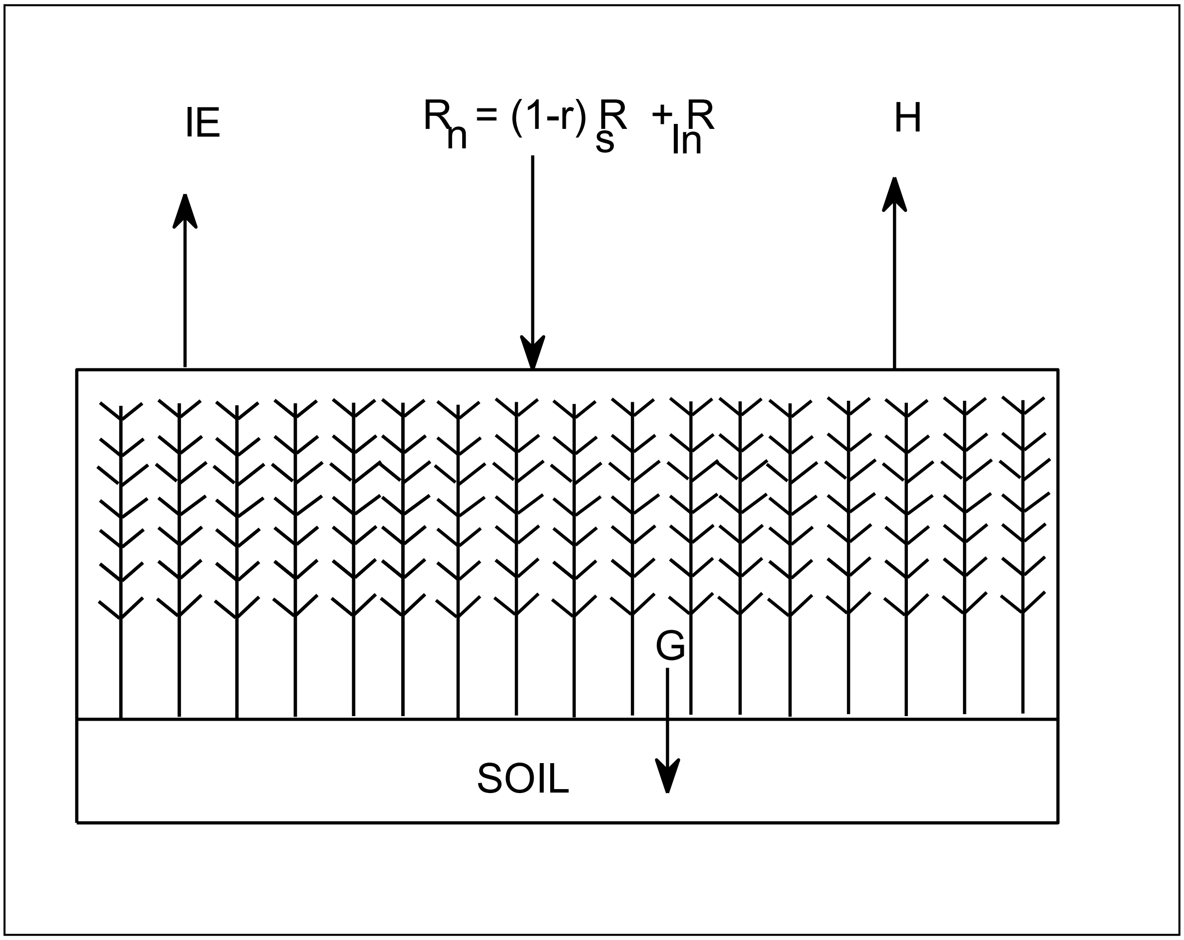
Evapotranspiration

Surface Energy Balance



Recall the energy balance equation

$$R_n + lE + H + G + aA = 0$$

R_n = Net radiation = $[(1 - r)R_s + R_{ln}]$
R_s = short-wave radiation arriving from the sun
rR_s = component of radiation which is reflected from the earth's surface

r = albedo or reflectivity of the surface (Table 5.4)
R_{ln} = net long wave radiation
lE = latent heat transfer and storage. l is the latent heat of vaporization, 2.45 MJ/kg or 590 cal/gm. E represents the amount of water vapor actually available.
H = energy present in the plant canopy in the form of sensible heat.
G = energy stored in the ground or in the plant parts.
aA = energy utilized in photosynthetic activity. a is the chemical energy storage coefficient and has a value of approximately 3600 cal/g of substance produced, and A represents the total mass of chemical compound produced in photosynthetic activity.

