333/82 = 28.45	740/82 = 9.02
	V_1I_2	2500/98 = 25.5	697/98 = 7.11
	V_1I_3	2416/113.5 = 21.29	710/113.5 = 6.26
	V_1I_4	2750/66.8 = 41.17	870/66.8 = 13.02
	V_2I_0	1667/108.6 = 15.35	507/108.6 = 4.67
	V_2I_1	2000/63.5 = 31.49	577/63.5 = 9.09
	V_2I_2	3000/87.5 = 34.28	600/87.5 = 6.86
	V_2I_3	2500/91.5 = 27.32	623/91.5 = 6.81
	V_2I_4	3667/82.4 = 44.5	1053/82.4 = 12.78
R_2	V_1I_0	2000/93 = 21.5	520/93 = 5.59
	V_1I_1	2000/73.5 = 27.2	637/73.5 = 8.67
	V_1I_2	2667/92.5 = 28.8	743/92.5 = 8.03
	V_1I_3	2333/120 = 19.44	687/120 = 5.72
	V_1I_4	2667/108.8 = 24.5	843/108.8 = 7.75
	V_2I_0	1917/82.2 = 23.32	580/82.2 = 7.06
	V_2I_1	2417/53.5 = 25.85	697/93.5 = 7.45
	V_2I_2	2833/109.5 = 25.87	567/109.5 = 5.18
	V_2I_3	2750/86 = 31.98	683/86 = 8.0
	V_2I_4	3333/80 = 41.67	957/80 = 11.96

ication	Treatment	W.U.F of TDM	W.U.F of G.Y.
R_3	V_1I_0	2167/111.6 = 19.4	563/111.6 = 5.04
	V_1I_1	2500/89.5 = 27.9	797/89.5 = 8.9
	V_1I_2	2333/111.5 20.92	650/111.5 = 5.83
	V_1I_3	2500/122 = 20.5	737/122 = 6.04
	V_1I_4	2833/86 = 32.9	897/86 = 10.4
	V_2I_0	2000/77.4 = 25.8	613/77.4 = 7.9
	V_2I_1	2000/77.5 = 25.8	573/77.5 = 7.39
	V_2I_2	2333/107 = 21.8	667/107 = 6.23
	V_2I_3	2667/89.5 = 29.8	667/89.5 = 7.45
	V_2I_4	3000/79.2 = 37.9	860/79.2 = 10.9
R_4	V_1I_0	1667/90.6 = 18.4	440/90.6 = 4.86
	V_1I_1	2500/81.5 = 30.7	797/81.5 = 9.78
	V_1I_2	2500/121.5 = 20.6	697/121.5 = 5.74
	V_1I_3	2416/101 = 23.9	710/101 = 7.03
	V_1I_4	2667/83.6 = 31.9	843/83.6 = 10.08
	V_2I_0	1833/91.8 = 19.96	557/91.8 = 6.07
	V_2I_1	2167/70 = 30.9	623/70 = 8.9
	V_2I_2	2917/87 = 33.5	583/87 = 6.7
	V_2I_3	2500/86.5 = 28.9	623/86.5 = 7.2
	V_2I_4	3167/94.8 = 33.4	910/94.8 = 9.6

Concept of Potential Soil Moisture Deficit (PSMD) & its calculation :-

① It ~~☆~~ was also given by Penman & tells about irrig-scheduling (when to$^{i)}$ apply, How much$^{ii)}$ to apply & response of crop yield to irrig.$^{iii)}$ applied)

1- PET :- potential evapotranspiration

2- Field capacity :- F.C

3- PWP → Permanent wilting point.

4- PSMD

5- Max. PSMD.

4) PSMD :

$$D = \underbrace{\Sigma PET}_{demand} - \underbrace{\Sigma (R+I)}_{supply\ of\ water}$$

① "Penman defined PSMD as the difference b/w $\overset{\text{sum of PET}}{\Sigma PET}$. & $\overset{\text{sum of irrig. \& rainfall}}{\Sigma (R+I)}$ at any time for the given period."

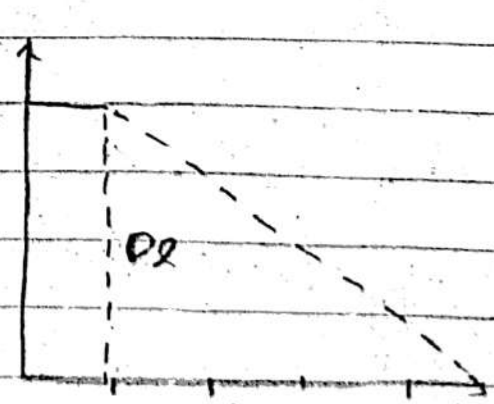
② The value of D is never -ve. The reason is that when ~~☆~~ supply exceeds PET, i-e when soil is saturated, the extra water go into the run off, seepage/drainage & not used in PET etc./ so ~~D will be~~ zero if it is calculated to be -ve it is assumed to be Zero.

5) Max. PSMD :-

③* "That value of D at which crop growth actually start declining is called limiting deficit (Dl)."

④ As Dl increases, the crop growth is adversely affected.
upto Dl, growth is not affected

As D exceeds Dl, the max. PSMD started. "The max. value of D reached during growth is called max. PSMD (Dm)."



*⑧ There are two levels of moisture in rhizosphere. upper level & lower level. At upper level, soil is at field capacity, but at lower level, soil is at PWP.

Effect of Drought on Crop growth :-

→ According to theory, conclusions are :-

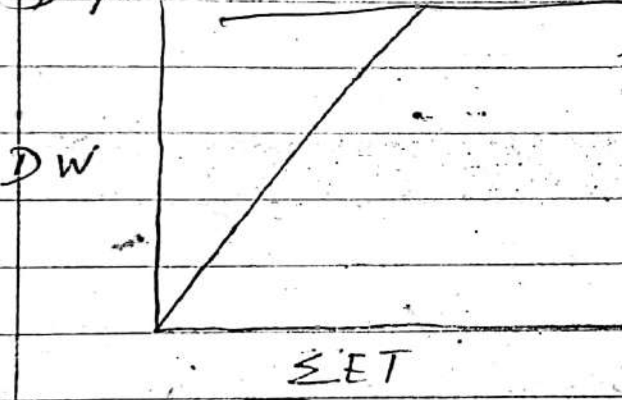
① when water is freely available (i.e $D_m < D_l$) the growth rate i.e DW. is proportional to cummulative ET.

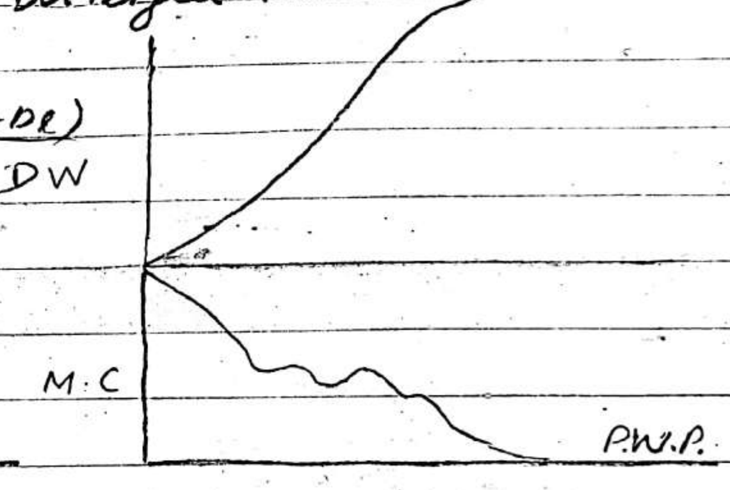
② when PSMO reaches and exceeds (i.e $D_m > D_l$) the limiting value called Limiting deficit (D_l) & growth slows down.

③ when water becomes again freely available either through rain or irrig., the crop grows at its full rate until extra water is utilized.

1) $Y = K \sum ET$

2) $Y = K \sum ET - K(D_m - D_l)$





① From No.1, it is clear that crop may be assumed fully irrigated provided $D_m < D_l$, throughout growth ② No.2 when D_m exceeds D_l at any stage, it means that crop is short of water ③ D_l is important variable for farmers & scientists to know, because yield will decline if crops are not irrigated beyond the value of D_l ④ D_l varies with crop species & soils. ⑥ Generally shallow rooted crops have less value than the deep rooted crops ⑦ Similarly heavy soils have higher value of D_l as compared to light soils.

