

## CROP WATER NEEDS

Fuente: FAO.

**The crop water need (ET crop) is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration.** In other words, it is the amount of water needed by the various crops to grow optimally.

The crop water need always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favourable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment.

The crop water need mainly depends on:

- the climate: in a sunny and hot climate crops need more water per day than in a cloudy and cool climate
- the crop type: crops like maize or sugarcane need more water than crops like millet or sorghum
- the growth stage of the crop; fully grown crops need more water than crops that have just been planted.

Section 3.1 indicates the influence of the climate on crop water needs: this influence is given by the reference crop evapotranspiration (ET<sub>o</sub>). Section 3.2 indicates the influence of the crop type and growth stage on crop water needs: the influence of the crop is expressed in the crop factor (K<sub>c</sub>).

### 3.1 INFLUENCE OF CLIMATE ON CROP WATER NEEDS (ET<sub>o</sub>)

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#### 3.1.1 Introduction

The major climatic factors (see Fig. 4) which influence the crop water needs are:

- sunshine
- temperature
- humidity
- windspeed

Fig. 4 Major climatic factors influencing crop water needs

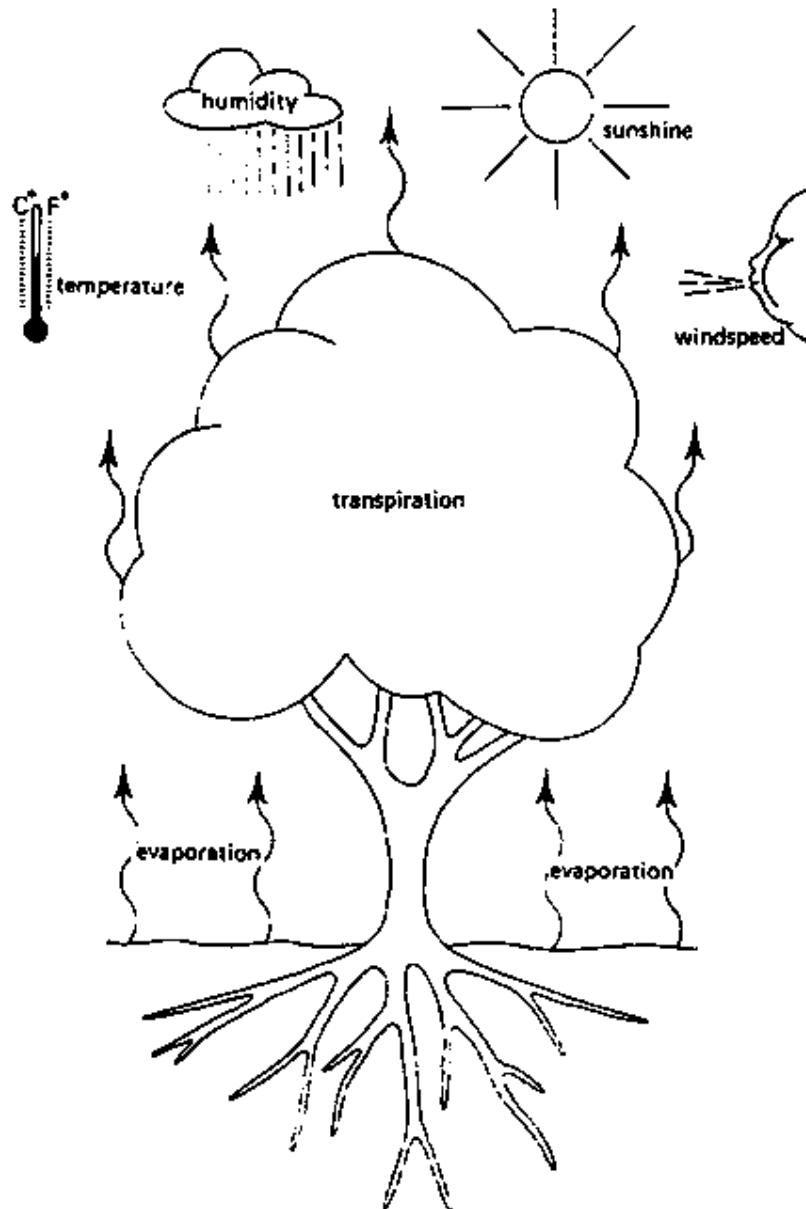


Table 3 indicates the effect of the various climatic factors on crop water needs.

**Table 3** EFFECT OF MAJOR CLIMATIC FACTORS ON CROP WATER NEEDS

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

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

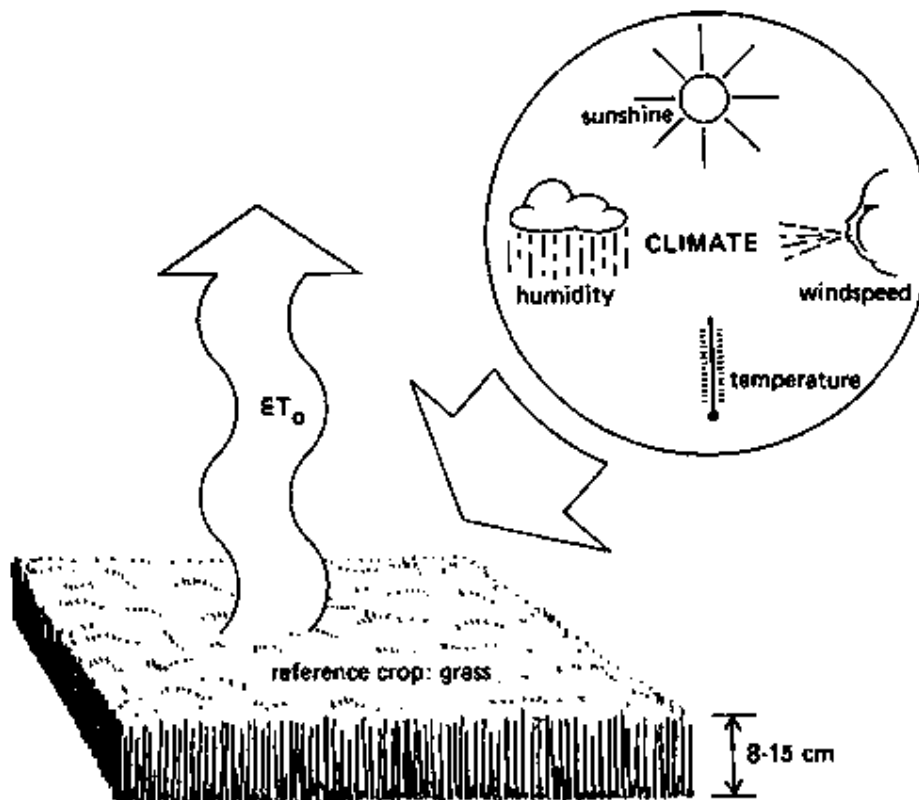
The influence of the climate on crop water needs is given by the **reference crop evapotranspiration (ET<sub>o</sub>)**. The ET<sub>o</sub> is usually expressed in millimetres per unit of time, e.g. mm/day, mm/month, or mm/season. Grass has been taken as the reference crop.



**Definition of the reference crop evapotranspiration (ET<sub>o</sub>):**

ET<sub>o</sub> is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water (see Fig. 5).

