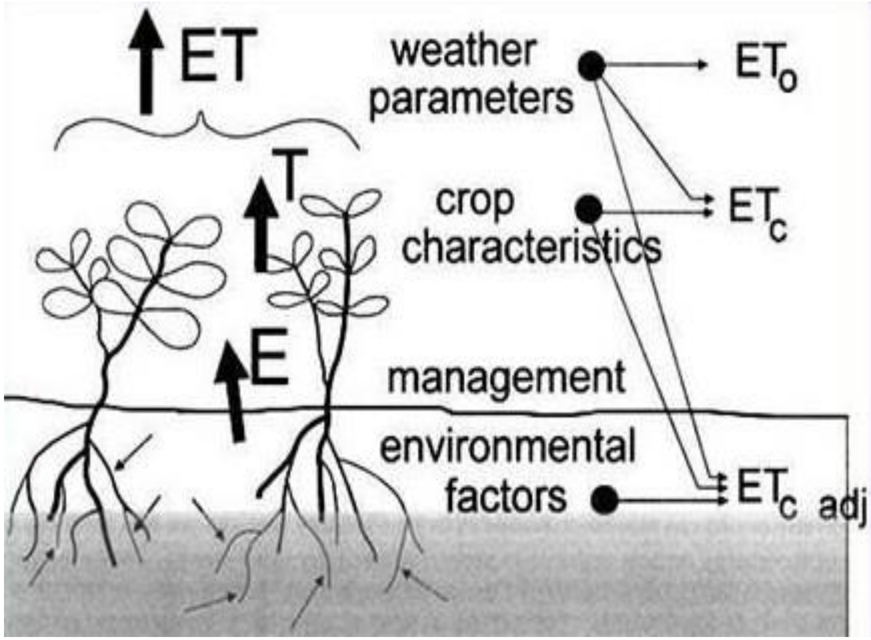
Crop Water Requirements

Lecture note for Soil and Water Management Course
Prepared by Dr ND Nang



- The crop water need (ET crop) is defined as the amount (or depth) of water needed to meet the water loss through evapotranspiration

- The crop water need mainly depends on
  - The climate
  - The crop type
  - The growth stage of crop

Calculation for crop water requirements

$$\mathbf{ET_c = K_c \times ET_o}$$

- ET_c : crop evaporation or crop water need (mm/day)
- K_c : Crop factor
- ET_o : Reference evapotranspiration (mm/day)

Calculation for crop water requirements

- K_c : mainly depends on
  - The type of crop
  - The growth stage of the crop
  - The climate

- ET_o : measure/predict by
  - Using evaporation pan
  - Using Penman-Monteith Equation
  - The Blaney-Criddle Equation

Crop factor, K_c

- Determination of crop factor Kc, it is necessary to
  - Determine of the total growing period of each crop
  - Determine of the various growth stages of each crop
  - Determine of the K_c values for each crop for each of the growth stages