→ Irrigation therefore provides two benifits.

1) There is +ve response to water added.

2) It also permits crop to make full use of rain that falls during. the growing season.

(Reference ET / ETo)

1) **PET** :- "The rate of ET from an extensive surface of ①8-15 cm tall green grass cover of ②uniform height, ③actively growing, ④completely shading the ground and ⑤not short of water is called PET." *·①·*

2) **Field capacity** :- "The soil moisture content, when all the gravitational water has been drained out of the soil and the moisture content has become relatively stable is called Field capacity."
usually the moisture content at $\frac{1}{3}$ atm tension ($-\frac{1}{3}$ bar water potential) is considered to be the F.C. that is usually attained 2-3 days after irrigation.

3) **PWP** :- "The soil moisture content at which plants can no longer obtain enough moisture to meet their transp.n requirements and remain wilted unless water is added to the soil is called P.W.P."
usually the moisture content at 15 atm tension (-15 bars water potential) is considered to be the P.W.P.

It represent the environmental demand for ET & is a reflection
the energy available to evaporate water, and of wind available
transport the water vapour from ground into the atmosphere.
is said to be equal to PET when there is an ample water *

calculating PSMD for Mungbean growing Season

1) For $V_1 I_0$:-

$\Sigma PET = 189$ mm , $\Sigma(R+I) = 74$ mm

$PSMD = \Sigma PET - \Sigma(R+I)$

$= 159 - 74 = 115$ mm

2) For $V_1 I_1$:-

$\Sigma PET = 193$ mm , $\Sigma(R+I) = 136$ mm

$PSMD = \Sigma(PET) - \Sigma(R+I)$

$= 193 - 136 = 57$ mm

3) For $V_1 I_2$:-

$\Sigma PET = 231$ mm , $\Sigma(R+I) = 251$ mm

$PSMD = \Sigma(PET) - \Sigma(R+I)$

$= 231 - 251 = 0$

4) For $V_1 I_3$:-

$\Sigma(PET) = 268$ mm , $\Sigma(R+I) = 218$ mm

$PSMD = \Sigma(PET) - \Sigma(R+I)$

$= 268 - 218 = 50$ mm

5) For $V_1 I_4$:-

$\Sigma(PET) = 197$ mm , $\Sigma(R+I) = 280$ mm

$PSMD = \Sigma(PET) - \Sigma(R+I)$

$= 197 - 280 = 0$

6) For $V_2 I_0$:-

$\Sigma PET = 213$ mm , $\Sigma(R+I) = 74$ mm

$PSMD = \Sigma(PET) - \Sigma(R+I)$

$= 213 - 74 = 139$ mm

7) For $V_2 I_1$:-

$\Sigma PET = 150$ mm , $\Sigma(R+I) = 136$ mm

$PSMD = \Sigma PET - \Sigma(R+I)$

$= 150 - 136 = 14$ mm

8) For $V_2 I_2$:-

$\Sigma(PET) = 207$ mm , $\Sigma(R+I) = 251$ mm

$PSMD = \Sigma PET - \Sigma(R+I)$

$= 207 - 251 = 0$

9) For $V_2 I_3$:-

$\Sigma PET = 216$ mm , $\Sigma(R+I) = 218$ mm

$PSMD = \Sigma PET - \Sigma(R+I)$

$= 216 - 218 = 0$

10) For $V_2 I_4$:-

$\Sigma PET = 243$ mm , $\Sigma(R+I) = 280$ mm

$PSMD = \Sigma PET - \Sigma(R+I)$

$= 243 - 280 = 0$

Calculation of PSMD for wheat Season:-

Day/Month	PET (mm)	Rainfall (mm)	Irrigation (mm)	SMD D = ΣPET−Σ(R+I) (mm)
10 Nov.	4.5	0	0	4.5
11 Nov.	4.0	0	0	8.5
:				
20 Nov.	2.5	20.0	0	40.5
				−20.0
				+ 2.5
				23.0

at crown initiation
- Establishment irrig. after 3-4 weeks
- 2nd irrig. at stem elongation Jan.
- 3rd " at earing/anthesis
- 4th " " grain growth

4th April

If (R + I) exceeds deficit, then value of D will be adjusted at zero.

Before calculating D, we have to consider:-
Generally in winter sowing, after sowing soil reaches to F.C. but not in true sense because some loss of water due to evaporation. But this evaporation is negligible so we consider D as zero at the 1st day of sowing.

10 Nov. Sowing :-

Ist irrig = after 28 days of sowing = 8 Dec.
2nd " = after 30 days of ~~sowing~~ Ist irrig = 10 Jan
3rd " = after 40 " 2nd irrig. = 20 Feb.
4th " = " 30 " 3rd irrig = 20 March.
5th " = At 4th April.

Calculation of PSMD for [redacted] wheat Season :-

Day/Month	PET (mm)	Rainfall (mm)	Irrigation (mm)	SMD D = Σ PET - Σ(R+I) (mm)
10 NOV.	4.34	0	0	4.34
11 NOV.	4.34	0	0	8.68
12 "	"	0	0	13.02
13 "	"	0	0	17.36
14 "	"	0	0	21.70
15 "	"	0	0	26.04
16 "	"	0	0	30.38
17 "	"	0	0	34.72
18 "	"	0	0	39.06
19 "	"	0	0	43.40
20 "	"	0	0	47.74
21 "	"	0	0	52.08
22 "	"	0	0	56.42
23 "	"	0	0	60.76
24 "	"	0	0	65.10
25 "	"	0	0	69.44
26 "	"	0	0	73.78
27 "	"	0	0	78.12
28 "	"	0	0	82.46
29 "	"	0	0	86.80
30 "	"	0	0	91.14
1 DEC	2.54	0	0	93.68
2 "	"	0	0	96.22
3 "	"	0	0	98.76
4 "	"	0	0	101.3
5 "	"	0	0	103.84

Day/Month	PET (mm)	Rainfall (mm)	Irrig. (mm)	SMD $D=\Sigma PET-\Sigma(R+I)$ (mm)
6 Dec	2.54	0	0	106.38
7 "	"	0	0	108.92
8 "	"	0	75	36.46
9 "	"	0	0	39.00
10 "	"	0	0	41.54
11 "	"	0	0	44.08
12 "	"	0	0	46.62
13 "	"	0	0	49.16
14 "	"	0	0	51.7
15 "	"	0	0	54.24
16 "	"	0	0	56.78
17 "	"	0	0	59.32
18 "	"	0	0	61.86
19 "	"	0	0	64.40
20 "	"	0	0	66.94
21 "	"	0	0	69.48
22 "	"	0	0	72.02
23 "	"	0	0	74.56
24 "	"	0	0	77.10
25 "	"	0	0	79.64
26 "	"	0	0	82.18
27 "	"	0	0	84.72
28 "	"	0	0	87.26
29 "	"	0	0	89.80
30 "	"	0	0	92.34
31 "	"	0	0	94.88
1 Jan	1.65	0	0	96.53
2 "	"	0	0	98.18

Day/month	PET (mm)	R.F. (mm)	Irrig. (mm)	SMD $D=\Sigma PET-\Sigma(R+I)$
3 Jan	1.65	0	0	99.83
4 "	"	0	0	101.48
5 "	"	0	0	103.13
6 "	"	0	0	104.78
7 "	"	0	0	106.43
8 "	"	0	0	108.08
9 "	"	0	0	109.73
10 "	"	0	75	36.38
11 "	"	1 mm	0	37.03
12 "	"	9	0	29.68
13 "	"	4	0	27.33
14 "	"	0.7	0	28.28
15 "	"	0	0	29.93
16 "	"	0	0	31.58
17 "	"	0	0	33.23
18 "	"	0	0	34.88
19 "	"	0	0	36.53
20 "	"	0	0	38.18
21 "	"	0	0	39.83
22 "	"	0	0	41.48
23 "	"	0	0	43.13
24 "	"	0	0	44.78
25 "	"	1.5	0	44.93
26 "	"	0	0	46.58
27 "	"	0	0	48.23
28 "	"	0	0	49.88
29 "	"	0	0	51.53
30 "	"	0	0	53.18