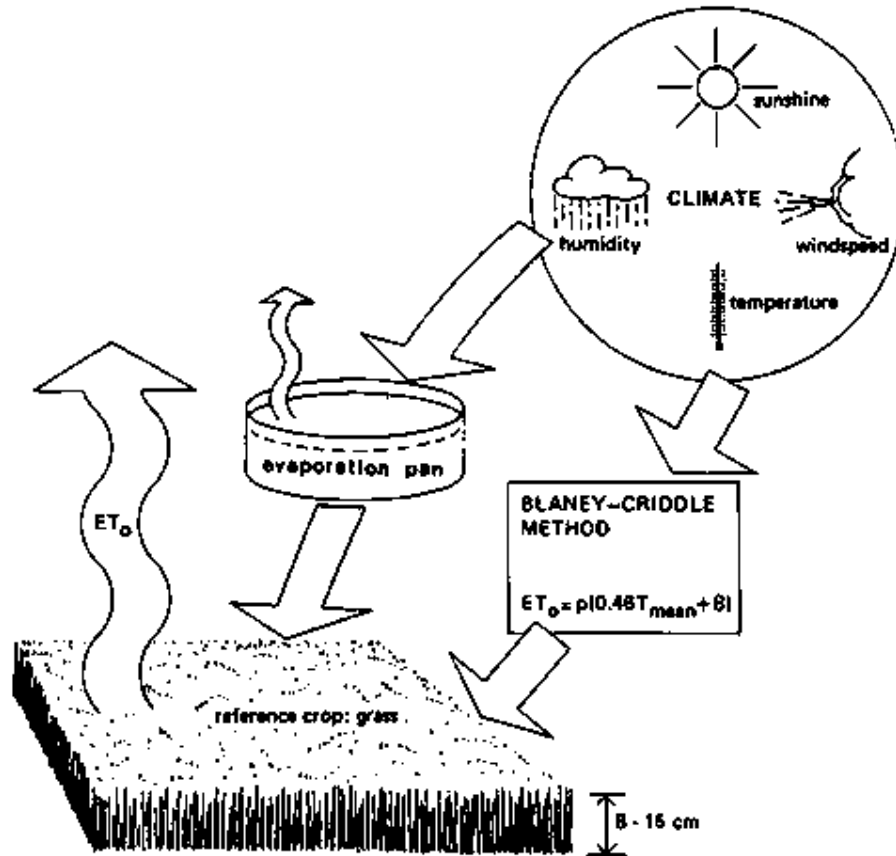
**Fig. 5 Reference crop evapotranspiration**



There are several methods to determine the ET<sub>o</sub> (see Fig. 6). They are either:

- experimental, using an evaporation pan, or
- theoretical, using measured climatic data, e.g. the Blaney-Criddle method

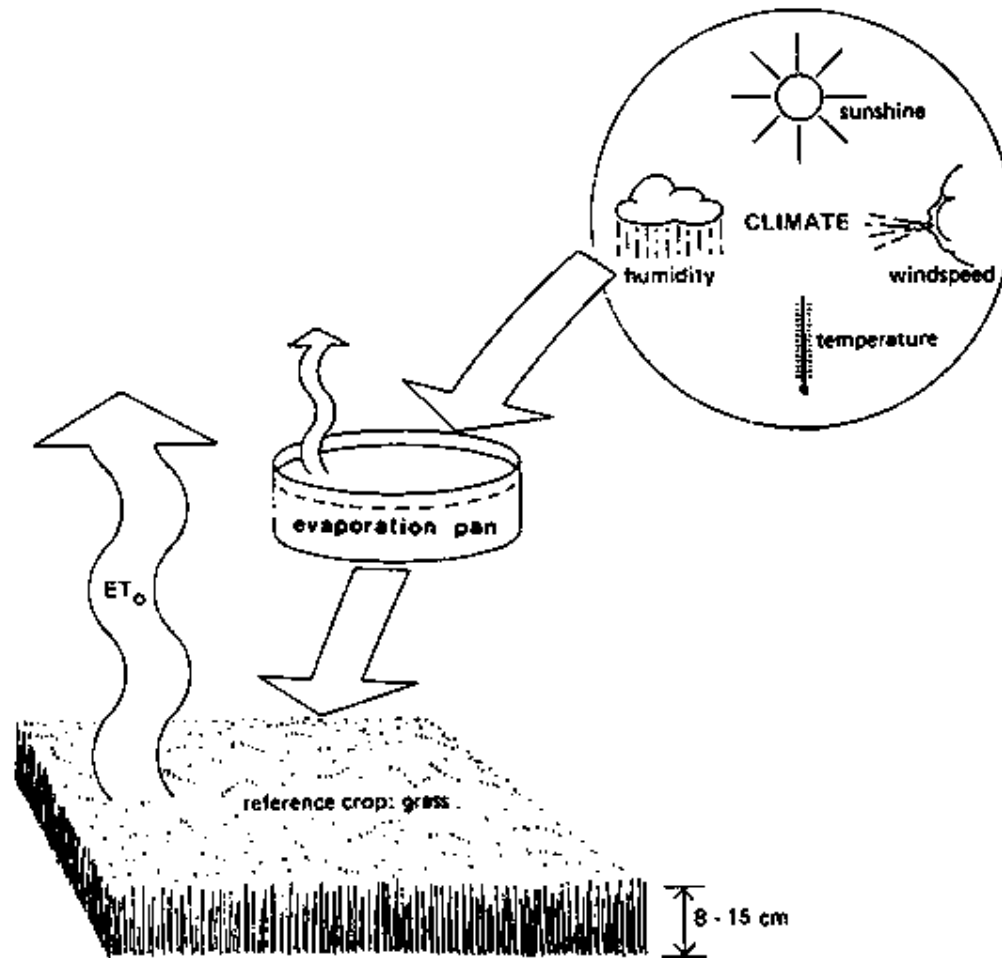
**Fig. 6 Methods to determine reference crop evapotranspiration**



### 3.1.2 Pan Evaporation Method

Evaporation pans provide a measurement of the combined effect of temperature, humidity, windspeed and sunshine on the reference crop evapotranspiration ET<sub>0</sub> (see Fig. 7).

Fig. 7 Pan evaporation method



Many different types of evaporation pans are being used. The best known pans are the Class A evaporation pan (circular pan) (Fig. 8a) and the Sunken Colorado pan (square pan) (Fig. 8b).

Fig. 8a Class A evaporation pan

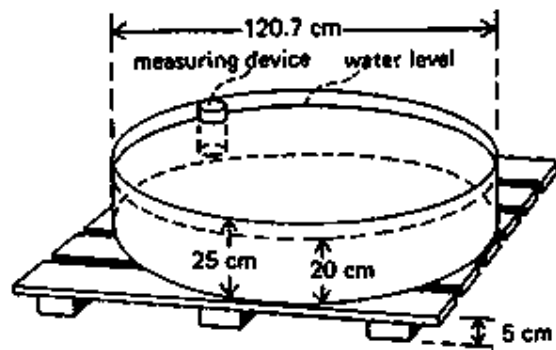
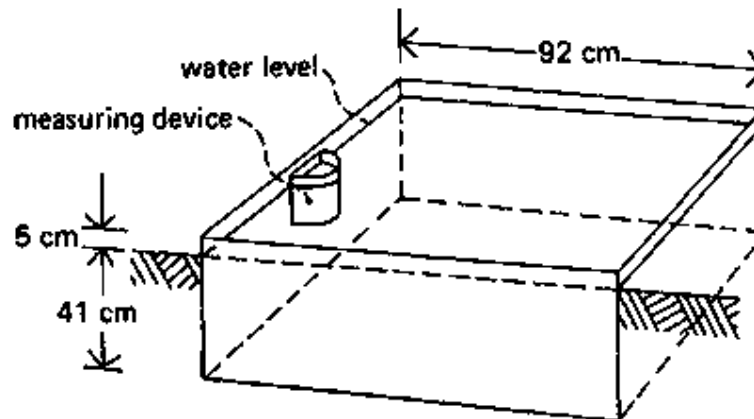