Crop factor, K_c

The total growing period of some crops

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

FAO, 1995

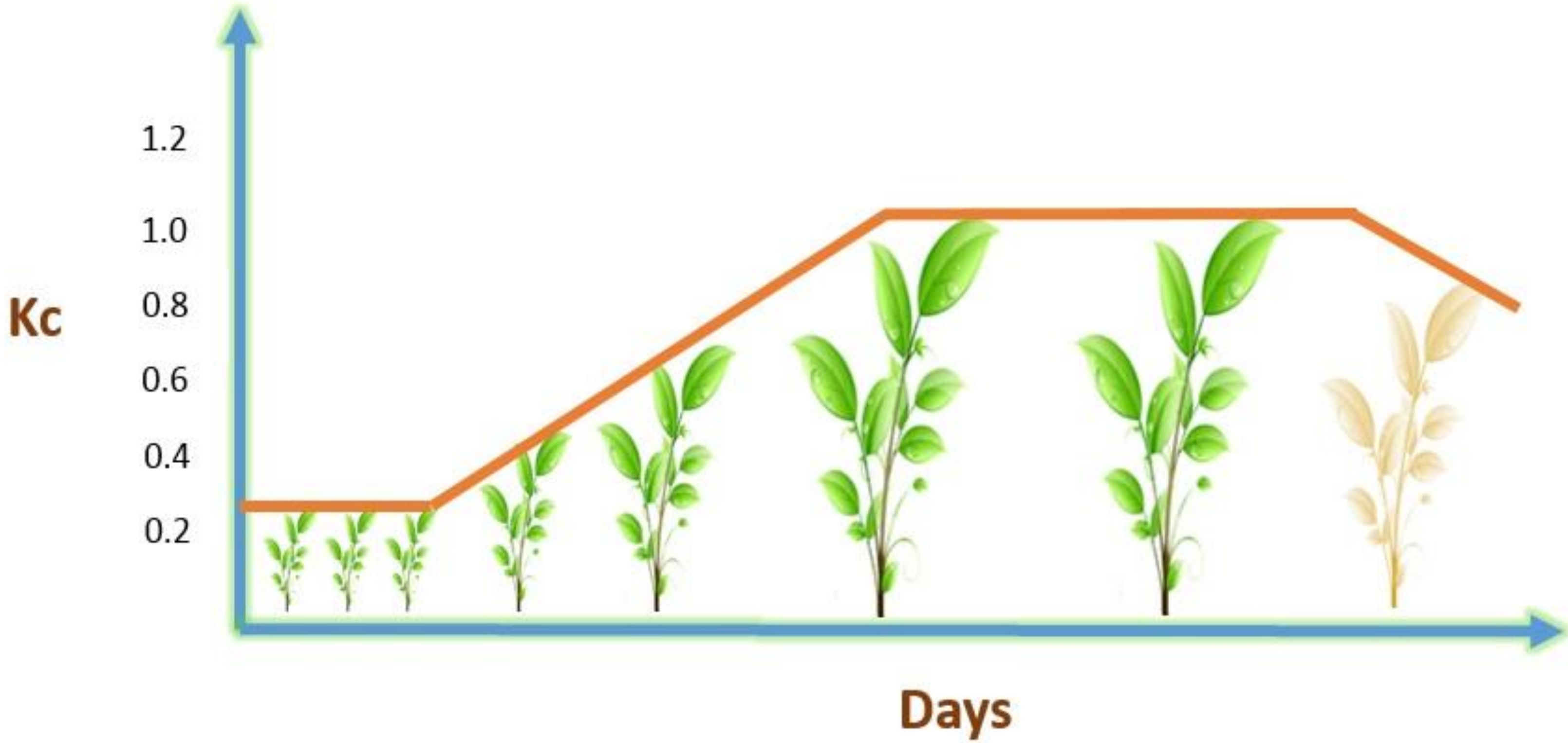
Crop factor, K_c

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

FAO, 1995

Crop factor, K_c



Crop factor, K_c

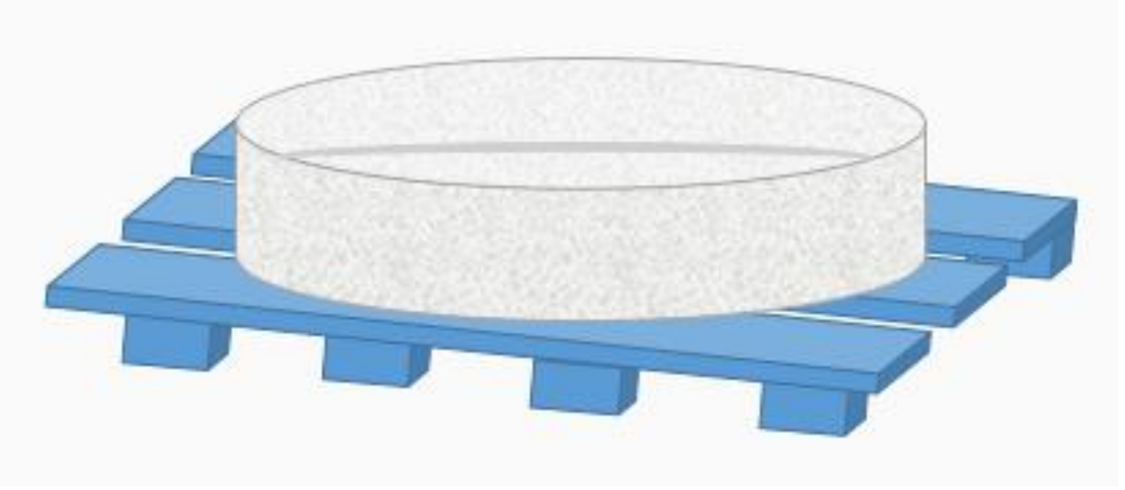
Values of the crop factor (K_c) for various crops and growth stages

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

FAO, 1995

Reference evapotranspiration, ET_o

- Using evaporation pan



$$\mathbf{ET_o = K_p \times ET_{pan}}$$

Kp : pan cofficient

ET_{pan} : Evaporation of the pan

Reference evapotranspiration, ET_o

- Using Penman-Monteith Equation

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

ET_o	reference evapotranspiration [mm/day],
R_n	net radiation at the crop surface [$MJ/m^2/day$],
G	soil heat flux density [$MJ/m^2/day$],
T	air temperature at 2 m height [°C],
u_2	wind speed at 2 m height [m/s],
e_s	saturation vapour pressure [kPa],
e_a	actual vapour pressure [kPa],
$e_s - e_a$	saturation vapour pressure deficit [kPa],
Δ	slope vapour pressure curve [kPa/°C],
γ	psychrometric constant [kPa /°C].