Day/Month	PET (mm)	R.F (mm)	Irrig. (mm)	SMD = D = ΣPET − Σ(R+I) (mm)
31 Jan	1.65	0	0	54.83
1 Feb	3.92	0	0	58.75
2 〃	〃	0	0	62.67
3 〃	〃	0	0	66.59
4 〃	〃	0	0	70.51
5 〃	〃	1	0	73.43
6 〃	〃	0	0	77.35
7 〃	〃	0	0	81.27
8 〃	〃	0	0	85.19
9 〃	〃	2	0	87.11
10 〃	〃	3.2	0	87.83
11 〃	〃	4	0	87.75
12 〃	〃	0	0	91.67
13 〃	〃	0	0	95.59
14 〃	〃	0	0	99.51
15 〃	〃	0	0	103.43
15 〃	〃	0	0	107.35
17 〃	〃	0	0	111.27
18 〃	〃	0	0	115.19
19 〃	〃	0	0	119.11
20 〃	〃	4.5	75	43.53
21 〃	〃	5.5	0	41.95
22 〃	〃	0	0	45.87
23 〃	〃	0	0	49.79
24 〃	〃	0	0	53.71
25 〃	〃	0	0	57.63
26 〃	〃	0	0	61.55
27 〃	〃	0	0	65.47

Day/Month	PET (mm)	R.F (mm)	Irrigation (mm)	SMD D = ΣPET (mm).
28 Feb	3.92	0	0	69.39
1 March	6.25	0	0	75.64
2 "	"	0	0	81.89
3 "	"	0	0	88.14
4 "	"	0.3	0	94.09
5 "	"	0	0	100.34
6 "	"	0	0	106.59
7 "	"	0	0	112.84
8 "	"	0	0	119.09
9 "	"	0	0	125.34
10 "	"	0	0	131.59
11 "	"	0	0	137.84
12 "	"	0	0	144.09
13 "	"	0	0	150.34
14 "	"	0	0	156.59
15 "	"	0	0	162.84
16 "	"	0	0	169.09
17 "	"	0	0	175.34
18 "	"	0	0	181.59
19 "	"	0	0	187.84
20 "	"	0	75	119.09
21 "	"	0	0	125.34
22 "	"	0	0	131.59
23 "	"	0	0	137.84
24 "	"	0	0	144.09
25 "	"	0	0	150.34
26 "	"	0	0	156.59
27 "	"	0	0	162.84

Day/Month	PET (mm)	R.F. (mm)	Irrig. (mm)	SMD $D = \Sigma(PET - \Sigma R + I)$ (mm)
28 March	6.25	0	0	169.09
29 "	"	0	0	175.34
30 "	"	0	0	181.59
31 "	"	0	0	187.84
1 April	8.24	0	0	196.08
2 "	"	0	0	204.32
3 "	"	0	0	212.56
4 "	"	0	75	145.80
5 "	"	0	0	154.04
6 "	"	0	0	162.28
7 "	"	0	0	170.52
8 "	"	0	0	178.76
9 "	"	0	0	187
10 "	"	0	0	195.24
11 "	"	0	0	203.48
12 "	"	0	0	211.72
13 "	"	0	0	219.96
15 "	"	0	0	228.20

ational Programme for improvement of watercourses."

Water Dispute

① False Informations
② Political gains
③ Loss to all especially Sindh
④ Economic growth:
22 million acre barren land
⑤ Water telemetry System telling flow at diff. barrages 35 Crores Rs.
⑥ In 2003, 6000 Cusec additional water to Sindh

16 March 1991 Water Accord

Punjab	Sindh	NWFP	BAL
51.26%	41.01%	5%	2%

Reduced 2.7% (Punjab) 1.7% added (Sindh)

At Kotri Barrage 10 MAF Required to reduced effect of sea water to Thatta & ~~B~~ Badin.

⇒ According to clause #6 Thal Canal to be built.

⇒ According to Clause #7 large Dams.

Greater Thall Canal:

Av = 35 MAF downstream to Kotry
~~At cost of 1 billion $~~ (Rs)
Mangla Dam raising to 30ft Approx by which 3 MAF additional water Storage in (2007)

	M.D.	T.D.
2015	1/2 life gone	
2030		1/2 life gone.
2050	2/3	3/4

	Bhasha Dam	Kala Bagh
	7.4 MAF	6.1 MAF
to Complete	7 year	7 year
Feasibility	2006	2004
Completed	2013	2011

⇐ بھارت نے اپریل 1948 میں نہری پانی بند کیا۔

⇐ 1960 سندھ طاس معاہدہ عالمی بینک کے تعاون سے طے پایا

⇐ زرعی اصلاحات

پہلی 1959

دوسری 1972

تیسری 1977

⇐ سب سے بڑا بیراج "سکھر" 1932 میں بنا اور اس میں سے 7 نہریں نکالی گئی۔

⇐ سندھ طاس کے تحت سب سے بڑا بیراج "مرالہ" میں بنا۔

{تربیلا = 1972 میں بنا۔ منگلا = 1967 = " " ۔} {وارسک ڈیم دریائے کابل اور ... }

غازی بروتھا ڈیم 2003ء میں مکمل ہوا

بجلی بنانے کی صلاحیت = 1450 میگا واٹ

Mangla Dam	~~Tarbala Dam~~
6.0 MAF	~~11.3 MAF~~
5.0 MAF	~~9.4 MAF~~

Capacity Bhasha = 73, 00, 000 AF
→ 3600 MW

Mangla	27 000
Tarbella	3400 MW

Blanney-criddle Methode:- Sir. Ahsan Safdar. 5th

Table 1

Mean Daily Percentage (p) of Annual Daytime Hours for Different Latitudes.

Latitude North	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
South 1/	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
60°	.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
58	.16	.21	.26	.32	.37	.40	.39	.34	.28	.23	.18	.15
56	.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
54	.18	.22	.26	.31	.36	.38	.37	.33	.28	.23	.19	.17
52	.19	.22	.27	.31	.35	.37	.36	.33	.28	.24	.20	.17
50	.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
48	.20	.23	.27	.31	.34	.36	.35	.32	.28	.24	.21	.19
46	.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
44	.21	.24	.27	.30	.33	.35	.34	.31	.28	.25	.22	.20
42	.21	.24	.27	.30	.33	.34	.33	.31	.28	.25	.22	.21
40	22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35	.23	.25	.27	.29	.31	.32	.32	.30	.28	.25	.23	.22
30	.24	.25	.27	.29	.31	.32	31*	.30	.28	.26	.24	.23
25	.24	.26	.27	.29	.30	.31	.31	.29	.28	.26	.25	.24
20	.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25
15	.26	.26	.27	.28	.29	.29	.29	.28	.28	.27	.26	.25
10	.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5	.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

1/ Southern latitudes: apply 6 month difference as shown.

Format for Calculation of Blaney-Criddle Method

DATA	Country: UAR Place: Cairo Latitude: 30°N Altitude: 45 m Period: July Longitude: 30
T mean 28.5°C	T mean data 28.5
latitude 30° month July	p Table 1 0.31 calc p(0.46T + 8) 6.6
RHmin %	estimate med.
n/N	estimate high/med
U$_2$ daytime m/sec	estimate Mod.
	Fig. 1 Block/line IV 2
	ETo Fig. 1 8.0 mm/day

((R.H.)) ✓

April, May. June - July) → March, ~~April~~ (Aug. Sept. Oct. Nov.) (Dec. Jan, Feb.)