Fig. 8b Sunken Colorado pan



The principle of the evaporation pan is the following:

- the pan is installed in the field
- the pan is filled with a known quantity of water (the surface area of the pan is known and the water depth is measured)
- the water is allowed to evaporate during a certain period of time (usually 24 hours). For example, each morning at 7 o'clock a measurement is taken. The rainfall, if any, is measured simultaneously
- after 24 hours, the remaining quantity of water (i.e. water depth) is measured
- the amount of evaporation per time unit (the difference between the two measured water depths) is calculated; this is the pan evaporation:  $E_{\text{pan}}$  (in mm/24 hours)
- the  $E_{\text{pan}}$  is multiplied by a pan coefficient,  $K_{\text{pan}}$ , to obtain the  $ET_o$ .

$$\text{Formula: } ET_o = K_{\text{pan}} \times E_{\text{pan}}$$

with:

$ET_o$ : reference crop evapotranspiration

$K_{\text{pan}}$ : pan coefficient

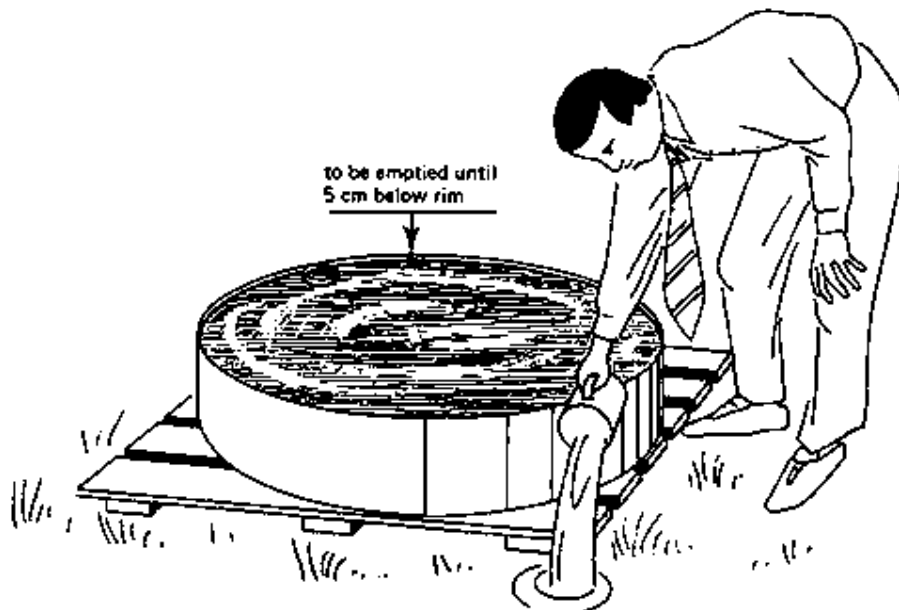
$E_{\text{pan}}$ : pan evaporation

If the water depth in the pan drops too much (due to lack of rain), water is added (see Fig. 9a) and the water depth is measured before and after the water is added. If the water level rises too much (due to rain) water is taken out of the pan (see Fig. 9b) and the water depths before and after are measured.

**Fig. 9a Add water when the water depth in the pan drops too much**



**Fig. 9b Take water out of the pan when the water depth rises too much**



#### Determination of K pan

When using the evaporation pan to estimate the  $E_{To}$ , in fact, a comparison is made between the evaporation from the water surface in the pan and the evapotranspiration of the standard grass. Of course the water in the pan and the grass do not react in exactly the same way to the climate. Therefore a special coefficient is used ( $K_{pan}$ ) to relate one to the other.

The pan coefficient,  $K_{pan}$ , depends on:

- the type of pan used
- the pan environment: if the pan is placed in a fallow or cropped area
- the climate: the humidity and windspeed

For the Class A evaporation pan, the K pan varies between 0.35 and 0.85. Average K pan = 0.70.

For the Sunken Colorado pan, the K pan varies between 0.45 and 1.10. Average K pan = 0.80.

**The K pan is high if:**

the pan is placed in a fallow area  
the humidity is high (i.e. humid)  
the windspeed is low

**The K pan is low if:**

the pan is placed in a cropped area  
the humidity is low (i.e. dry)  
the windspeed is high

Details of the pan coefficient are usually provided by the supplier of the pan.

If the pan factor is not known the average value could be used (see box). If more accuracy is required, the pan factors given in Annex 1 should be applied. These values, however, only refer to the Class A evaporation pan and the Sunken Colorado pan.

Some examples

1) Type of pan: Class A evaporation pan

Water depth in pan on day 1 = 150 mm (see Fig. 10a)

Water depth in pan on day 2 = 144 mm (after 24 hours; see Fig. 10b)

Rainfall (during 24 hours) = 0 mm

K pan = 0.75

Formula:  $ET_o = K \text{ pan} \times E \text{ pan}$

Calculation:  $E \text{ pan} = 150 - 144 = 6 \text{ mm/day}$

$ET_o = 0.75 \times 6 = 4.5 \text{ mm/day}$

[Fig. 10a Measuring the water depth on day 1\\*](#)

[Fig. 10b Measuring the water depth on day 2 \(after 24 hours\)\\*](#)

\* Measuring devices are usually more accurate than the ruler indicated in Fig. 10 and thus allow for more accurate readings (see Data Sheet 1).

2) Type of pan: Sunken Colorado pan

Water depth in pan on day 1 = 411 mm

Water depth in pan on day 2 = 409 mm (after 24 hours)

Rainfall (during 24 hours) = 7 mm

K pan = 0.90

Formula:  $ET_o = K \text{ pan} \times E \text{ pan}$

Calculation:  $E \text{ pan} = 411 - 409 + 7 = 9 \text{ mm/day}$

$ET_o = 0.90 \times 9 = 8.1 \text{ mm/day}$

[DATA SHEET 1 Determination  \$ET\_o\$ : Pan Evaporation Method](#)

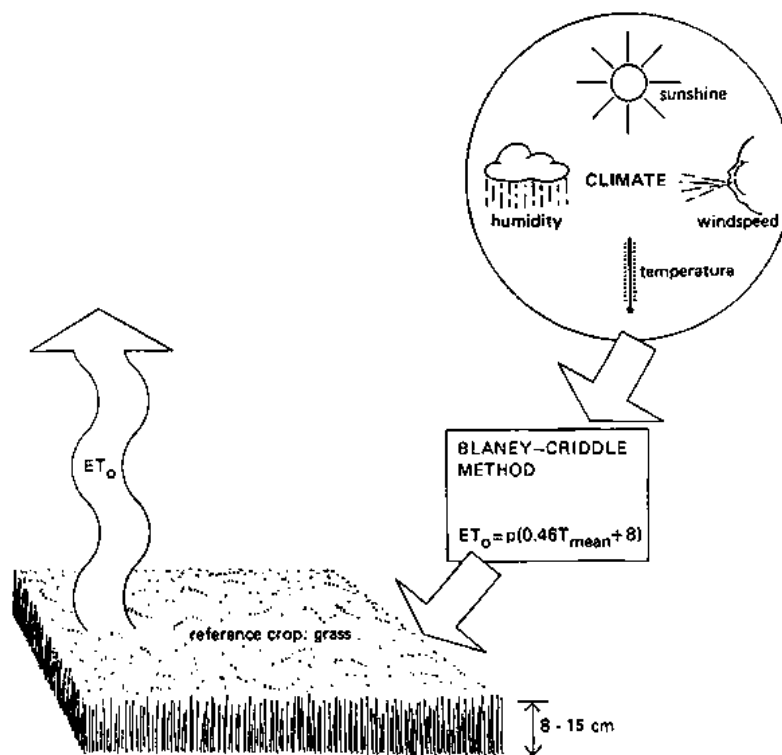
### 3.1.3 Blaney-Criddle Method

If no measured data on pan evaporation are available locally, a theoretical method (e.g. the Blaney-Criddle method) to calculate the reference crop evapotranspiration  $ETo$  has to be used. There are a large number of theoretical methods to determine the  $ETo$ . Many of them have been determined and tested locally. If such local formulae are available they should be used. If such local formulae are not available one of the general theoretical methods has to be used.