With simplifying assumptions the energy balance becomes:

$$R_n + lE + H = 0$$

In this lecture we are interested in the latent heat term lE. Dividing through by latent heat of vaporization (l) gives the evaporative flux:

$E = lE / l$

Where l is the latent heat of vaporization = 590 cal/gram of water

In practice E is referred to as the potential evapotranspiration (ET_c).

ET_c depends on the climatic conditions and the plant physiology.

<u>An important assumption upon which ET_c is based, is that water in the root zone is not limited!</u>

ET_c can be calculated with two terms, one accounting for the climatic conditions, the other the physiological conditions.

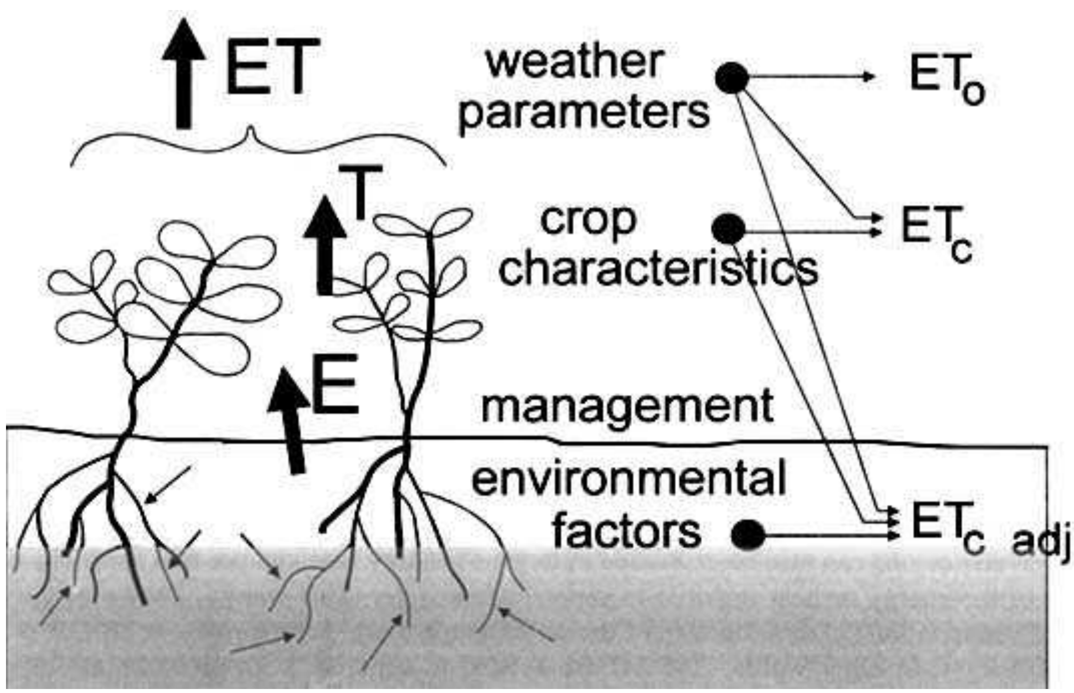