Reference evapotranspiration, ET_o

- Using Blaney-Criddle Equation

$$\mathbf{ET_o = p\,(0.46T_{mean} + 8)}$$

ET_o reference evapotranspiration (mm/day),
p mean daily percentage of annual daytime hours
Tmean mean daily temperature (°C)

Example for calculating the water requirement of crops

- Crop: potato
  - Growth stage: Initial growth
  - K_c for initial stage: 0.45
  - ET_o : 9 mm/day
  - => $ETc = Kc*ET_0 = 0.45 \times 9 = 4.05$ mm/day
- Tomato crops
  - Given data:

Month	Jan	Feb Mar	Apr	May	June	July
ETo (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: Estimating the duration of the various growth stages

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

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

CALCULATION

- Step 1: Estimating the duration of the various growth stages
- Step 2: Estimating the Kc factor for each of the 4 growth stages
- Step 3: Calculating the crop water need on a monthly basis
- Step 4: Calculate the monthly and seasonal crop water needs

CALCULATION

- Step 2: Estimating the Kc factor for each of the 4 growth stages
  - K_c initial stage = 0.45
  - K_c crop development stage = 0.75
  - K_c mid season stage = 1.15
  - K_c late season stage = 0.8
- February K_c Feb = 0.45
- March 5 days K_c = 0.45

  25 days K_c = 0.75

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

CALCULATION

- April 15 days K_c = 0.75

  15 days K_c = 1.15

  => K_c April = 0.95
- May K_c May = 1.15
- June 5 days K_c = 1.15

  25 days K_c = 0.8

  => K_c Jun = 0.85

CALCULATION

- Step 3: Calculating the crop water need on a monthly basis

$$\mathbf{ET_{crop} = ET_o \times K_c} \quad \textbf{(mm/day)}$$

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

CALCULATION

- Step 4: 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

IRRIGATION CYCLE

Determination of soil water content

a/ Gravimetric water content (θ_m, %):

$$\theta_m(\%) = \frac{(Mass_{wet\ soil} - Mass_{oven\text{-}dry\ soil})}{Mass_{oven\text{-}dry\ soil}} * 100$$

b/ Volumetric water content (θ_v,%):

$$\theta_v(\%) = [(Volume_{water})/Volume_{total}]*100$$

IRRIGATION CYCLE

c/ Depth of water (h)

$$h = \theta_v * \text{depth of soil (cm)}$$

d/ Relationship between θ_m và θ_v

$$\theta_v = \theta_m * \rho_b$$

e/ Soil porosity (f)

$$f = Volume_{void}/Volume_{total} = 1 - \rho_{b/}\rho_p$$

ρ_b : bulk density = $Mass_{oven\text{-}dry\ soil}/Volume_{total}$

ρ_p : particle density = $Mass_{solid}/Volume_{solid}$

$= Mass_{oven\text{-}dry\ soil}/Volume_{oven\text{-}dry\ soil}$

IRRIGATION CYCLE

- Given soil conditions
  - Soil bulk density (ρb) = 1.5 g/cm3
  - Soil water content at FC = 25%
  - Soil water content at PWP = 11%
  - Depth of roots = 40 cm

Determine depth of water and irrigation cycle ?

- Available water = 25% - 11% = 14%
- MAD for shallow root 25 – 40%
- Minimum water content = 25 – 14*0.4 = 19.4%

IRRIGATION CYCLE

- Depth of water need

$$h = (25 - 19.4)*\rho_b* 40(cm)*10$$

$$= (5.6/100)*1.5\ g/cm^3*40\ *10 = 33.6\ mm$$

February:	n = 33.6 / 2.3 = 14 days
March:	n = 33.6 / 4.1 = 8 days
April:	n = 33.6 / 6.0 = 5 days
May:	n = 33.6 /7.8 = 4 days
June:	n = 33.6 /6.0 = 5 days

Assumption: Evaporation for soil surface = 0 and no rainfall

Yield Response To Water

$$\left(1 - \frac{Y_a}{Y_x}\right) = K_y\left(1 - \frac{ET_a}{ET_x}\right)$$

- Y_x and Y_a are the maximum and actual yields,
- ET_x and ET_a are the maximum and actual evapotranspiration
- K_y is a yield response factor (K_y is representing the effect of a reduction in evapotranspiration on yield losses)
  - $K_y > 1$: crop response is very sensitive to water defic
  - $K_y < 1$: crop is more tolerant to water deficit
  - $K_y = 1$: yield reduction is directly proportional to reduced water use

Yield Response To Water

Seasonal Ky values from FAO Irrigation and Drainage Paper No.33

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