The Islamic University of Gaza- Civil Engineering Department
Irrigation and Drainage- ECIV 5327

Lecture 4: Irrigation Water Requirements

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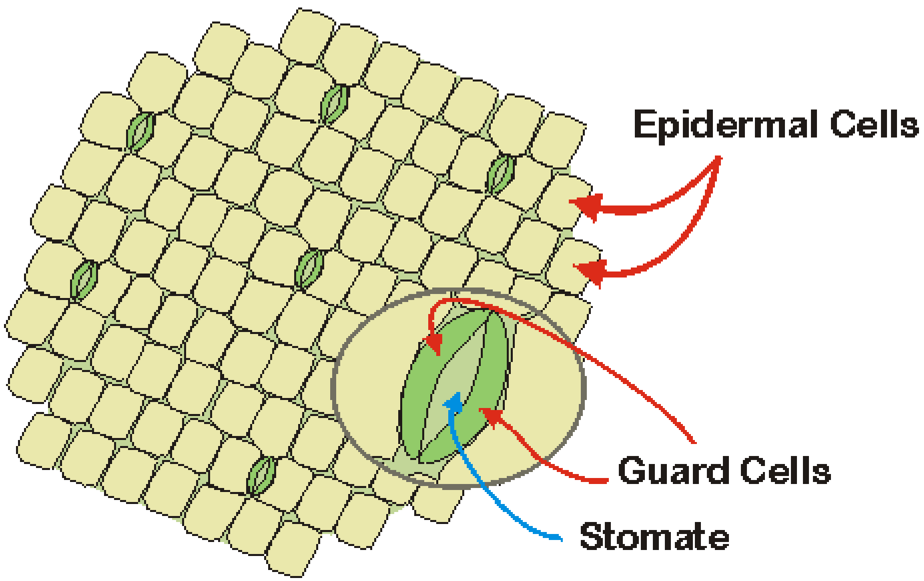
Evapotranspiration

Evaporation: Process of water movement, in the vapor form, into the atmosphere from soil, water, or plant surfaces

Transpiration: Evaporation of water from plant stomata into the atmosphere

Evapotranspiration: Sum of evaporation and transpiration (abbreviated "ET")

Consumptive use: Sum of ET and the water taken up the plant and retained in the plant tissue (magnitude approximately equal to ET, and often used interchangeably)