$ET_c = K_c \, ET_o$

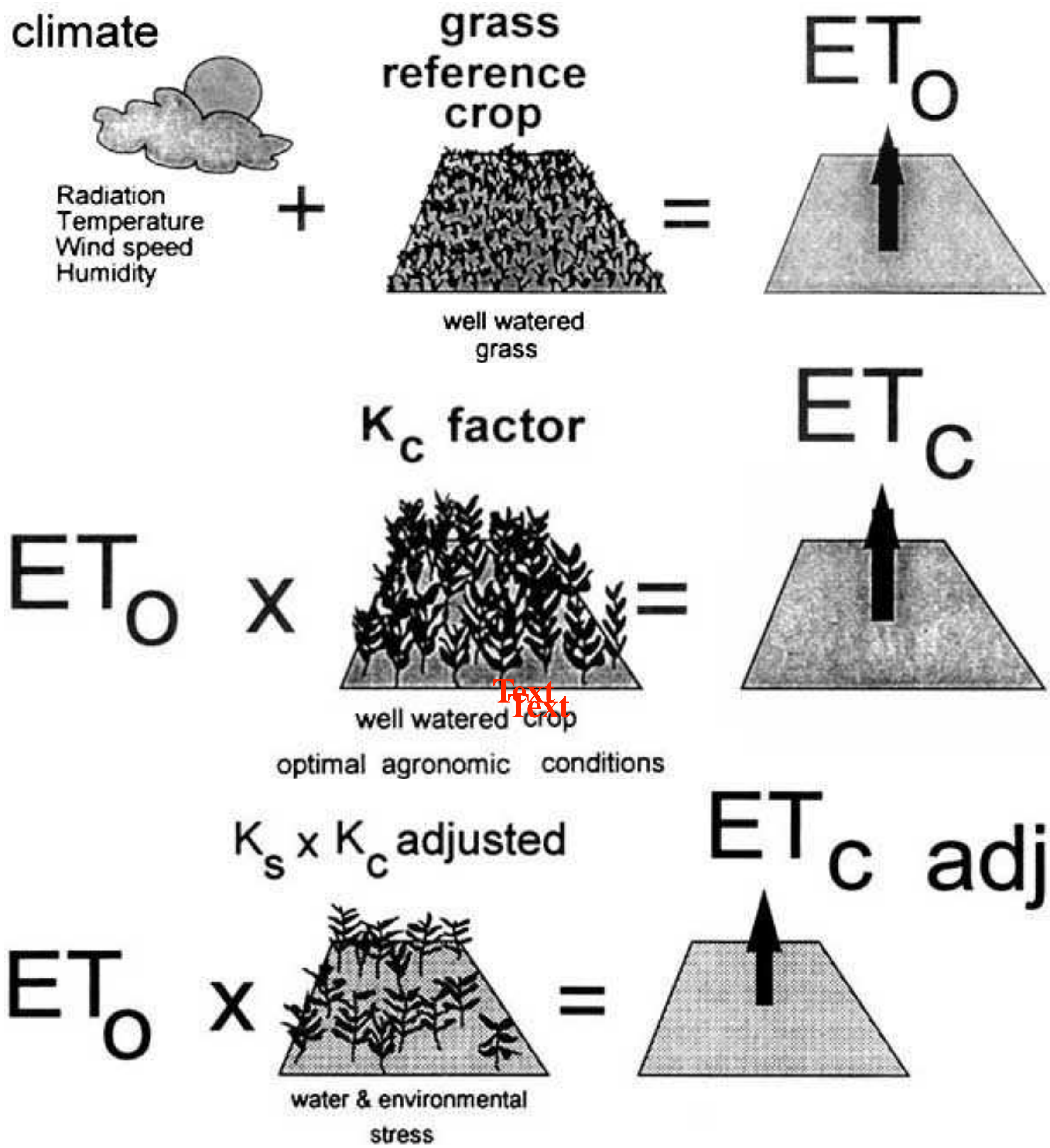
Where
Kc = crop coefficient (accounting for physiological conditions)

ET_o = reference evapotranspiration (accounting for climatic conditions).

If water is not readily available in the root zone then the actual evapotranspiration becomes $ET_{c\ adj}$.

$ET_{c\ adj} = K_s \, ET_c$





climate
Radiation
Temperature
Wind speed
Humidity
grass
reference
crop
well watered
grass
ET o
Kc factor
ET o x
=
ET c
well watered crop
optimal agronomic conditions
Ks x Kc adjusted
ET o x
=
ET c adj
water & environmental
stress
Text
Text

Lets talk about ET_o, K_c and K_s.

Reference Evapotranspiration (ET_o)

The ETc can be directly using the Penman-Monteith equation:

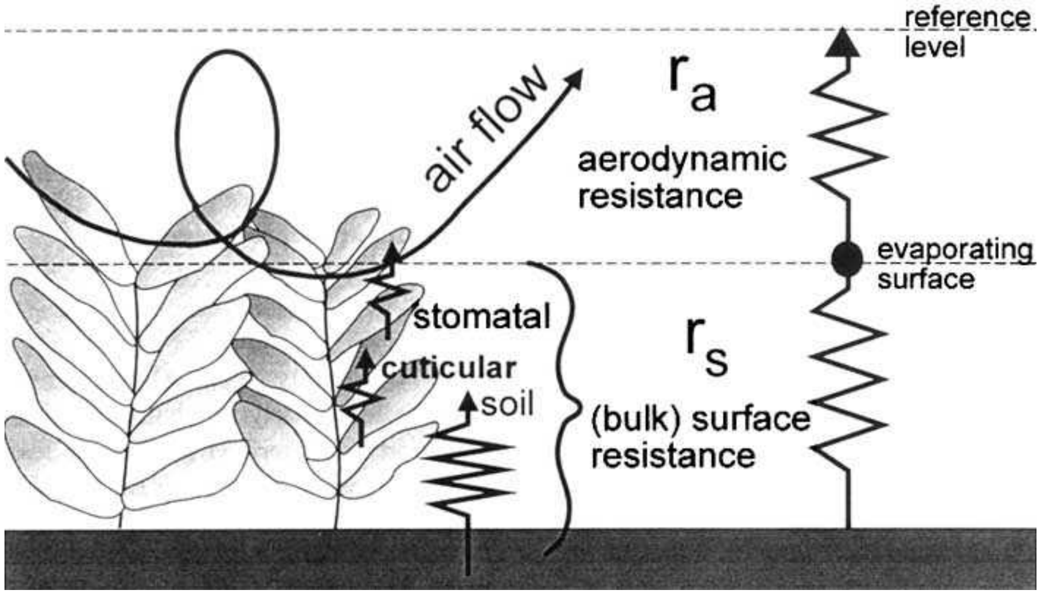
$V = IR$

$qR = \frac{\Delta H}{\Delta X}$

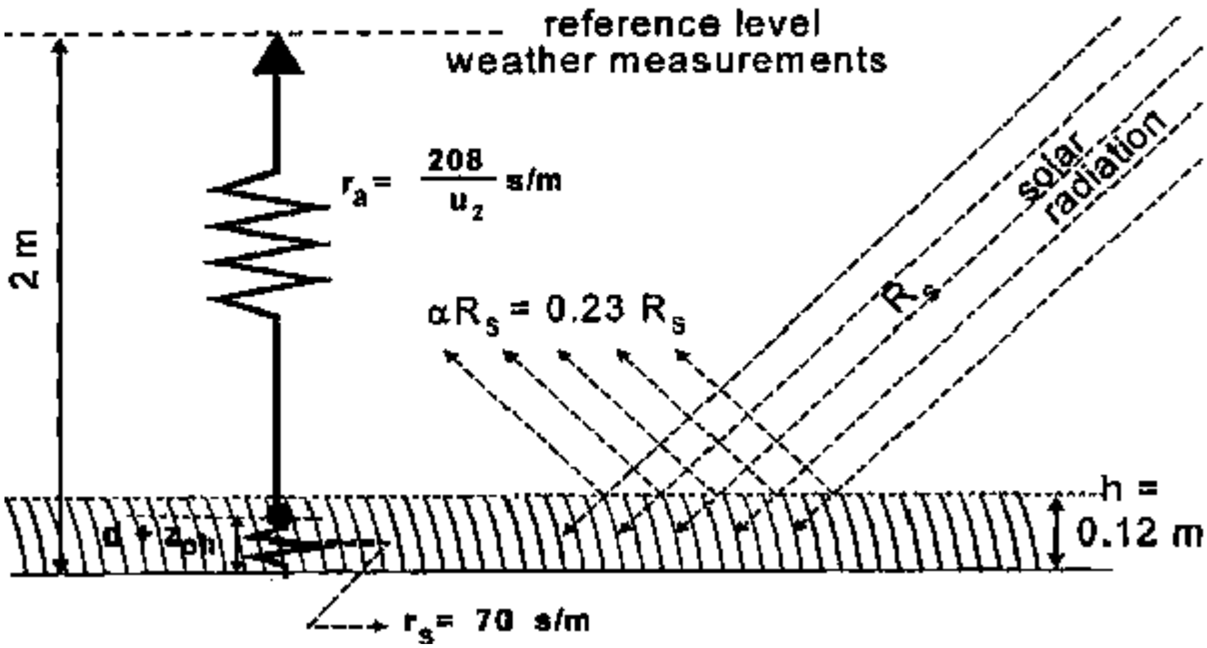
$q = K \frac{\Delta H}{\Delta X}$

$q = \frac{1}{R} \frac{\Delta H}{\Delta X}$

$$ET_c = \frac{\Delta \cdot (R_n - G) + \rho_a \cdot C_p \cdot \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \cdot \left(1 + \frac{r_s}{r_a}\right)}$$



It is difficult to get the resistance coefficients so let's take another approach



These assumptions yield the following equation:

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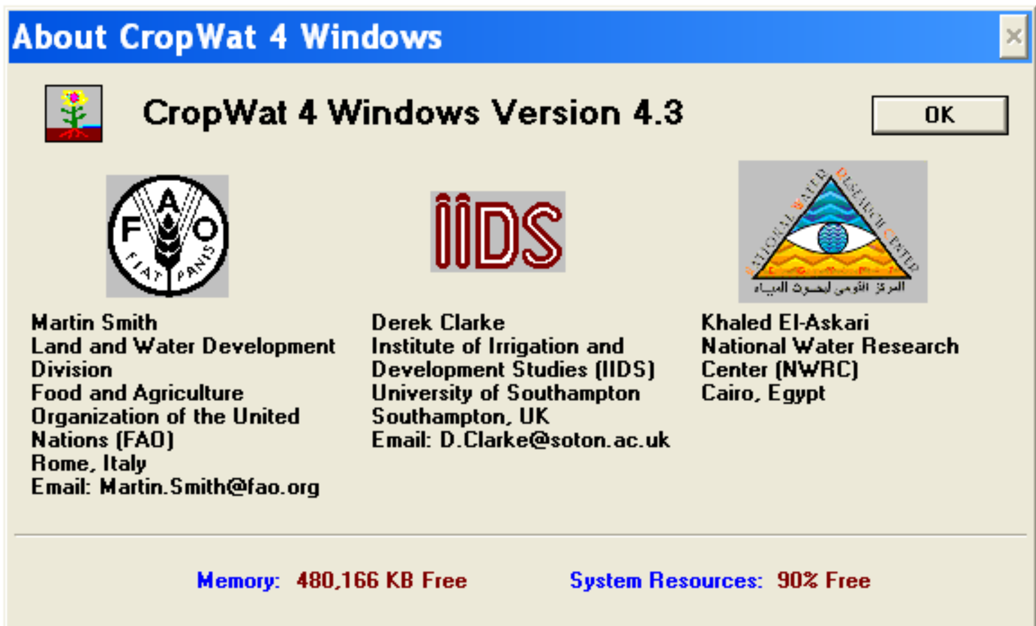
$$ET_o = \frac{0.408\ \Delta\ (R_n - G) + \gamma \left(\frac{900}{T + 273}\right) u_2\ (e_s - e_a)}{\Delta + \gamma\ (1 + 0.34\ u_2)}$$

where Δ is the slope of the vapor pressure curve (kPa $^oC^{-1}$), R_n is net radiation (MJ m^{-2} d^{-1}), G is the soil heat flux density (MJ m^{-2} d^{-1}), γ is the psychrometric constant (kPa^{-1}), T is mean daily air temperature at 2 m height (^oC), u_2 is wind speed at 2-m height, e_s is the saturated vapor pressure (kPa^{-1}) and e_a is the actual vapor pressure (kPa^{-1}). Equation 4 applies specifically to a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec m^{-1} and an albedo of 0.23.

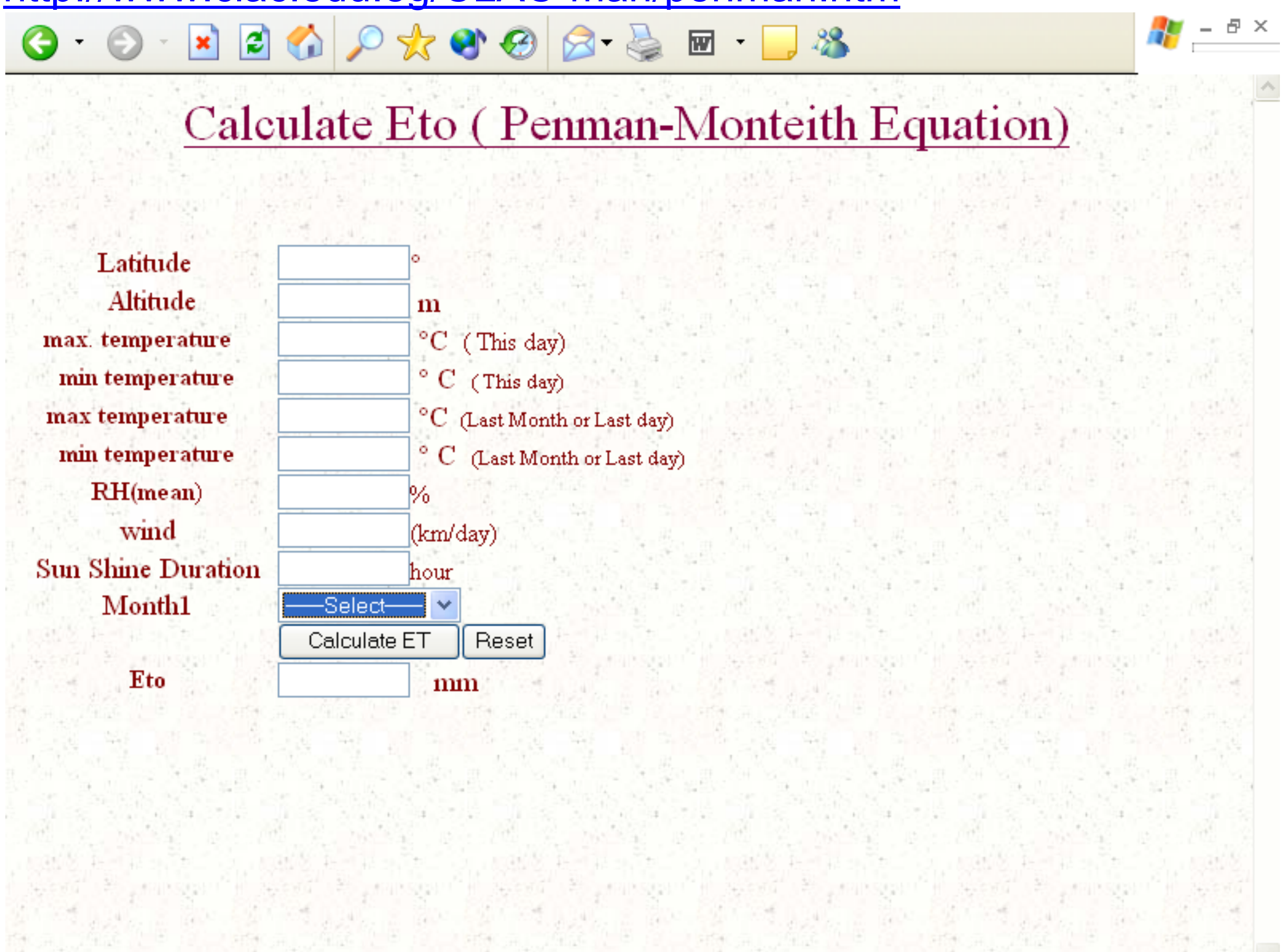
The Penman-Monteith equation for reference evapotranspiration can be calculated using computer programs. For example:

CROPWAT
http://www.fao.org/waicent/FaoInfo/Agricult/AGL/AGLW/cropwat.htm



PR-ET
http://www.uprm.edu/abe/PRAGWATER/

Online Calculators:
http://www.clac.edu.eg/CLAC-man/penman.htm



http://www.tfrec.wsu.edu/Orchard/pET/pETCalc.html

Another site is:
http://www.springirrigation.com/management/penman_calculator_for_water_use_.htm

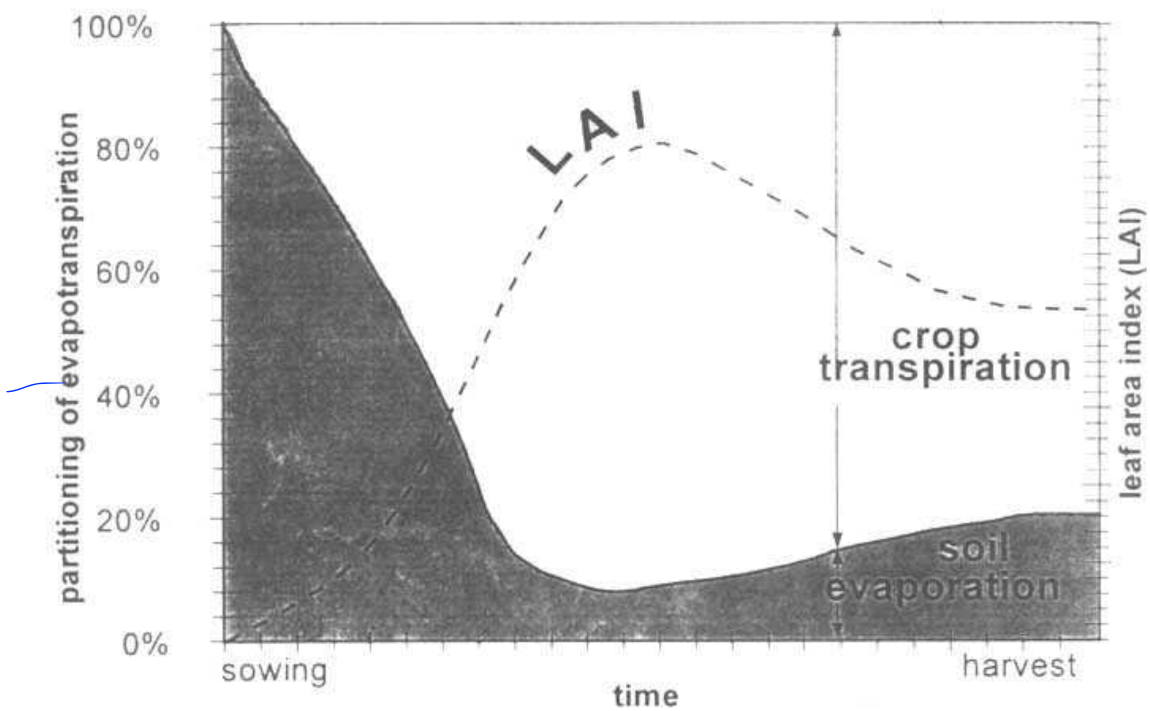
Be careful!!!!!!!!!!!!!!!! The calculations used may be limited to certain geographical regions (e.g., Washington State). Make sure you read the “fine print” before using any method.