The most commonly used theoretical method is the modified Penman method which is described in detail in FAO Irrigation and Drainage Paper 24. This method, however, is rather complicated and beyond the scope of this manual.

Here only the Blaney-Criddle method is given. The Blaney-Criddle method is simple, using measured data on temperature only (see also Fig. 11). It should be noted, however, that this method is not very accurate; it provides a rough estimate or "order of magnitude" only. Especially under "extreme" climatic conditions the Blaney-Criddle method is inaccurate: in windy, dry, sunny areas, the  $ETo$  is underestimated (up to some 60 percent), while in calm, humid, clouded areas, the  $ETo$  is overestimated (up to some 40 percent).

Fig. 11 The Blaney-Criddle method



The Blaney-Criddle formula:  $ETo = p (0.46 T_{\text{mean}} + 8)$

$ETo$  = Reference crop evapotranspiration (mm/day) as an average for a period of 1 month

$T_{\text{mean}}$  = mean daily temperature ( $^{\circ}\text{C}$ )

$p$  = mean daily percentage of annual daytime hours

### The use of the Blaney-Criddle formula

#### Step 1: Determination of the mean daily temperature: T mean

The Blaney-Criddle method always refers to mean **monthly** values, both for the temperature and the ETo. If, for example, it is found that T mean in March is 28°C, it means that during the whole month of March the mean daily temperature is 28°C.

If in a local meteorological station the daily minimum and maximum temperatures are measured, the mean daily temperature is calculated as follows:

$$T_{\max} = \frac{\text{sum of all } T_{\max} \text{ values during the month}}{\text{number of days of the month}}$$

$$T_{\min} = \frac{\text{sum of all } T_{\min} \text{ values during the month}}{\text{number of days of the month}}$$

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

#### Step 2: Determination of the mean daily percentage of annual daytime hours: p

To determine the value of p, Table 4 is used. To be able to determine the p value it is essential to know the approximate latitude of the area: the number of degrees north or south of the equator (see Fig. 12).

Suppose the p value for the month **March** has to be determined for an area with a latitude of 45° South. From Table 4 it can be seen that the p value during March = 0.28.

#### [Fig. 12 The latitude](#)

**Table 4 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	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
55		.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
50		.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
45		.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
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

**Step 3: Calculate ETo**, using the formula:  $ETo = p (0.46 T \text{ mean} + 8)$

For example, when  $p = 0.29$  and  $T \text{ mean} = 21.5^\circ\text{C}$  the ETo is calculated as follows:

$$ETo = 0.29 (0.46 \times 21.5 + 8) = 0.29 (9.89 + 8) = 0.29 \times 17.89 = 5.2 \text{ mm/day}$$

### 3.1.4 Calculation Example Blaney-Criddle

#### Given

Latitude -  $35^\circ$  North

Mean T max in April =  $29.5^\circ\text{C}$

Mean T min in April =  $19.4^\circ\text{C}$

#### Question

Determine for the month April the mean ETo in mm/day using the Blaney-Criddle method

#### Answer

Formula:  $ETo = p (0.46 T \text{ mean} + 8)$

$$\text{Step 1: determine } T \text{ mean: } T \text{ mean} = \frac{T \text{ max} + T \text{ min}}{2} = \frac{29.5 + 19.4}{2} = 24.5^\circ\text{C}$$

Step 2: determine p: Latitude:  $35^\circ$  North

Month: April

From Table 4:  $p = 0.29$

Step 3: calculate ETo:  $ETo = 0.29 (0.46 \times 24.5 + 8) = 5.6 \text{ mm/day}$

Thus the mean reference crop evapotranspiration  $ETo = 5.6 \text{ mm/day}$  during the whole month of April.

### 3.1.5 Indicative Values of ETo

If only a rough estimate of the ETo value is required. Table 5 can be used.

**Table 5 INDICATIVE VALUES OF ETo (mm/day)**

Climatic zone	Mean daily temperature		
	low (less than $15^\circ\text{C}$ )	medium ( $15\text{-}25^\circ\text{C}$ )	high (more than $25^\circ\text{C}$ )
Desert/arid	4-6	7-8	9-10
Semi arid	4-5	6-7	8-9
(Moist) Sub-humid	3-4	5-6	7-8
Humid	1-2	3-4	5-6

**DATA SHEET 2 Calculation of the mean monthly temperature: T max and T min****DATA SHEET 3 Determination ETo: Blaney-Criddle Method**

Location: EXAMPLE... Date: 1/18/86...  
 Latitude: 13.....°North/South

Month	T min (°C)	T max (°C)	T mean (°C)	p Table 4	ETo mm/day
Jan	15.5	32.1	23.8	0.26	4.9
Feb	18.8	35.8	27.3	0.26	5.3
Mar	21.8	38.0	29.9	0.27	5.9
Apr	24.5	38.7	31.6	0.28	6.3
May	26.0	39.0	32.5	0.29	6.7
Jun	25.0	36.6	30.8	0.29	6.4
Jul	22.7	32.6	27.6	0.29	6.0
Aug	22.0	30.8	26.4	0.28	5.6
Sep	23.0	31.8	27.4	0.28	5.8
Oct	21.3	34.8	28.0	0.27	5.6
Nov	18.7	35.0	26.8	0.26	5.3
Dec	16.6	32.0	24.3	0.25	4.8

Note:

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

$$ETo = p (0.46 T_{\text{mean}} + 8)$$

**3.2 INFLUENCE OF CROP TYPE ON CROP WATER NEEDS (Kc)****3.2.1 Introduction****3.2.2 Determination of the Total Growing Period****3.2.3 Determination of the Growth Stages****3.2.4 Determination of Crop Factors****3.2.1 Introduction**

In section 3.1 the influence of the climate on crop water needs has been discussed. The influence of the climate is given by the reference crop evapotranspiration ETo; the reference crop used for this purpose is grass (see Fig. 13a).

Fig. 13a Reference crop evapotranspiration



This section (3.2) deals with the influence of the crop type and growth stage on crop water needs. In other words, this section discusses the relationship between the reference grass crop and the crop actually grown in the field.

The relationship between the reference grass crop and the crop actually grown is given by the **crop factor**,  $K_c$ , as shown in the following formula:

$$E_{To} \times K_c = ET_{\text{crop}}$$

with  $ET_{\text{crop}}$  = crop evapotranspiration or crop water need (mm/day)

$K_c$  = crop factor

$E_{To}$  = reference evapotranspiration (mm/day)

Both  $ET_{\text{crop}}$  and  $E_{To}$  are expressed in the same unit: usually in mm/day (as an average for a period of one month) or in mm/month.

Fig. 13b Crop evapotranspiration or crop water need



The crop factor,  $K_c$ , mainly depends on:

- the type of crop
- the growth stage of the crop
- the climate

#### $K_c$ and the type of crop

Fully developed maize, with its large leaf area will be able to transpire, and thus use, more water than the reference grass crop:  $K_c$ , maize is higher than 1. Cucumber, also fully developed, will use less water than the reference grass crop:  $K_c$ , cucumber is less than 1.

#### $K_c$ and the growth stage of the crop

A certain crop will use more water once it is fully developed, compared to a crop which has just recently been planted.