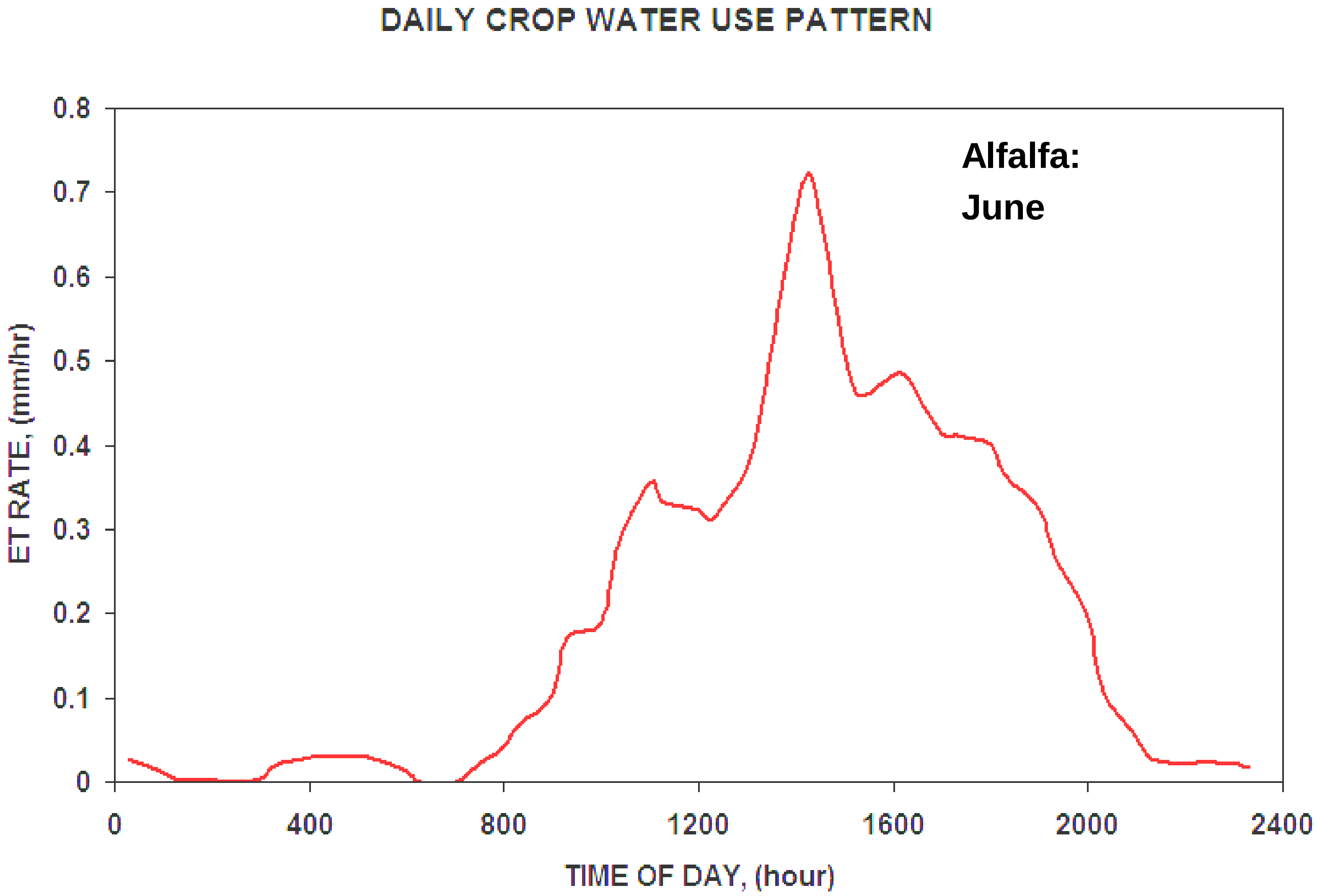


Magnitude of ET

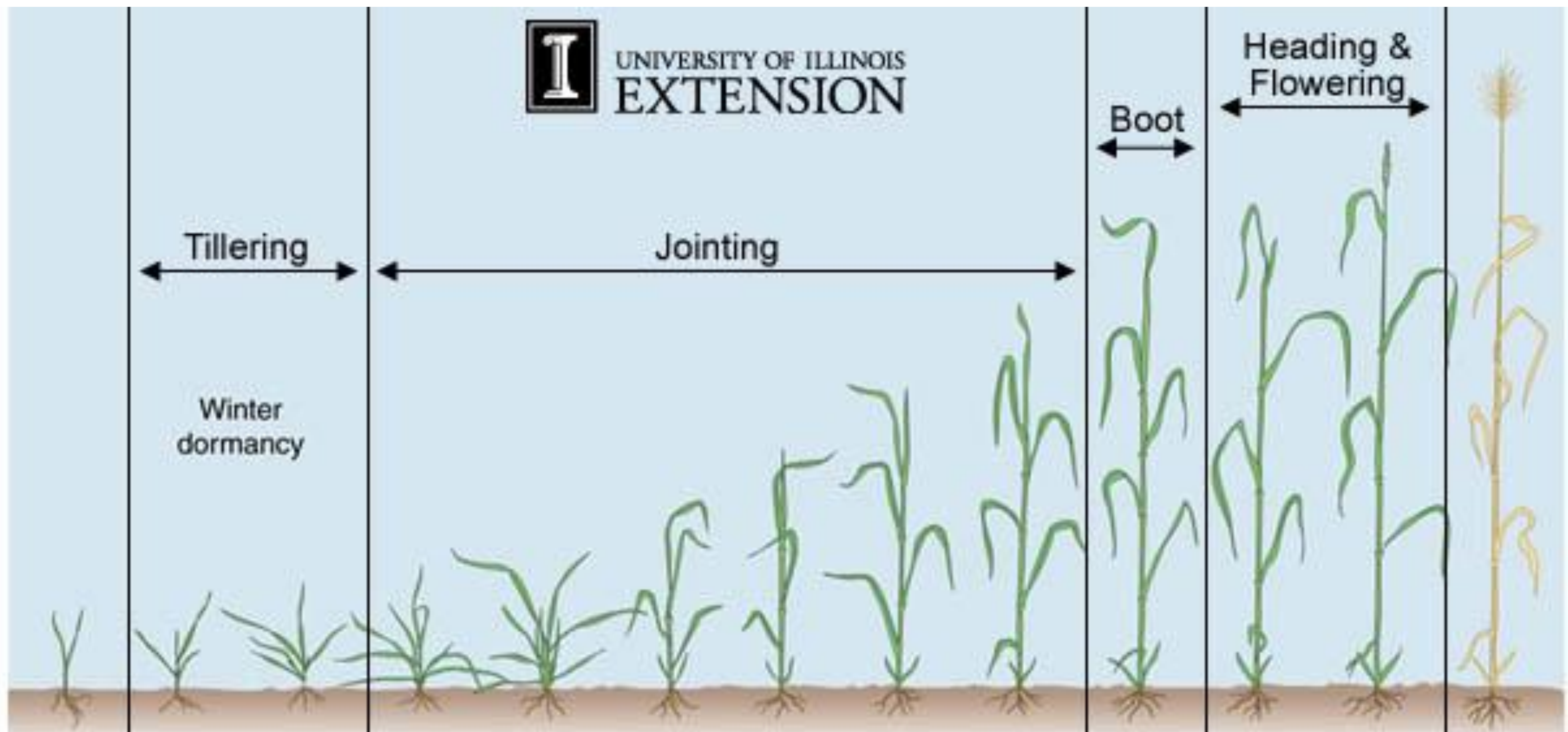
- Generally tenths of an inch per day, or tens of inches per growing season
- Varies with type of plant, growth stage, weather, soil water content, etc.
- Transpiration ratio: Ratio of the mass of water transpired to the mass of plant dry matter produced (g H_2O/g dry matter)
- Typical values:
- 250 for sorghum
- 500 for wheat
- 900 for alfalfa