(Evapotranspiration)

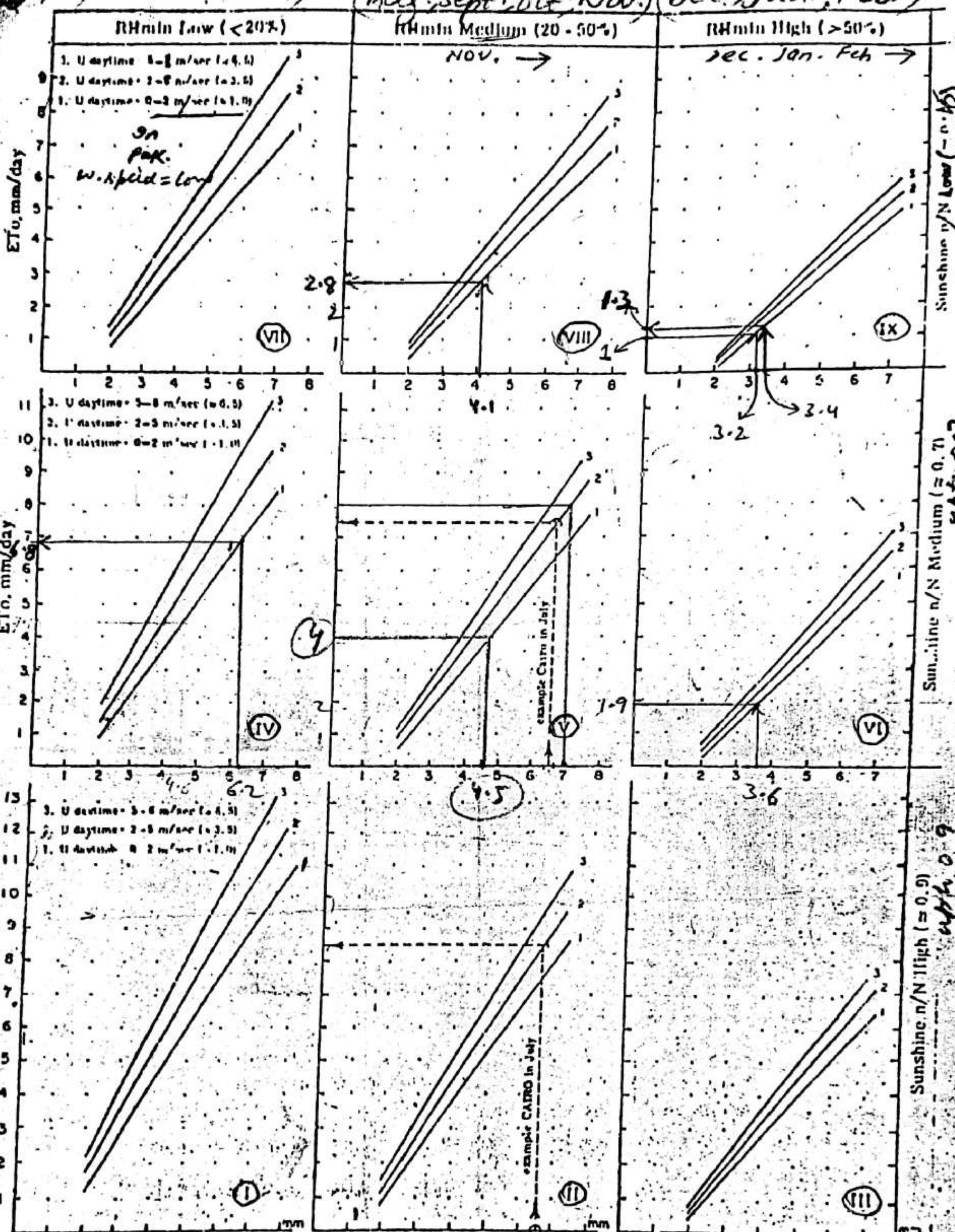


Fig. 1 Prediction of ETo from Blaney-Criddle f factor for different conditions of minimum relative humidity, sunshine duration and day time wind.

upto 0.4 — Oct Nov. Dec Jan (Low)

upto 0.7 Feb - March. April. May (Medium)

upto 0.9 Jun. July - August. Sept (High)

(Sunshine)

(C factor) Sunshine, $R.H._{min}$ & wind speed

AGR- 610.

2) Radiation Method :-

Table 2

Extra Terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day

Northern Hemisphere													Southern Hemisphere											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.2
4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9.3	13.2	16.6	18.2
4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	18.3
5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	18.3
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	18.3
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8*	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

2) Radiation Method :-

Table 3

Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes

Northern Lats	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Southern Lats	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
50	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	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	12.6	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* (14)	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	11.0	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 4

Values of Weighting Factor (W) for the Effect of Radiation on ETo at Different Temperatures and Altitudes

(Mean Temperature)

Temperature °C	2	4	6	8	10	12	14	16 ~~17~~	18	19	20	22	24	26	28	30	31	32	34	36	38	40
W at altitude m										0.67							.79					
0	0.43	.46	.49	.52	.55	.58	.61	.64	.66		.68	.71	.73	.75	.77*	.78		.80	.82	.83	.84	.85
500	.45	.48	.51	.54	.57	.60	.62	.65	.67		.70	.72	.74	.76	.78	.79		.81	.82	.84	.85	.86
1 000	.46	.49	.52	.55	.58	.61	.64	.66	.69		.71	.73	.75	.77	.79	.80		.82	.83	.85	.86	.87
2 000	.49	.52	.55	.58	.61	.64	.66	.69	.71		.73	.75	.77	.79	.81	.82		.84	.85	.86	.87	.88
3 000	.52	.55	.58	.61	.64	.66	.69	.71	.73		.75	.77	.79	.81	.82	.84		.85	.86	.88	.88	.89
4 000	.55	.58	.61	.64	.66	.69	.71	.73	.76		.78	.79	.81	.83	.84	.85		.86	.88	.89	.90	.90

(altitude)

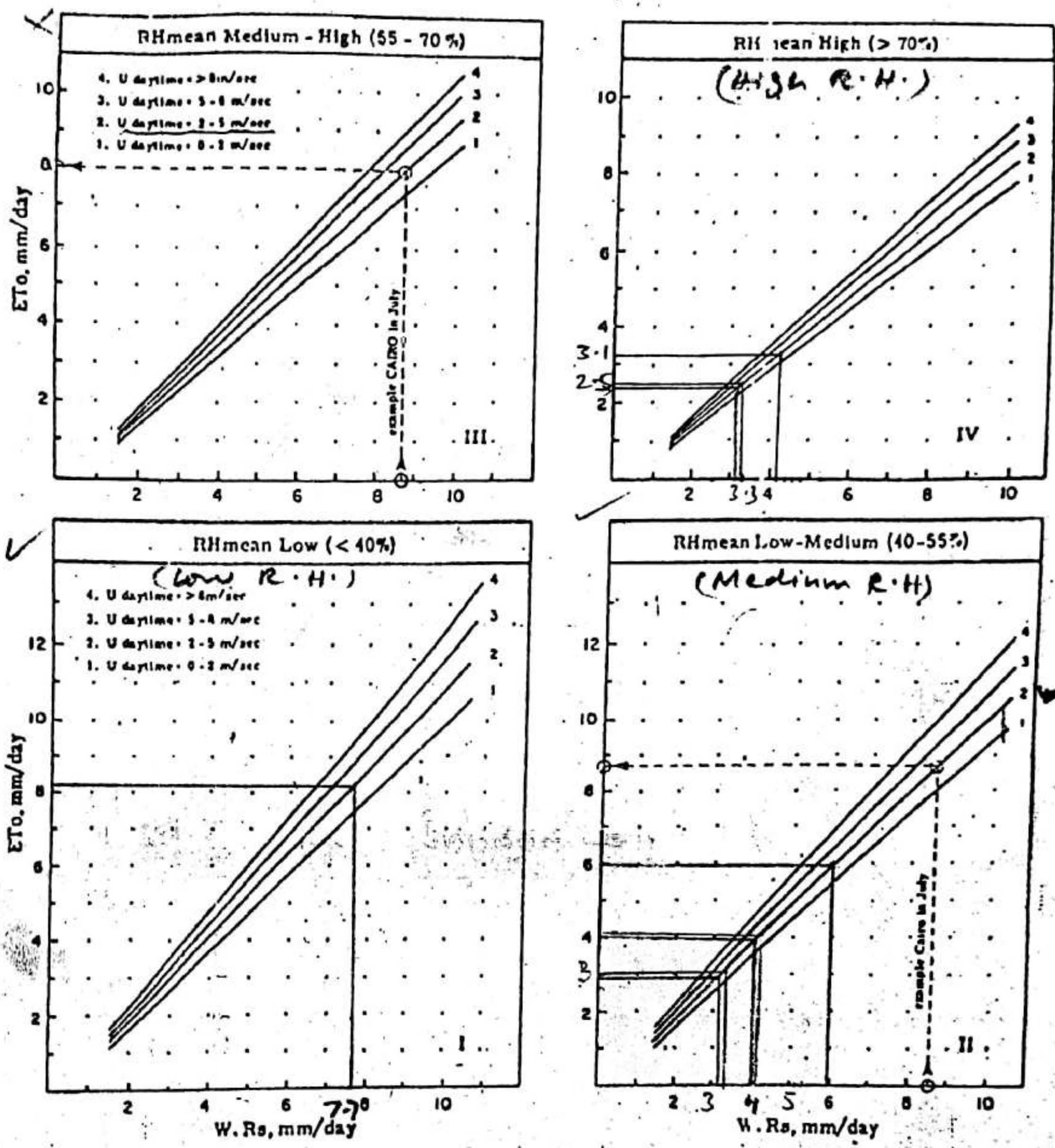


Fig. 2 Prediction of ETo from W. RS for different conditions of mean relative humidity and day time wind.