### Kc and the climate

The climate influences the duration of the total growing period and the various growth stages. In a cool climate a certain crop will grow slower than in a warm climate.

**Thus, to determine the crop factor Kc, it is necessary, for each crop, to know the total length of the growing season and the lengths of the various growth stages.**

The determination of the Kc values for the various growth stages of the crops involves several steps:

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

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

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

The 3 steps mentioned above are dealt with in the sections 3.2.2, 3.2.3 and 3.2.4 respectively. Section 3.3 explains how the crop water need or crop evapotranspiration is determined.

## 3.2.2 Determination of the Total Growing Period

The total growing period (in days) is the period from sowing or transplanting to the last day of the harvest. It is mainly dependent on:

- the type of crop and the variety
- the climate
- the planting date

As the growing period heavily depends on local circumstances (e.g. local crop varieties) it is always best to obtain these data locally. Only if no data are available locally should Table 6 be used.

As can be seen from Table 6 there is a large variation of values not only between crops but also within one crop type. In general it can be assumed that the growing period for a certain crop is longer when the climate is cool and shorter when the climate is warm.

**Table 6 INDICATIVE VALUES OF THE TOTAL GROWING PERIOD**

Crop	Total growing period (days)	Crop	Total growing period (days)
Alfalfa	100-365	Millet	105-140
Banana	300-365	Onion green	70-95
Barley/Oats/Wheat	120-150	Onion dry	150-210
Bean green	75-90	Peanut/Groundnut	130-140
Bean dry	95-110	Pea	90-100
Cabbage	120-140	Pepper	120-210
Carrot	100-150	Potato	105-145
Citrus	240-365	Radish	35-45

Cotton	180-195	Rice	90-150
Cucumber	105-130	Sorghum	120-130
Eggplant	130-140	Soybean	135-150
Flax	150-220	Spinach	60-100
Grain/small	150-165	Squash	95-120
Lentil	150-170	Sugarbeet	160-230
Lettuce	75-140	Sugarcane	270-365
Maize sweet	80-110	Sunflower	125-130
Maize grain	125-180	Tobacco	130-160
Melon	120-160	Tomato	135-180

### 3.2.3 Determination of the Growth Stages

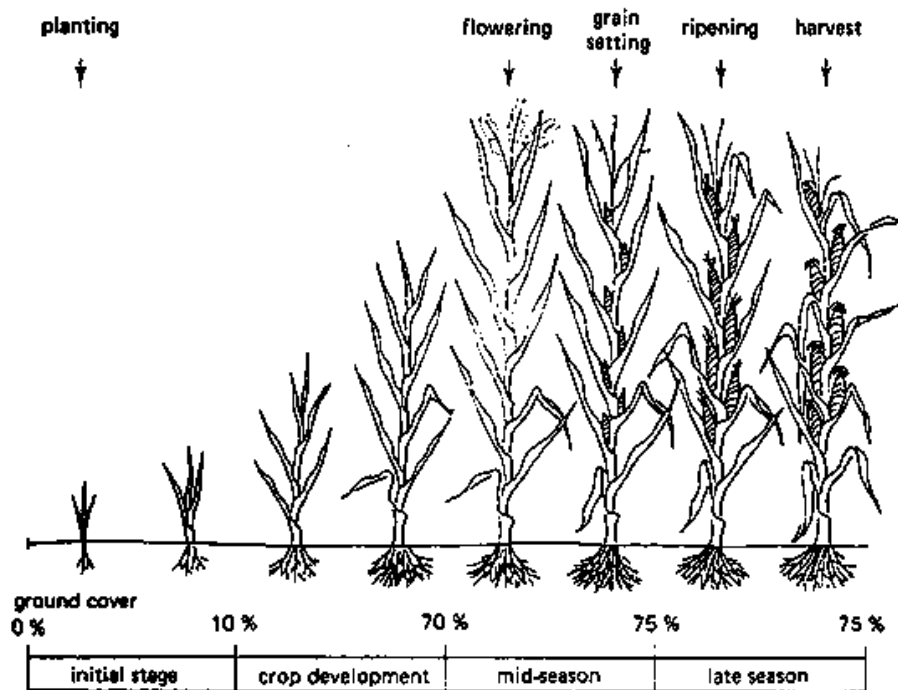
Once the total growing period is known, the duration (in days) of the various growth stages has to be determined.

The total growing period is divided into 4 growth stages (see Fig. 14):

1. **The initial stage:** this is the period from sowing or transplanting until the crop covers about 10% of the ground.
2. **The crop development stage:** this period starts at the end of the initial stage and lasts until the full ground cover has been reached (ground cover 70-80%); it does not necessarily mean that the crop is at its maximum height.
3. **The mid - season stage:** this period starts at the end of the crop development stage and lasts until maturity; it includes flowering and grain-setting.
4. **The late season stage:** this period starts at the end of the mid season stage and lasts until the last day of the harvest; it includes ripening.

Table 7 shows the duration of the various growth stages for some of the major field crops. For each crop the "minimum" and "maximum" duration of total growing period (see also Table 6) have been taken and sub-divided in the various growth stages.

Fig. 14 Growth stages



**Table 7 APPROXIMATE DURATION OF GROWTH STAGES FOR VARIOUS FIELD CROPS**

	Total	Initial stage	Crop Development stage	Mid season stage	Late season stage
Barley/Oats/Wheat	120	15	25	50	30
	150	15	30	65	40
Bean/green	75	15	25	25	10
	90	20	30	30	10
Bean/dry	95	15	25	35	20
	110	20	30	40	20
Cabbage	120	20	25	60	15
	140	25	30	65	20
Carrot	100	20	30	30	20
	150	25	35	70	20
Cotton/Flax	180	30	50	55	45
	195	30	50	65	50
Cucumber	105	20	30	40	15
	130	25	35	50	20
Eggplant	130	30	40	40	20
	140	30	40	45	25
Grain/small	150	20	30	60	40
	165	25	35	65	40
Lentil	150	20	30	60	40

	170	25	35	70	40
Lettuce	75	20	30	15	10
	140	35	50	45	10
Maize, sweet	80	20	25	25	10
	110	20	30	50	10
Maize, grain	125	20	35	40	30
	180	30	50	60	40
Melon	120	25	35	40	20
	160	30	45	65	20
Millet	105	15	25	40	25
	140	20	30	55	35
Onion/green	70	25	30	10	5
	95	25	40	20	10
Onion/dry	150	15	25	70	40
	210	20	35	110	45
Peanut/Groundnut	130	25	35	45	25
	140	30	40	45	25
Pea	90	15	25	35	15
	100	20	30	35	15
Pepper	120	25	35	40	20
	210	30	40	110	30
Potato	105	25	30	30	20
	145	30	35	50	30
Radish	35	5	10	15	5
	40	10	10	15	5
Sorghum	120	20	30	40	30
	130	20	35	45	30
Soybean	135	20	30	60	25
	150	20	30	70	30
Spinach	60	20	20	15	5
	100	20	30	40	10
Squash	95	20	30	30	15
	120	25	35	35	25
Sugarbeet	160	25	35	60	40
	230	45	65	80	40
Sunflower	125	20	35	45	25
	130	25	35	45	25
Tomato	135	30	40	40	25
	180	35	45	70	30

### Example

Carrots: the "minimum" growing period is 100 days. This growing period corresponds with the following duration of growth stages:

Initial stage : 20 days  
 Crop development stage : 30 days  
 Mid-season stage : 30 days  
 Late season stage : 20 days  
 Total 100 days

For the "maximum" growing period of 150 days the following values apply: respectively 25, 35, 70 and 20 days.