Crop Coefficient (K_c)

The crop coefficient accounts for the physiological factors, for example:

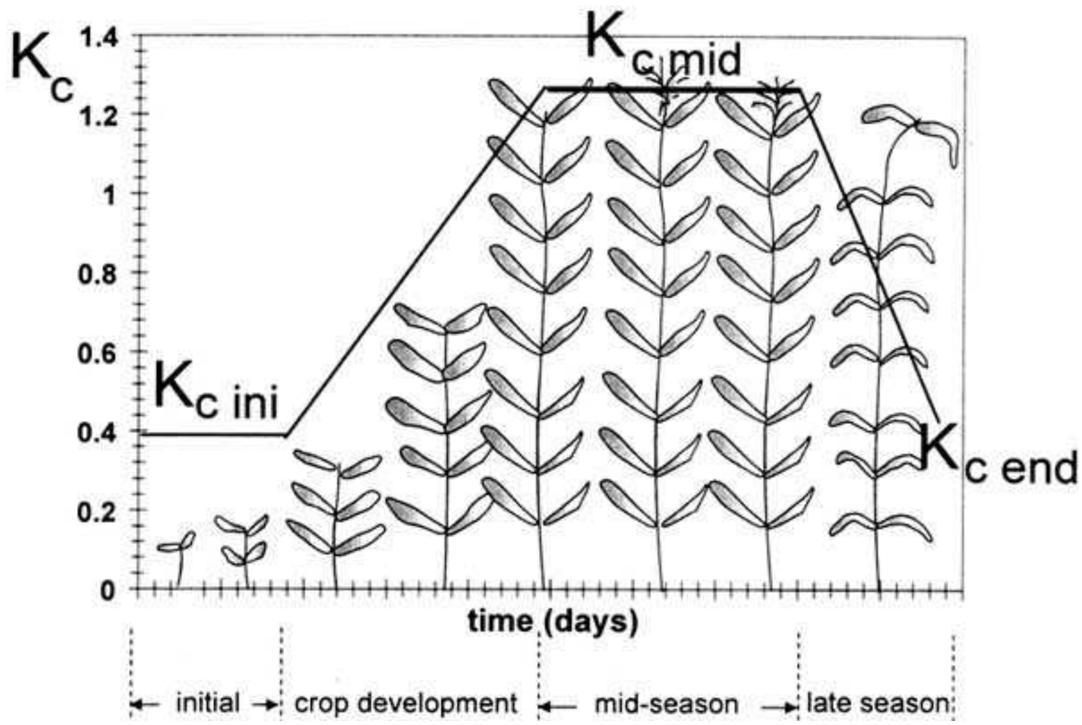
- Crop height
- Leaf area
- Crop color
- Stomatal resistance
- Crop maturity
- Etc.

The crop coefficient is a function of time.

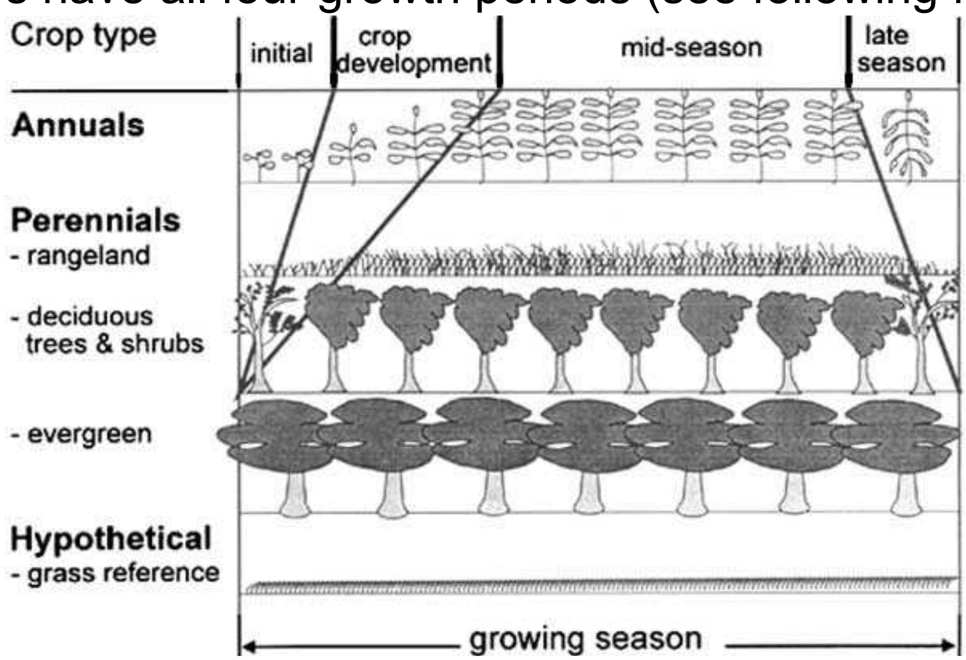


The crop coefficient curve can be simplified into several straight lines as shown in the following figure. Note that the straight lines are associated with growth periods:

- **Initial**
- **Crop Development**
- **Mid-Season**
- **Late Season**



Not all crops have all four growth periods (see following figure)



Methods for obtaining crop coefficients are given in FAO Paper No. 56.

Crop Stress Factor (K_s)

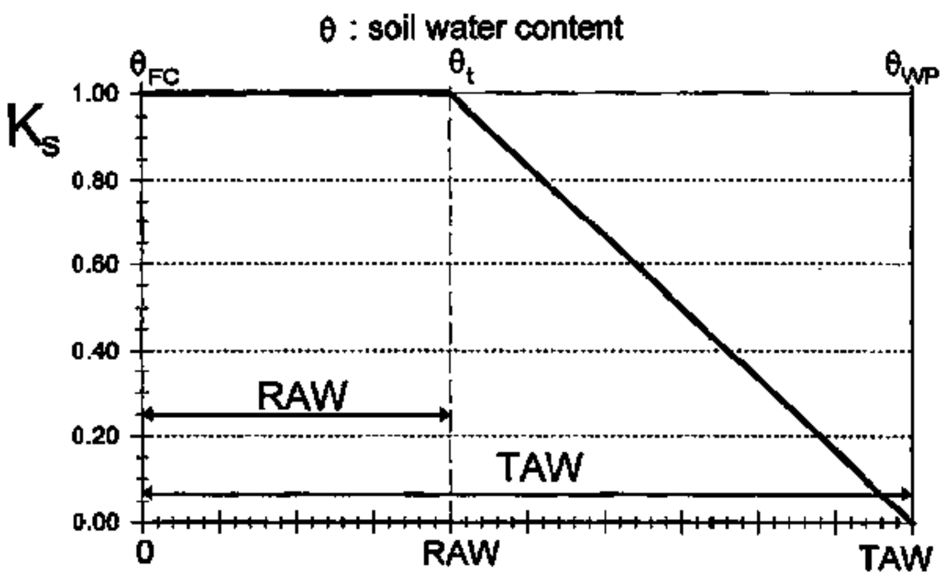
Adjusted Evapotranspiration

Evapotranspiration Adjusted for Water Stress

$ET_{c\ adj} = K_s K_c ET_o$

where
$ET_{c\ adj}$ = potential ET adjusted for water stress conditions (mm/day)
K_s = water stress coefficient
K_c = evapotranspiration crop coefficient
ET_o = reference evapotranspiration

For non-soil water limiting conditions, Ks = 1
For soil water limiting conditions, Ks < 1.



Yield-Moisture Stress Relationship

The following equation is given in FAO Paper No. 56 to estimate crop yield as a function of crop water stress:

$$(1 - Y_a/Y_m) = K_y[1 - (ET_{c\ adj}/ET_c)]$$

where

Y_a = Actual yield
Y_m = Maximum potential yield
K_y = Yield response factor.

Seasonal yield response functions from FAO Irrigation and Drainage Paper No. 33.

Crop	K_y	Crop	K_y
Alfalfa	1.1	Potato	1.1
Banana	1.2-1.35	Safflower	0.8
Beans	1.15	Sorghum	0.9
Cabbage	0.95	Soybean	0.85
Citrus	1.1-1.3	Spring Wheat	1.15
Cotton	0.85	Sugarbeet	1.0
Grape	0.85	Sugarcane	1.2
Groundnet	0.70	Sunflower	0.95
Maize	1.25	Tomato	1.05
Onion	1.1	Watermelon	1.1
Peas	1,15	Winter wheat	1.05
Pepper	1.1		

Obtained from FAO Irrigation and Drainage Paper No. 56.

Example Problem:

$$Y_r = Y_a/Y_m = 1 - K_y[1 - (ET_{c\ adj}/ET_c)]$$ **= 1 - Ky(Ks)**

where Y_r = relative yield

Assume
Ky = 1.27 for Banana
ETcadj = 400 mm for the season

ETc = 500 mm for the season

$$Y_r = 1 - 1.27 \cdot \left(1 - \left(\frac{400}{500}\right)\right)$$

$$Y_r = 0.746$$