(Line 2 is used)

Pan-Evaporation Method AG:R610 (P)

ial from which the pan is made may account for variations of only a few percent. The level at ch the water is maintained in the pan is very important; resulting errors may be up to 15 per cent hen water levels in Class A pans fall 10 cm below the accepted standard of between 5 and 7.5 cm below the rim. Screens mounted over pans will reduce Epan by up to 10 percent. In an endeavour to avoid pans being used by birds for drinking, a pan filled to the rim with water can be placed near the Class A pan; birds may prefer to use the fully filled pan. Turbidity of the water in the pan does not affect Epan data by more than 5 percent. Overall variation in Epan is not constant with time because of ageing, deterioration and repainting.

Sample Calculations

EXAMPLE:

Given:

Cairo; July. Epan = 11.1 mm/day from Class A pan; RHmean = medium; wind moderate; pan station is located within a cropped area of several hectares; the pan is not screened.

Calculation:

Monthly data: since pan station is covered by grass and is surrounded by some 100 m of cropped area case A applies.

From Table 19 for moderate wind and medium humidity value of Kp = 0.75.

ETo = Kp x Epan = 0.75 x 11.1 = 8.3 mm/day

Yearly data:

	J	F	M	A	M	J	J	A	S	O	N	D
wind	light to moderate				moderate			light to moderate				
RHmean	mod. to high		medium							med. to high		
Kp	.8	.8	.8	.77	.75	.75	.75	.77	.77	.8	.8	.8
Epan	3.3	4.5	6.4	8.5	11.2	12.8	11.1	9.7	7.9	6.9	4.3	3.3
ETo mm/day	2.6	3.6	5.1	6.5	8.4	9.6	8.3	7.4	6.0	5.5	3.4	2.6
mm/months	82	100	158	196	260	289	258	231	180	165	102	81

7 Ratios Between Evaporation from Sunken Pans Mentioned and From Colorado Sunken Pan for Different Climatic Conditions and Pan Environments

Climate		Ratio Epan mentioned and Epan Colorado Humid-temperate climate		Arid to semi-arid (dry season)	
Groundcover surrounding pan (50 m or more)		Short green cover	Dry fallow	Short green cover	Dry fallow
	Pan area m^2				
CGI 20 dia. 5 m, depth 2 m (USSR)	20	1.0	1.1	1.05	1.25
Sunken pan dia. 12 ft, depth 3.3 ft. (Israel)	10.5				
Symmons pan 6 ft^2, depth 2 ft (UK)	3.3				
BPI dia. 6 ft, depth 2 ft (USA)	2.6				
Kenya pan dia. 4 ft, depth 14 in	1.2				
Australian pan dia. 3 ft, depth 3 ft	0.7		1.0		1.0
Aslyng pan 0.33 m^2, depth 1 m (Denmark)	0.3			1.0	
CGI 3000 dia. 61.8 cm, depth 60-80 cm (USSR)	0.3				
Sunken pan dia. 50 cm, depth 25 cm (Netherlands)	0.2	1.0	.95	1.0	.95

EXAMPLE: CGI 20 in semi-arid climate, dry season, placed in dry fallow land; for given month Epan CGI 20 = 8 mm/day.
Corresponding Epan sunken Colorado is 1.25 x 8 = 10 mm/day.

ble 18 Pan Coefficient (Kp) for Class A Pan for Different Groundcover and Levels of Mean Relative Humidity and 24 hour Wind

Class A pan	Case A: Pan placed in short green cropped area				Case B1/ Pan placed in dry fallow area			
RHmean %		low <40	medium 40-70	high >70		low <40	medium 40-70	high >70
Wind km/day	Windward side distance of green crop m				Windward side distance of dry fallow m			
Light <175	1	.55	.65	.75	1	.7	.8	.85
	10	.65	.75	.85	10	.6	.7	.8
	100	.7	.8	.85	100	.55	.65	.75
	1 000	.75	.85	.85	1 000	.5	.6	.7
Moderate 175-425	1	.5	.6	.65	1	.65	.75	.8
	10	.6	.7	.75	10	.55	.65	.7
	100	.65	.75	.8	100	.5	.6	.65
	1 000	.7	.8	.8	1 000	.45	.55	.6
Strong 425-700	1	.45	.5	.6	1	.6	.65	.7
	10	.55	.6	.65	10	.5	.55	.65
	100	.6	.65	.7	100	.45	.5	.6
	1 000	.65	.7	.75	1 000	.4	.45	.55
Very strong >700	1	.4	.45	.5	1	.5	.6	.65
	10	.45	.55	.6	10	.45	.5	.55
	100	.5	.6	.65	100	.4	.45	.5
	1 000	.55	.6	.65	1 000	.35	.4	.45

Table 19 Pan Coefficient (Kp) for Colorado Sunken Pan for Different Groundcover and Levels of Mean Relative Humidity and 24 hour Wind

Sunken Colorado	Case A: Pan placed in short green cropped area				Case B1/ Pan placed in dry fallow area			
RHmean %		low <40	medium 40-70	high >70		low <40	medium 40-70	high >70
Wind km/day	Windward side distance of green crop m				Windward side distance of dry fallow m			
Light <175	1	.75	.75	.8	1	1.1	1.1	1.1
	10	1.0	1.0	1.0	10	.85	.85	.85
	≥100	1.1	1.1	1.1	100	.75	.75	[illegible]
					1 000	.7	.7	.75
Moderate 175-425	1	.65	.7	.7	1	.95	.95	.95
	10	.85	.85	.9	10	.75	.75	.75
	≥100	.95	.95	.95	100	.65	.65	.7
					1 000	.6	.6	.65
Strong 425-700	1	.55	.6	.65	1	.8	.8	.8
	10	.75	.75	.75	10	.65	.65	.65
	≥100	.8	.8	.8	100	.55	.6	.65
					1 000	.5	.55	.6
Very strong >700	1	.5	.55	.6	1	.7	.75	.75
	10	.65	.7	.7	10	.55	.6	.65
	≥100	.7	.75	.75	100	.5	.55	.6
					1 000	.45	.5	.55

1/ For extensive areas of bare-fallow soils and no agricultural development, reduce Kpan by 20% under hot, windy conditions; by 5-10% for moderate wind, temperature and humidity conditions.

3) Penman Method :-

610 - (P)

Agronomy 8th Semester

(f) Adjustment factor (c)

The Penman equation given assumes the most common conditions where radiation is medium to high, maximum relative humidity is medium to high and moderate daytime wind about double the night time wind. However, these conditions are not always met. For instance, coastal are with pronounced sea breezes and calm nights generally have day/night wind ratios of 3 to 5; par of the Middle East have dry winds during the day and calm wind conditions during the night with m. imum relative humidity approaching 100 percent. For such conditions correction to the Penman e iation is required. Table 16 presents the values of c for different conditions of RHmax, Rs, Uday and Uday/Unight. Examples (Near East):

RHmax 90%; Rs 12 mm/day; Uday 3 m/sec; Uday/Unight 3: c = 1.28 (Table)
RHmax 60%; Rs 6 mm/day; Uday 3 m/sec; Uday/Unight 2: c = 0.91 (Table)

The information for using Table 16 may be difficult to obtain from available climatic records ut it can usually be derived for the different seasons from published weather descriptions or fror local sources. The conditions involving very low c values may seldom occur and may persist only or a few days in most climates. Table 16 does reveal a rather common need for c values smaller han 1.0 for low radiation, non-summer conditions (similar factors no doubt caused the use of wir er crop coefficients of 0.6 as compared to 0.8 for mid-summer in the original 1948 Penman method).