Should, under certain local circumstances, the duration of the growing period be 120 days, the duration of the growth stages could be estimated as follows:

Initial stage : 25 days  
 Crop development stage : 35 days  
 Mid-season stage : 40 days  
 Late season stage : 20 days  
 Total 120 days

With respect to Table 7 the following should be noted:

1. The table always refers to "sown" crops. When the crop is transplanted, the length of the initial stage should be reduced. For example:

Tomatoes: growing period 180 days from sowing  
 Direct sowing: initial stage 35 days  
 Transplanted: (estimated) initial stage 15 days  
 The growing period from transplant is thus  $(180 - 20) = 160$  days

<b>Direct sowing</b>			
Initial stage	crop development stage	mid-season stage	late season stage
35 days	45 days	70 days	30 days
<b>Transplanting</b>			
Initial. Stage	crop development stage	mid-season stage	late season stage
15 days	45 days	70 days	30 days

2. When a crop is harvested "green" or "fresh" the late season stage is short.

Compare, for example, green beans with dry beans (Table 7). The duration of the late season stage is 10 and 20 days respectively.

3. If a crop is planted in the winter or is growing in the cool season the total growing period is long. The same is the case with the individual lengths of growing stages. The difference will be most pronounced for the stage during which the temperature is the lowest.

It should be kept in mind that the influence of variations in the total growing period on the crop water need is very important. Less important is the choice of the various lengths of growth stages.

In other words: it is important to obtain (preferably locally) an accurate estimate of the total growing period. The duration of the four growth stages can be estimated with the help of Table 7.

**Note: The sum of the four growth stages should always equal the total growing period.**

### SOME EXAMPLES

#### QUESTION

Estimate the duration of the four growth stages for the following crops: cotton (190 days), lentils (160 days), sweet maize (100 days), potatoes (130 days), tomatoes/transplanted (140 days from transplant), etc. (the figures in brackets refer to the total growing period).

#### ANSWER

Crop	Initial stage (day)	Crop dev. stage (days)	Mid-season stage (days)	Late season stage (days)
Cotton (190 days)	30	50	60	50
Lentils (160 days)	25	30	65	40
Sweet Maize (100 days)	20	30	40	10
Potatoes (130 days)	30	35	40	25
Tomatoes/Transplanted (140 days from transplant)	15	40	60	25

### [Surface irrigation of a large field](#)

#### 3.2.4 Determination of Crop Factors

Per crop, **four** crop factors have to be determined: one crop factor for each of the **four** growth stages. Table 8 indicates per crop the Kc values for each of the four growth stages.

**Table 8 VALUES OF THE CROP FACTOR (Kc) FOR VARIOUS CROPS AND GROWTH STAGES**

Crop	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
Barley/Oats/Wheat	0.35	0.75	1.15	0.45
Bean, green	0.35	0.70	1.10	0.90
Bean, dry	0.35	0.70	1.10	0.30
Cabbage/Carrot	0.45	0.75	1.05	0.90
Cotton/Flax	0.45	0.75	1.15	0.75
Cucumber/Squash	0.45	0.70	0.90	0.75
Eggplant/Tomato	0.45	0.75	1.15	0.80
Grain/small	0.35	0.75	1.10	0.65
Lentil/Pulses	0.45	0.75	1.10	0.50

Lettuce/Spinach	0.45	0.60	1.00	0.90
Maize, sweet	0.40	0.80	1.15	1.00
Maize, grain	0.40	0.80	1.15	0.70
Melon	0.45	0.75	1.00	0.75
Millet	0.35	0.70	1.10	0.65
Onion, green	0.50	0.70	1.00	1.00
Onion, dry	0.50	0.75	1.05	0.85
Peanut/Groundnut	0.45	0.75	1.05	0.70
Pea, fresh	0.45	0.80	1.15	1.05
Pepper, fresh	0.35	0.70	1.05	0.90
Potato	0.45	0.75	1.15	0.85
Radish	0.45	0.60	0.90	0.90
Sorghum	0.35	0.75	1.10	0.65
Soybean	0.35	0.75	1.10	0.60
Sugarbeet	0.45	0.80	1.15	0.80
Sunflower	0.35	0.75	1.15	0.55
Tobacco	0.35	0.75	1.10	0.90

The table above shows average  $K_c$  values for the various crops and growth stages. In fact, the  $K_c$  is also dependent on the climate and, in particular, on the relative humidity and the windspeed. The values indicated above should be reduced by 0.05 if the relative humidity is high ( $RH > 80\%$ ) and the windspeed is low ( $u < 2$  m/sec), e.g.  $K_c = 1.15$  becomes  $K_c = 1.10$ . The values should be increased by 0.05 if the relative humidity is low ( $RH < 50\%$ ) and the windspeed is high ( $u > 5$  m/sec), e.g.  $K_c = 1.05$  becomes  $K_c = 1.10$ .

DATA SHEET 4 Determination of crop factors

Location : Example... Date : 1/8/86  
 Humidity : crop 1: high medium / low Wind speed : crop 1: high medium / low  
 crop 2: high medium / low crop 2: high medium / low

Crop 1 : <u>Maize (grain)</u> .....	Planting Date : <u>1 July</u> .....
Duration of total growing period : <u>130</u> .... days (from local information or Table 6)	
Estimated duration of growth stages (Table 7) :	
	<u>Dates</u>
Initial stage : <u>20</u> .... days	<u>1 July - 20 July</u> .....
Crop dev. stage : <u>35</u> .... days	<u>21 July - 25 August</u> .....
Mid-season stage : <u>45</u> .... days	<u>26 August - 10 October</u> .....
Late season stage : <u>30</u> .... days	<u>11 October - 10 November</u> .....
Crop factors, K <sub>c</sub> (Table 8) :	
Initial stage : <u>0.40*</u> ....	
Crop dev. stage : <u>0.80*</u> ....	
Mid-season stage : <u>1.15*</u> ....	
Late season stage : <u>0.70*</u> ....	

Crop 2 : <u>Cotton</u> .....	Planting Date : <u>1 JUNE</u> .....
Duration of total growing period : <u>165</u> .... days (from local information or Table 6)	
Estimated duration of growth stages (Table 7) :	
	<u>Dates</u>
Initial stage : <u>25</u> .... days	<u>1 June - 25 June</u> .....
Crop dev. stage : <u>45</u> .... days	<u>26 June - 10 August</u> .....
Mid-season stage : <u>50</u> .... days	<u>11 August - 30 September</u> .....
Late season stage : <u>45</u> .... days	<u>1 October - 15 November</u> .....
Crop factors, K <sub>c</sub> (Table 8) :	
Initial stage : <u>0.45</u> ....	
Crop dev. stage : <u>0.75</u> ....	
Mid-season stage : <u>1.15</u> ....	
Late season stage : <u>0.75</u> ....	

\* In case of low RH & high windspeed the K<sub>c</sub> values would resp. be: 0.45, 0.85, 1.20 & 0.75. In case of high RH & low windspeed the K<sub>c</sub> values would resp. be: 0.35, 0.75, 1.10 & 0.65.