EXAMPLE:
Given:
Cairo; July. Rs 11.2 mm/day; RHmax 80%; Uday 3.2 m/sec; Unight 2.1 m/sec; Uday/Unight 1.5.
Calculation:
c value Table 16 = 1.06 (by interpolation)

Sample Calculations

Reference crop evapotranspiration (ETo) can be calculated using:

$$ETo = c\left[W \cdot Rn + (1-W) \cdot f(u) \cdot (ea-ed)\right]$$

EXAMPLE:
Given:
Cairo; July. W = 0.77; Rn = 6.6; (1-W) = 0.23; f(u) = 0.90; (ea-ed) = 17.5; c = 1.01.
Calculation:
ETo = 1.01 (0.77 x 6.6 + 0.23 x 0.90 x 17.5) = 8.8 mm/day

Using mean daily data for each month calculation of ETo in mm/day for each month:

Cairo latitude 30°N; altitude 95 m

	J	F	M	A	M	J	J	A	S	O	N	D
T mean °C	14	15	17.5	21	25.5	27.5	28.5	28.5	26	24	20	15.5
RHmean	65	65	63	50	45	50	55	57	60	64	68	68
n hours	7.4	8.0	8.9	9.7	10.8	11.4	11.5	11.1	10.4	9.6	8.6	7.5
U km/day	173	181	207	207	232	251	232	181	164	190	164	155
Rs mm/day	4.9	6.4	8.5	9.8	10.8	11.3	11.3	10.4	9.1	7.1	5.4	2.5
RHmax % (est)	95	95	95	70	65	70	75	80	80	90	95	95
Uday m/sec (est)	2.5	2.5	3.0	3.0	3.3	3.5	3.3	2.5	2.3	2.5	2.3	2.3 1/
c	0.9	0.95	1.02	1.0	1.0	1.0	1.01	1.01	1.01	0.95	0.93	0.93
ETO mm/day	2.7	3.8	5.0	7.0	8.9	9.4	8.8	7.6	6.1	4.8	3.2	2.3
mm/month	84	106	154	210	276	282	273	236	183	149	96	71

1/ Based on general climatic descriptions for Cairo; day/night wind ratio is some 1.5 produ ed by calm morning and mid-day conditions, with breezes in late afternoon; an exception would b the April and May 'Khamsin' winds which blow day and night but somewhat stronger during da time.

Required
Daily Temp
" R.H
" wind speed (Uo)
" n & N
Uday ratio
Unight

	flat sowing	Bed sowing
	4 Acre inches rauni	$1\frac{1}{2}$ acre inches (sowing)
	4 " " (after 35 days)	$1\frac{1}{2}$ " " (5 -7 days)
		$1\frac{1}{2}$ " " (15 days)
		$1\frac{1}{2}$ " " (15 days).
total rrig' fter 35 days	8 inches.	6 acre inches

Better & yield therefore
W.U.E increases more.

By Cut Throat flume, water is measured.

I-(ea-ed)

Table 5 **Saturation Vapour Pressure (ea) in mbar as Function of Mean Air Temperature (T) in oC 1/**

Temperature oC	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ea mbar	6.1	6.6	7.1	7.6	8.1	8.7	9.3	10.0	10.7	11.5	12.3	13.1	14.0	15.0	16.1	17.0	18.2	19.4	20.6*	22.0

Temperature oC	20	21	22	23	24	25	26	27	28 28.5	29	30	31	32	33	34	35	36	37	38	39
ea mbar	23.4	24.9	26.4	28.1	29.8	31.7	33.6	35.7	37.8*	40.1	42.4	44.9	47.6	50.3	53.2	56.2	59.4	62.8	66.3	69.9

1/ Also actual vapour pressure (ed) can be obtained from this table using available Tdewpoint data.
(Example: Tdewpoint is 18oC; ed is 20.6 mbar)

38.9

Table 6a **Vapour Pressure (ed) in mbar from Dry and Wet Bulb Temperature Data in °C (Aspirated Psychrometer)**

Depression wet bulb T°C altitude 0-1 000 m												drybulb T°C	Depression wet bulb T°C altitude 1 000-2 000 m											
0	2	4	6	8	10	12	14	16	18	20	22		0	2	4	6	8	10	12	14	16	18	20	22
73.8	64.9	56.8	49.2	42.2	35.8	29.8	24.3	19.2	14.4	10.1	6.0	40	73.8	65.2	57.1	49.8	43.0	41.8	31.0	25.6	20.7	16.2	12.0	8.1
66.3	58.1	50.5	43.6	37.1	31.1	25.6	20.5	15.8	11.4	7.3		38	66.3	58.2	50.9	44.1	37.9	36.7	26.8	21.8	17.3	13.2	9.2	5.7
59.4	51.9	44.9	38.4	32.5	26.9	21.8	17.1	12.7	8.6	4.9		36	59.4	52.1	45.2	39.0	33.3	32.1	23.0	18.4	14.3	10.4	6.8	3.5
53.2	46.2	39.8	33.8	28.3	23.2	18.4	14.0	10.0	6.2			34	53.2	46.4	40.1	34.4	29.1	24.1	19.6	15.4	11.5	8.0	4.6	1.5
47.5	41.1	35.1	29.6	24.5	19.8	15.4	11.3	7.5	4.0			32	47.5	41.3	35.5	30.2	25.3	20.7	16.6	12.6	9.1	5.8	2.6	
42.4	36.5	30.9	25.8	21.1	16.7	12.6	8.8	5.3				30	42.4	36.7	31.3	26.4	21.9	17.7	13.8	10.2	6.9	3.8	0.9	
37.8	32.3	27.2	22.4	18.0	14.0	10.2	6.7	3.4				28	37.8	32.5	27.5	23.0	18.9	14.9	11.4	8.0	4.9	2.1		
33.6	28.5	23.8	19.4	15.3	11.5	8.0	4.7	1.6				26	33.6	28.7	24.1	20.0	16.1	12.5	9.2	6.0	3.2	0.5		
29.8	25.1	20.7*	16.6	12.8	9.3	6.0	2.9					24	29.8	25.3	21.1	17.2	13.9	10.3	7.2	4.3	1.6			
26.4	22.0	18.0	14.2	10.6	7.4	4.3	1.4					22	26.4	22.3	18.3	14.3	11.5	8.3	5.5	2.7	0.2			
23.4	19.3	15.5	12.0	8.7	5.6	2.7						20	23.4	19.5	15.9	12.6	9.5	6.6	3.9	1.3				
20.6	16.8	13.3	10.0	6.9	4.1	1.4						18	20.6	17.1	13.7	10.6	7.8	5.0	2.5	0.1				
18.2	14.6	11.4	8.3	5.4	2.7							16	18.2	14.9	11.7	8.9	6.2	3.6	1.3					
16.0	12.7	9.6	6.7	4.0	1.5							14	16.0	12.9	10.0	7.3	4.8	2.4	0.3					
14.0	10.9	8.1	5.3	2.8								12	14.0	11.2	8.4	5.9	3.6	1.4						
12.3	9.4	6.7	4.1	1.7								10	12.3	9.6	7.0	4.7	2.6	0.4						
10.7	8.0	5.5	3.1	0.8								8	10.7	8.2	5.8	3.7	1.6							
9.3	6.8	4.4	2.1									6	9.3	7.0	4.8	2.7	0.7							
8.1	5.7	3.4	1.6									4	8.1	6.0	3.8	1.8								
7.1	4.8	2.8	0.8									2	7.1	5.0	2.9	1.0								
6.1	4.0	2.0										0	6.1	4.1	2.1									

Table 6b

Vapour Pressure (ed) in mbar from Dry and Wet Bulb Temperature Data in °C (Non-Ventilated Psychrometer)