**3.3 CALCULATION OF THE CROP WATER NEED**

### [3.3.1 Introduction](#)

### [3.3.2 Crop Water Need Calculation Example](#)

### [3.3.3 Special Cases](#)

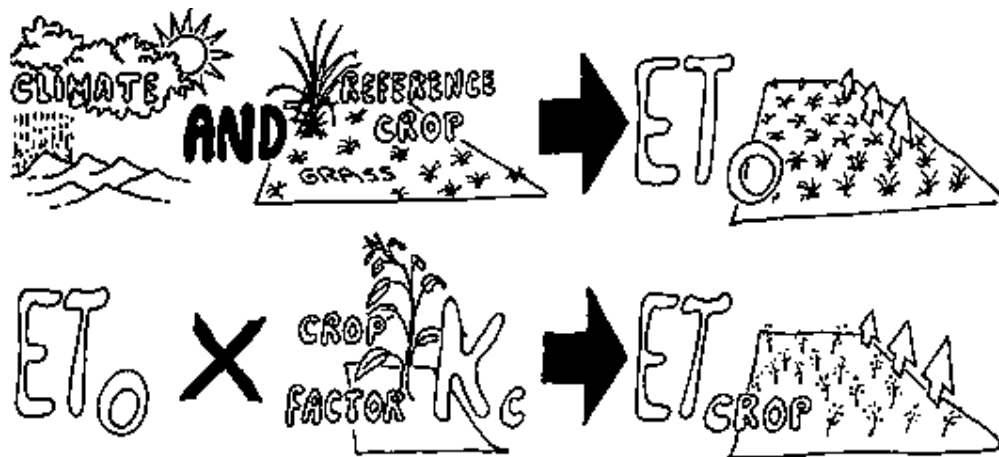
### [3.3.4 Indicative Values of Crop Water Needs](#)

### 3.3.1 Introduction

In section 3.1 the determination of the reference crop evapotranspiration  $ET_0$  has been discussed, while in section 3.2 it has been indicated how the crop factor  $K_c$  can be determined.

This section (3.3) explains how the crop water need  $ET_{crop}$  is calculated (see Fig. 15) on a monthly basis, using the formula:  $ET_{crop} = ET_0 \times K_c$ .

**Fig. 15 Calculation of the crop water need ( $ET_{crop}$ )**



Although the formula to calculate  $ET_{crop}$  is easy to apply, there are still some practical problems to be overcome, which can best be explained using an example.

### 3.3.2 Crop Water Need Calculation Example

#### QUESTION

Determine the crop water need of tomatoes

#### GIVEN

Month	Jan	Feb	Mar	Apr	May	June	July
$ET_0$ (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5
Humidity	medium	(60%)					
Windspeed	medium	(3 m/sec)					
Duration of growing period (from sowing): 150 days							
Planting date: 1 February (direct sowing)							

## CALCULATION

Step 1: Estimate the duration of the various growth stages, using Table 7.

Crop	Total growing period (days)	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
Tomatoes	150	35	40	50	25

Step 2: Indicate on table, as per example below, the ETo values and the duration of the growth stages.

**Note:** When calculating the crop water needs, all months are assumed to have 30 days. For the calculation of the reference crop evapotranspiration (ETo, section 3.1), the actual number of days of each month is used e.g., January 31 days, February 28 or 29 days, etc.

Crop: Tomatoes..... Planting Date: 1 February..

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		Initial St.	Crop dev. St.	Mid season St.	Late S. St.							

Planting date	1 Feb
Initial stage, 35 days	1 Feb-5 Mar
Crop development stage, 40 days	6 Mar-15 Apr
Mid season stage, 50 days	16 Apr-5 Jun
Late season stage, 25 days	6 Jun-30 Jun
Last day of the harvest	30 Jun

Step 3: Estimate the Kc factor for each of the 4 growth stages, using Table 8 and bearing in mind that the humidity and windspeed are medium

Kc, initial stage = 0.45

Kc, crop development stage = 0.75

Kc, mid season stage = 1.15

Kc, late season stage = 0.8

The Kc values are inserted in the Table:

Crop: Tomatoes..... Planting Date: 1 February.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		Initial st.	Crop dev. st.	Mid season st.	Late s. st.							
Kc per gr. st.		0.45	0.75	1.15	0.8							

It can be seen from the table above that the months and growth stages do not correspond. As a consequence the ETo and the Kc values do not correspond.

Yet the ET crop (= ETo × Kc) has to be determined on a monthly basis. It is thus necessary to determine the Kc on a monthly basis, which is done as follows:

(see also the table above)

February: Kc Feb = 0.45

March: 5 days: Kc = 0.45  
25 days: Kc = 0.75

$$\text{Kc March: } Kc = \frac{5}{30} \times 0.45 + \frac{25}{30} \times 0.75 = 0.07 + 0.62 = 0.69 = \text{approx. } 0.70$$

**NOTE: The Kc values are rounded to the nearest 0.05 or 0.00.**

**Thus Kc, March = 0.70**

April: 15 days: Kc = 0.75  
15 days: Kc = 1.15

$$\text{Kc, April: } Kc = \frac{15}{30} \times 0.75 + \frac{15}{30} \times 1.15 = 0.38 + 0.58 = 0.96 = \text{approx. } 0.95$$

Thus Kc, April = 0.95

May: Kc, May = 1.15

June: 5 days: Kc = 1.15  
: 25 days: Kc = 0.80

$$\text{Kc, June: } = \frac{5}{30} \times 1.15 + \frac{25}{30} \times 0.80 = 0.19 + 0.67 = 0.86 = \text{approx. } 0.85$$

Thus Kc, June = 0.85

In summary:

Crop: Tomatoes..... Planting Date: 1 February.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		INITIAL ST.	Crop dev. st.	mid season st.	late s. st.							
Kc per gr. st.		0.45	0.75	1.15	0.8							
Kc per month		0.45	0.70	0.95	1.15	0.85						

Step 4: Calculate, on a monthly basis, the crop water need, using the formula:

ET crop = ETo × Kc (mm/day)

February: ET crop = 5.0 × 0.45 = 2.3 mm/day

March: ET crop = 5.8 × 0.70 = 4.1 mm/day

April: ET crop = 6.3 × 0.95 = 6.0 mm/day

May: ET crop = 6.8 × 1.15 = 7.8 mm/day

June: ET crop = 7.1 × 0.85 = 6.0 mm/day

In summary:

Crop: Tomatoes..... Planting Date: 1 February

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		INITIAL ST.	Crop dev. st.	mid season st.	late s. st.							
Kc per gr. st.		0.45	0.75	1.15	0.8							
Kc per month		0.45	0.70	0.95	1.15	0.85						
ET crop (mm/day)		2.3	4.1	6.0	7.8	6.0						

Step 5: Calculate the monthly and seasonal crop water needs.

**Note: all months are assumed to have 30 days.**

February ET crop = 30 × 2.3 = 69 mm/month

March ET crop = 30 × 4.1 = 123 mm/month

April ET crop = 30 × 6.0 = 180 mm/month

May ET crop = 30 × 7.8 = 234 mm/month

June ET crop = 30 × 6.0 = 180 mm/month

The crop water need for the whole growing season of tomatoes is 786 mm. In summary:

Crop: Tomatoes..... Planting Date: 1 February.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET <sub>0</sub> (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		initial st.	crop dev. st.	mid season st.	late s. st.							
K <sub>c</sub> per gr. st.		1.0	0.45	0.75	1.15	0.8						
K <sub>c</sub> per month		0.45	0.70	0.95	1.15	0.85						
ET crop (mm/day)		2.3	4.1	6.0	7.8	6.0						
ET crop (mm/m)		69	123	180	234	180						

### 3.3.3 Special Cases

In the previous sections it has been indicated how the crop water need is calculated for a variety of field crops:  $ET_{crop} = K_c \times ET_0$ . However there are some crops that do not directly fit this model: their crop factor  $K_c$  is determined in a different way. The determination of their crop factor is explained in this section. Once the crop factor  $K_c$  has been determined, the same procedure (as described in the sections 3.3.1 and 3.3.2) is used to calculate the crop water needs.

The special cases include:

- alfalfa, pasture and clover
- bananas
- citrus
- rice
- sugarcane
- cacao, coffee, tea
- olives
- grapes

#### Alfalfa, Pasture and Clover

Alfalfa, pasture and clover are regularly cut during the year. Just after cutting they are in the "initial stage", while just before the next cutting, they are in the "late season stage". To determine the crop water need it is best to use an average value of the crop factor  $K_c$ . The average  $K_c$  values are given in Table 9.