Depression wet bulb T°C altitude 0-1 000 m												drybulb T °C	Depression wet bulb T°C altitude 1 000-2 000 m											
0	2	4	6	8	10	12	14	16	18	20	22		0	2	4	6	8	10	12	14	16	18	20	22
73.8	64.7	56.2	48.4	41.2	34.4	28.2	22.4	17.0	12.0	7.4	3.0	40	73.8	64.9	56.7	49.1	42.0	35.6	29.6	34.1	18.9	14.1	9.8	5.6
66.3	57.8	50.0	42.8	36.0	29.8	24.0	18.6	13.6	9.0	4.6	0.6	38	66.3	58.0	50.5	43.4	36.9	31.0	25.4	20.3	15.5	11.1	7.0	3.2
59.4	51.6	44.4	37.6	31.4	25.6	20.2	15.2	10.6	6.2	2.2		36	59.4	51.8	44.8	38.3	32.3	26.8	21.2	16.9	12.5	8.3	4.6	1.0
53.2	45.9	39.2	33.0	27.2	21.8	16.8	12.2	7.8	3.8			34	53.2	46.1	39.7	33.7	28.1	23.0	18.2	13.9	9.7	5.9	2.4	
47.5	40.8	34.6	28.8	23.2	18.2	13.8	9.4	5.2	1.6			32	47.5	41.0	35.1	29.5	24.3	19.6	15.2	11.1	7.3	3.7	0.4	
42.4	36.2	30.4	25.0	20.0	15.4	11.0	7.0	3.2				30	42.4	36.4	30.9	25.7	20.9	16.6	12.4	8.7	5.1	1.7		
37.8	32.0	26.6	21.6	17.0	12.6	8.6	4.8	1.2				28	37.8	32.2	27.1	22.3	17.9	13.8	10.0	6.5	3.1			
33.6	28.2	23.2	18.6	14.2	10.2	6.4	2.8					26	33.6	28.4	23.7	19.3	15.1	11.4	7.8	4.5	1.4			
29.8	24.8	20.2	15.8	11.8	8.0	4.4	1.1					24	29.8	25.0	20.7	16.5	12.7	9.2	5.8	2.8				
26.4	21.8	17.4	13.4	9.6	6.0	2.7						22	26.4	22.0	17.9	14.1	10.5	7.2	4.1	1.2				
23.4	19.0	15.0	11.2	7.6	4.3	1.1						20	23.4	19.2	15.5	11.9	8.5	5.5	2.5					
20.6	16.6	12.8	9.2	5.9	2.7							18	20.6	16.8	13.3	9.9	6.8	3.9	1.1					
18.2	14.4	10.8	7.5	4.3	1.4							16	18.2	14.6	11.3	8.2	5.2	2.5						
16.0	12.4	9.1	5.9	3.0	0.1							14	16.0	12.6	9.6	6.6	3.8	1.3						
14.0	10.7	7.5	4.6	1.7								12	14.0	10.9	8.0	5.2	2.6	0.3						
12.3	9.1	6.1	3.3	0.7								10	12.3	9.3	6.7	4.0	1.6							
10.7	7.7	4.9	2.3									8	10.7	7.9	5.4	3.0	0.6							
9.3	6.5	3.9	1.5									6	9.3	6.7	4.4	2.0								
8.1	5.5	2.9	0.9									4	8.1	5.7	3.4	1.1								
7.1	4.5	2.3	–									2	7.1	4.7	2.5	0.3								
6.1	3.7	1.5										0	6.1	3.8	1.7									

Table 7

Values of Wind Function $f(u) = 0.27\,(1 + \frac{U_2}{100})$ for Wind Run at 2 m height in km/day

(Latitude)

Wind km/day	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
	-	.30	.32	.35	.38	.41	.43	.46	.49	.51
100	.54	.57	.59	.62	.65	.67	.70	.73	.76	.78
200	.81	.84	.86	.89*	.92	.94	.97	1.00	1.03	1.05
300	1.08	1.11	1.13	1.16	1.19	1.21	1.24	1.27	1.30	1.32
400	1.35	1.38	1.40	1.43	1.46	1.49	1.51	1.54	1.57	1.59
500	1.62	1.65	1.67	1.70	1.73	1.76	1.78	1.81	1.84	1.90
600	1.89	1.92	1.94	1.97	2.00	2.02	2.05	2.08	2.11	2.15
700	2.16	2.19	2.21	2.24	2.27	2.29	2.32	2.35	2.38	2.40
800	2.43	2.46	2.48	2.51	2.54	2.56	2.59	2.62	2.64	2.65
900	2.70									

Table 8 Values of Weighting Factor (1-W) for the Effect of Wind and Humidity on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
(1-W) at altitude m 0	0.57	.54	.51	.48	.45	.42	.39	.36	.34	.32	.29	.27	.25	.23*	.22	.20	.19	.17	.16	.15
500	.56	.52	.49	.46	.43	.40	.38	.35	.33	.30	.28	.26	.24	.22	.21	.19	.18	.16	.15	.14
1 000	.54	.51	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.20	.18	.17	.15	.14	.13
2 000	.51	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12
3 000	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12	.11
4 000	.46	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12	.11	.10

Table 9 Values of Weighting Factor (W) for the Effect of Radiation on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
W at altitude m 0	0.43	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77*	.78	.80	.82	.83	.84	.85
500	.44	.48	.51	.54	.57	.60	.62	.65	.67	.70	.72	.74	.76	.78	.79	.81	.82	.84	.85	.86
1 000	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.80	.82	.83	.85	.86	.87
2 000	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88
3 000	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88	.89
4 000	.54	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.89	.90	.90

IV- Rn :-

a) Ra :-

Table 10

Extra Terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day

Northern Hemisphere													Southern Hemisphere											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.2
4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9.3	13.2	16.6	18.2
4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	18.3
5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	18.3
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	18.3
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

5) N :-

Table 11 **Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes**

Northern Lats	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Southern Lats	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
50°	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	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	12.6	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	11.0	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	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

8.32 8.45 8.70

1.59 1.47 1.32

زق(7.88)
3 – 5

	Temp		R.H	wind Speed (km/h)
J°	max	min.	max.	
	16.8	8.9	90 95.7	3.42 × 2 = 6.84 = $\frac{6.84 \times 1000}{60 \times 60}$ = 164.16
F	23.6	10	66 75.8	4.09 × 2 = 8.18 = $\frac{8.18 \times 1000}{3600}$ = 2.27 196.32
M	25.2	13.8	44.4 50.6	4.71 × 2 = 9.42 = 2.62 = 226.08
A	37.9	19	30.2 (25.6 max) (34.7 min)	4.6 × 2 = 9.2 = 2.56 = 220.8
M	41.1	25.5	31.6/37.1	5.72 × 2 = 11.44 = 3.18 = 274.56
J	40.1	27.5	32/38.6	6.93 × 2 = 13.86 = 3.85 = 332.64
J	38.5	28.8	44.3 (54.5 max)	7.69 × 2 = 15.38 = 4.27 = 369.12
A	37.9	27.9	49.5/55.6	6.7 × 2 = 13.4 = 3.72 = 321.6
S	38	26.4	44/50.4	~~3.22~~ 5.14 × 2 = 10.28 = 2.86 O = 246.72
O	35.1	19.6	44.6/53.9	3.22 × 2 = 6.44 = 1.79 O = 154.56
N	29	13.2	50.8/62.5	3.21 × 2 = 6.42 = 1.78 U = 154.08
D	24	7.7	60/78	2.45 × 2 = 4.90 = 1.36 = 117.6

c) $f(T)$, $f(ed)$, $f(n/N)$ –

(Conversion factor for Ra to Rns)

Table 12 Conversion Factor for Extra-Terrestrial Radiation (Ra) to Net Solar Radiation (Rns) for a Given Reflection α of 0.25 and Different Ratios of Actual to Maximum Sunshine Hours $(1-\alpha)(0.25 + 0.50\ n/N)$

n/N	0.0	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.0
$(1-\alpha)(0.25 + 0.50n/N)$	0.19	.21	.22	.24	.26	.28	.30	.32	.34	.36	.37	.39	.41	.43	.45	.47	.49*	.51	.52	.54	.56

$f(T)$

Table 13 Effect of Temperature $f(T)$ on Longwave Radiation (Rnl)

T°C	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
$f(T) = \sigma Tk^4$	11.0	11.4	11.7	12.0	12.4	12.7	13.1	13.5	13.8	14.2	14.6	15.0	15.4	15.9	16.3*	16.7	17.2	17.7	18.1

$f(ed)$

Table 14 Effect of Vapour Pressure $f(ed)$ on Longwave Radiation (Rnl)

ed mbar	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
$f(ed) = 0.34 - 0.044\sqrt{ed}$	0.23	.22	.20	.19	.18	.16	.15	.14	.13*	.12	.12	.11	.10	.09	.08	.08	.07	.06

$f(n/N)$

Table 15 Effect of the Ratio of Actual and Maximum Bright Sunshine Hours $f(n/N)$ on Longwave Radiation (Rnl)

n/N	0	.05	.1	.15	.2	.25	.3	.35	.4	.45	.5	.55	.6	.65	.7	.75	.80	.85	.9	.95	1.0
$f(n/N) = 0.1 + 0.9\ n/N$	0.10	.15	.19	.24	.28	.33	.37	.42	.46	.51	.55	.60	.64	.69	.73	.78	.82*	.87	.91	.96	1.0

n/N 1.92 1.68 1.50 1.43 1.43 1.40 1.74 1.59 1.47 1.32 1.25 1.28

$f(n/N)$ 1.83 1.61 1.45 1.39 1.39 1.36 1.67 1.53 1.42 1.29 1.22 1.25

(V) For 'C' factor, we uses $R.H._{max}$, R_S, $\frac{U_{day}}{U_{night}}$ ratio and U_{day} (in m/sec)

e.g. $R.H._{max.} = 80\%$

$R_S = 11.2 \text{ mm day}^{-1}$

$\frac{U_{day}}{U_{night}} = 1.5$, $U_{day} = 232 \text{ km/day}$

$= \frac{232 \times 1000}{1 \times 3600 \times 24} = 2.7 m$

From table - 16

$C = 1.06$

(VI) using all the calculated values, we can calculate ETo by using Penman's equation.

$$ETo = C\left[\underline{W.R_n + (1-W).f(u).(e_a - e_d)}\right]$$

V) C :-

able 16 Adjustment Factor (c) in Presented Penman Equation

R.H.$_{(max)}$ (%age) $\boxed{75\%}$ ✓

	RHmax = 30%				RHmax = 60%				RHmax = 90% (80%			
Rs mm/day →	3	6	9	12	3	6	9	12	3	6	9	12
Uday m/sec	Uday/Unight = 4.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.1
✓ 3	.79	.84	.92	.97	.92	1.00	1.11	1.19	.99	1.10	1.27	1.3
6	.68	.77	.87	.93	.85	.96	1.11	1.19	.94	1.10	1.26	1.3
9	.55	.65	.78	.90	.76	.88	1.02	1.14	.88	1.01	1.16	1.2
	Uday/Unight = 3.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.76	.81	.88	.94	.87	.96	1.06	1.12	.94	1.04	1.18	1.2
6	.61	.68	.81	.88	.77	.88	1.02	1.10	.86	1.01	1.15	1.2
9	.46	.56	.72	.82	.67	.79	.88	1.05	.78	.92	1.06	1.1
✓	([illegible]) → Uday/Unight = 2.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
✓ 3	.69	.76	.85	.92	.83	.91	.99*	1.05*	✓ .89	.98	1.10*	1.14
6	.53	.61	.74	.84	.70	.80	.94	1.02	.79	.92	1.05	1.12
9	.37	.48	.65	.76	.59	.70	.84	.95	.71	.81	.96	1.06
✓	Uday/Unight = 1.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	$\boxed{1.10}$	1.10
✓ 3	.64	.71	.82	.89	.78	.86	.94*	.99*	~~.85~~	.92	$\boxed{1.01*}$	1.05
6	.43	.53	.68	.79	.62	.70	.84	.93	.72	.82	.95	1.00
9	.27	.41	.59	.70	.50	.60	.75	.87	.62	.72	.87	.96

$$C = \frac{1.10 + 1.0}{2} = 1.0$$

$= 1.055 \Rightarrow 1.06$

$$\frac{3}{2} = 1.5$$

✓ $u_{day} = 232$ km/day

$$= \frac{232 \times 1000}{1 \times 3600 \times 24} = \frac{232000}{86400} = 2.68$$

$\simeq 1$

$$\cancel{= \frac{232 \times 1000}{1 \times 24}}$$

$$\cancel{= \frac{232 \times 1000}{3600 \times 12} = 5.37037}$$

(IV) To calculate R_n, we uses T_{mean}, $R \cdot H_{mean}$, altitude, latitude, ed, n & N.

e.g. $T_{mean} = 28.5°C$, $R \cdot H_{mean} = 55\%$

Altitude = 95 m, Latitude = 30°N ✓

ed = 21.4 m.bar, n = 11.5 hrs, N = 13.9 hrs

$$\boxed{R_n = R_{ns} - R_{nl}} \qquad \frac{n}{N} = \frac{11.5}{13.9} = 0.83$$

→ $R_{ns} = (1 - \alpha) R_s$

① $R_a = 16.8\ \text{mmday}^{-1}$ (from table-10 by using Latitude)

② $R_s = \left(0.25 + 0.50 \frac{n}{N}\right) R_a$

$= \left(0.25 + 0.50 \times \frac{11.5}{13.9}\right) 16.8 = 11.2\ \text{mmday}^{-1}$

③ $\alpha = 0.25$

④ $R_{ns} = (1 - 0.25)\ 11.2 = 8.4\ \text{mmday}^{-1}$ ✓

→ $R_{nl} = f(T) \cdot f(ed) \cdot f\left(\frac{n}{N}\right)$

① $f(T) = 16.4$ (from table-13 by using T_{mean})

② $f(ed) = 0.13$ (" " 14 " " ed)

③ $f\left(\frac{n}{N}\right) = 0.85$ (" " 15 " " $\frac{n}{N}$)

④ $R_{nl} = 16.4 \times 0.13 \times 0.85 = 1.8\ \text{mmday}^{-1}$ ✓

→ $R_n = R_{ns} - R_{nl}$

$= 8.4 - 1.8$

$= 6.6\ \text{mm day}^{-1}$

FORMAT FOR CALCULATION OF PENMAN METHOD

Penman reference crop ETo = c [W.Rn + (1-W) f(u)(ea-ed)]

Country: UAR
Period : July
Place: Cairo
Latitude : 30°N
Longitude: 30°
Altitude: 95m

DATA			
Tmean 28.5 °C	ea mbar	(5) 1/	38.9
RHmean 55 %	RH/100	data	0.55
	ed mbar	calc	21.4
or T wetbulb depression or T dewpoint		(5) or (6)	
	(ea-ed) mbar	calc	17.5
U₂ 232 km/day	f(u)	(7)	0.90
Tmean 28.5 °C altitude 95 m	(1-W)	(8)	0.23
	(1-W) f(u)(ea-ed) mm/day	calc	3.6
month July latitude 30°N	Ra mm/day	(10)	16.8
	n hr/day	data	11.5
month July latitude 30°N	N hr/day	(11)	13.9
	n/N	calc	0.83
	(0.25+0.50 n/N)	calc (12)	0.67
	Rs mm/day	calc	11.2
(α = 0.25)	Rns mm/day (1 - α) Rs	calc	8.4 2/
Tmean 28.5 °C	f(T)	(13)	16.4
ed 21.4 mbar	f(ed)	(14)	0.15
n/N 0.83	f(n/N)	(15)	0.85
	Rnl = f(T) f(ed) f(n/N) mm/day	calc	1.8
	Rn = Rns - Rnl	calc	6.6
Tmean 28.5 °C altitude 95 m	W	(9)	0.77
	W.Rn	calc	5.1
			8.7
Uday/Unight 1.5	c	(16)	1.01
RHmax, Rs 80% 11.2	ETo = c[W.Rn + (1-W) f(u)(ea-ed)] mm/day		8.8

1/ Numbers in brackets indicate Table of reference.

2/ When Rs data are available Rns = 0.75 Rs.

→ Penman formula uses 4 variables:- ① Temp ② Humidity (R.H. & Saturation v.p. deficit) ③ wind ④ Sunshine - duration or radiation measurements.

$$ET_o = \overset{(V)}{C}\left[\underbrace{\overset{(IV)}{W\cdot R_n}}_{\text{radiation term}} + \underbrace{\overset{(III)}{(1-W)}\cdot \overset{(II)}{f(u)}\cdot \overset{(I)}{(e_a-e_d)}}_{\text{Aerodynamic term}}\right]$$

→ (I) we use T_{mean} & $R.H_{mean}$ to calculate $(e_a - e_d)$.

e.g. $T_{mean} = 28.5°c$, $R.H_{mean} = 55\%$

→ From table - 5

Saturation v.p (e_a) at 28.5°c = 38.9 m.bar.

actual v.p (e_d) " " $= \frac{e_a \times R.H_{mean}}{100}$

$= \frac{38.9 \times 55}{100} = 21.4$ m.bar.

$e_a - e_d = 38.9 - 21.4 = \boxed{17.5 \text{ m.bar}}$

→ (II) To calculate f(u), we uses U (wind run at 2m height) in km/day.

$$f(u) = 0.27\left(1 + \frac{u}{100}\right)$$

e.g. U = 232 km/day

$f(u) = 0.27\left(1 + \frac{u}{100}\right)$

$= 0.27\left(1 + \frac{232}{100}\right) = \boxed{0.9}$.

→ (III) To calculate (1 − W) and W, we use T_{mean} & altitude by using table - 8 and table - 9

e.g. $T_{mean} = 28.5°c$, altitude = 95 m.

$(1 - W) = 0.23$ (in table - 8)

$W = 0.77$ (in table - 9)