**Table 9 K<sub>c</sub> VALUES FOR ALFALFA, PASTURE AND CLOVER**

Climate:	Alfalfa	Pasture	Clover
Humid Light/medium wind	0.85	0.95	1.0
Dry Light/medium wind	0.95	1.0	1.05
Humid or Dry Strong wind	1.05	1.05	1.05

#### Bananas

The establishment of a new banana plantation takes approximately 6 months from planting to full ground cover. One year after planting, the first harvest takes place, after

which the shoots that have produced are removed. Meanwhile young shoots have fully developed and take over the production.

The Kc values for the first 6 months after planting are indicated in Table 10. After 6 months the Kc value remains constant:  $K_c = 1.1$ .



**Table 10 Kc VALUES FOR BANANA**

Months after planting	1	2	3	4	5	6	7 onward
Kc	0.7	0.75	0.8	0.75	0.9	1.0	1.1

### Citrus

The crop factor Kc for clean cultivated citrus is 0.70 year-round. This value is applicable for large mature trees, covering some 70% of the ground surface. If there is no weed control, a Kc value of 0.90 year-round should be used.

### Rice

For paddy rice the values indicated in Table 11 should be used.

**Table 11 Kc VALUES FOR PADDY RICE**

Climate	Little wind		Strong wind	
	dry	humid	dry	humid
Growth stage (days)				
0-60 days after transplant or direct sowing	1.1	1.1	1.1	1.1
Mid-season	1.2	1.05	1.35	1.3
last 30 days before harvest	1.0	1.0	1.0	1.0

Example: Suppose the total growing season of rice from sowing to harvest =150 days in a humid climate with strong wind

Kc day 0 to 60: 1.1

Kc day 60 to 120: 1.3

Kc day 120 to 150: 1.0

### Sugarcane

Crop coefficients for sugarcane vary widely depending on climate and sugarcane variety. It is best to use locally available data. If such data are not available. Tables 12a and 12b can be used.

Table 12a refers to a virgin sugarcane crop from establishment to first harvest, which is assumed to take 18 months. Table 12b refers to a ratoon crop, which is the regrowth after the harvest of the virgin crop. The regrowth is assumed to take 12 months. Sometimes, depending on local practices, a virgin crop is followed by 2 or 3 ratoon crops.

**Table 12a Kc VALUES FOR VIRGIN SUGARCANE**

Climate	Little wind		Strong wind	
	dry	humid	dry	humid
0-2	0.4	0.5	0.5	0.6
2-4	0.8	0.8	0.8	0.85
4-6	1.1	1.0	1.2	1.1
6-12	1.25	1.05	1.3	1.15
12-17	0.95	0.8	1.05	0.85
17-18	0.7	0.6	0.75	0.65

**Table 12b Kc VALUES FOR RATOON SUGARCANE**

Climate	Little wind		Strong wind	
	dry	humid	dry	humid
0-1	0.4	0.5	0.5	0.6
1-2	0.8	0.8	0.8	0.85
2-4	1.1	1.0	1.2	1.1
4-10	1.25	1.05	1.3	1.15
10-11	0.95	0.8	1.05	0.85
11-12	0.7	0.6	0.75	0.65

### Cacao, coffee, tea

For cacao, coffee and tea the following year-round Kc values are recommended:

- no cover crop, no shade: Kc = 0.95
- with cover crops and shade trees: Kc = 1.1

## Olives

For mature olive trees the following year-round Kc values are recommended:

- wide spacing of trees: Kc = 0.4
- close spacing of trees: Kc = 0.7



## Grapes

With the assumption that the grape harvest starts some 5 months after the first leaves appear, the Kc values indicated in Table 13 can be used for the months starting with the first leaf appearance.

**Table 13 Kc VALUES FOR GRAPES (35% GROUND COVER)**

Months after first leaves appear	1	2	3	4	5	6	7	8	9
Kc	0.25	0.45	0.65	0.75	0.75	0.7	0.55	0.45	0.35

### **3.3.4 Indicative Values of Crop Water Needs**

Table 14 gives indicative values of the crop water needs for the total growing period of various important field crops.

The values indicated in the table provide a rough estimate and should only be used if the crop water needs cannot be calculated more accurately due to lack of data.

Table 14 gives for each crop a minimum and a maximum value for the crop water need. As the crop water needs depend heavily on the duration of the total growing period, the maximum value should be used in the case of a long total growing period (see also Table 6) and the minimum value should be used when the total growing period is short. An average value is to be used with a medium total growing period.

In addition, Table 14 gives an indication of the sensitivity of the various crops to water shortages or drought. If the sensitivity is high it means that the crop cannot withstand water shortages very well and such shortages should be avoided. If the sensitivity is low it means that the crop is relatively drought resistant and can withstand water shortages fairly well.

**Table 14 INDICATIVE VALUES OF CROP WATER NEEDS AND SENSITIVITY TO DROUGHT**

<b>Crop</b>	<b>Crop water need (mm/total growing period)</b>	<b>Sensitivity to drought</b>
Alfalfa	800-1600	low-medium
Banana	1200-2200	high
Barley/Oats/Wheat	450-650	low-medium
Bean	300-500	medium-high
Cabbage	350-500	medium-high
Citrus	900-1200	low-medium
Cotton	700-1300	low
Maize	500-800	medium-high
Melon	400-600	medium-high
Onion	350-550	medium-high
Peanut	500-700	low-medium
Pea	350-500	medium-high
Pepper	600-900	medium-high
Potato	500-700	high
Rice (paddy)	450-700	high
Sorghum/Millet	450-650	low
Soybean	450-700	low-medium
Sugarbeet	550-750	low-medium
Sugarcane	1500-2500	high
Sunflower	600-1000	low-medium
Tomato	400-800	medium-high

**DATA SHEET 5 Determination of crop water needs (see also Data Sheet 4)**

Location : Example.. Date : 1/8/86

Crop: Maize (grain)..... Planting date: 1 July.....

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET <sub>o</sub> (mm/day)	4.9	5.3	5.9	6.3	6.7	6.4	6.0	5.6	5.8	5.6	5.3	4.8
Growth stages							ini. st.	crop dev. st.	mid season st.	late s. st.		
K <sub>c</sub> per gr. st.							0.45	0.80	1.15	0.70		
K <sub>c</sub> per month							0.55	0.85	1.15	0.85	(0.70)*	
ET crop (mm/d)							3.3	4.8	6.7	4.8	(3.7)*	
ET crop (mm/m)							99	144	201	144	37**	

\* 10 days in November  
\*\* 10 days x 3.7 mm/day

Crop: Cotton..... Planting date: 1 June.....

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET <sub>o</sub> (mm/day)	4.9	5.3	5.9	6.3	6.7	6.4	6.0	5.6	5.8	5.6	5.3	4.8
Growth stages						ini. st.	crop dev. st.	mid season st.	late season st.			
K <sub>c</sub> per gr. st.						0.45	0.75	1.15	0.75			
K <sub>c</sub> per month						0.50	0.75	1.00	1.15	0.75	(0.75)*	
ET crop (mm/d)						3.2	4.5	5.6	6.7	4.2	(4.0)*	
ET crop (mm/m)						96	135	168	201	126	60**	

Note: ET<sub>crop</sub> (mm/day) = K<sub>c</sub> (per month) x ET<sub>o</sub> (mm/day) \* 15 days in Nov.  
ET<sub>crop</sub> (mm/month) = 30 x ET<sub>crop</sub> (mm/day) \*\* 15 x 4.0 mm/day

Fuente: FAO.