Plant Water Use Patterns

Daily Water Use: peaks late in afternoon; very little water use at night



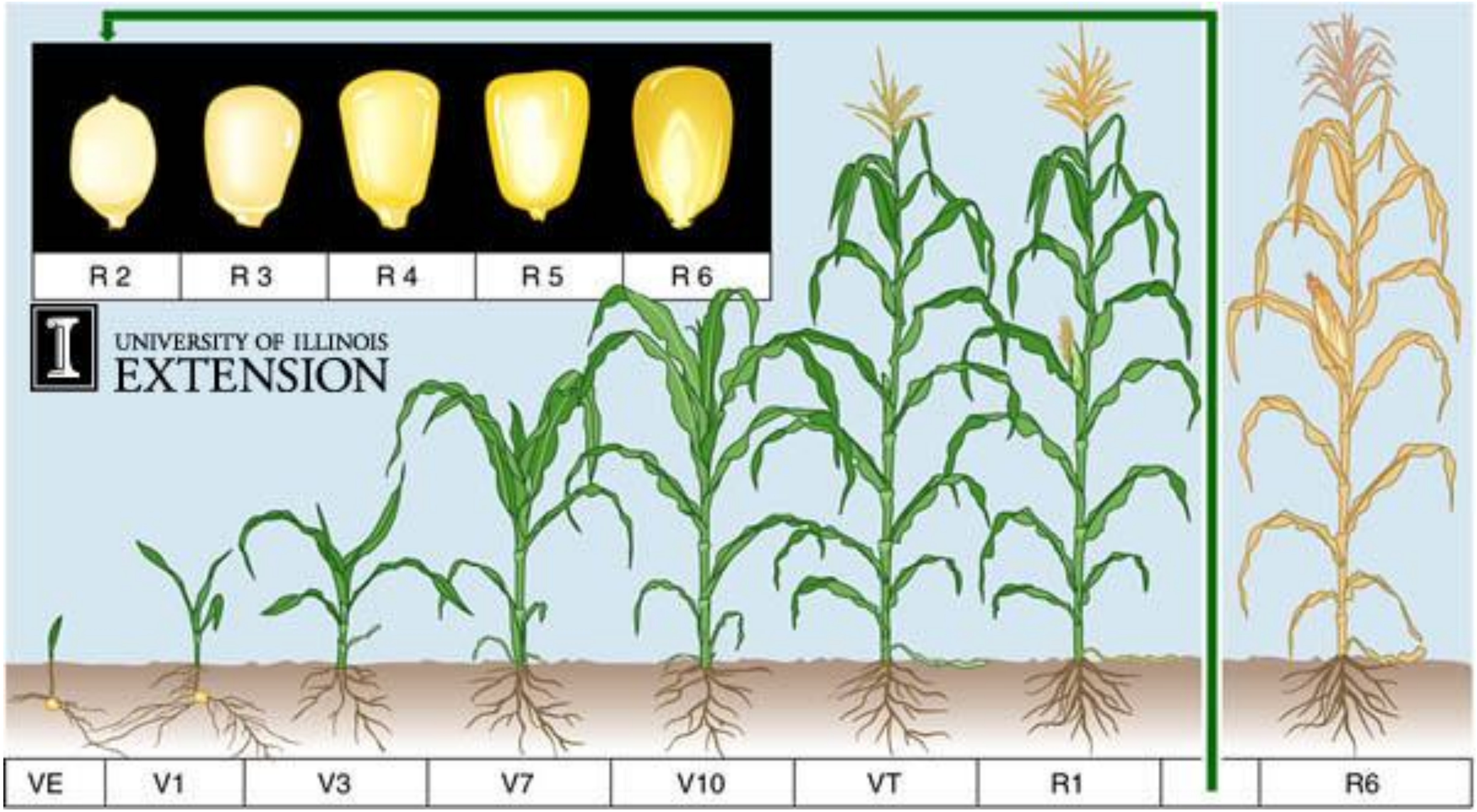
Wheat Growth Stage



Feekes	1	2	3	4	5	6	7	8	9	10	10.1	10.5	11
Zadoks	10	21	26	30	30	31	32	37	39	45	50	60	90

Feekes scale: Growth stages in cereals
Zadoks: A decimal code for the growth stages of cereals

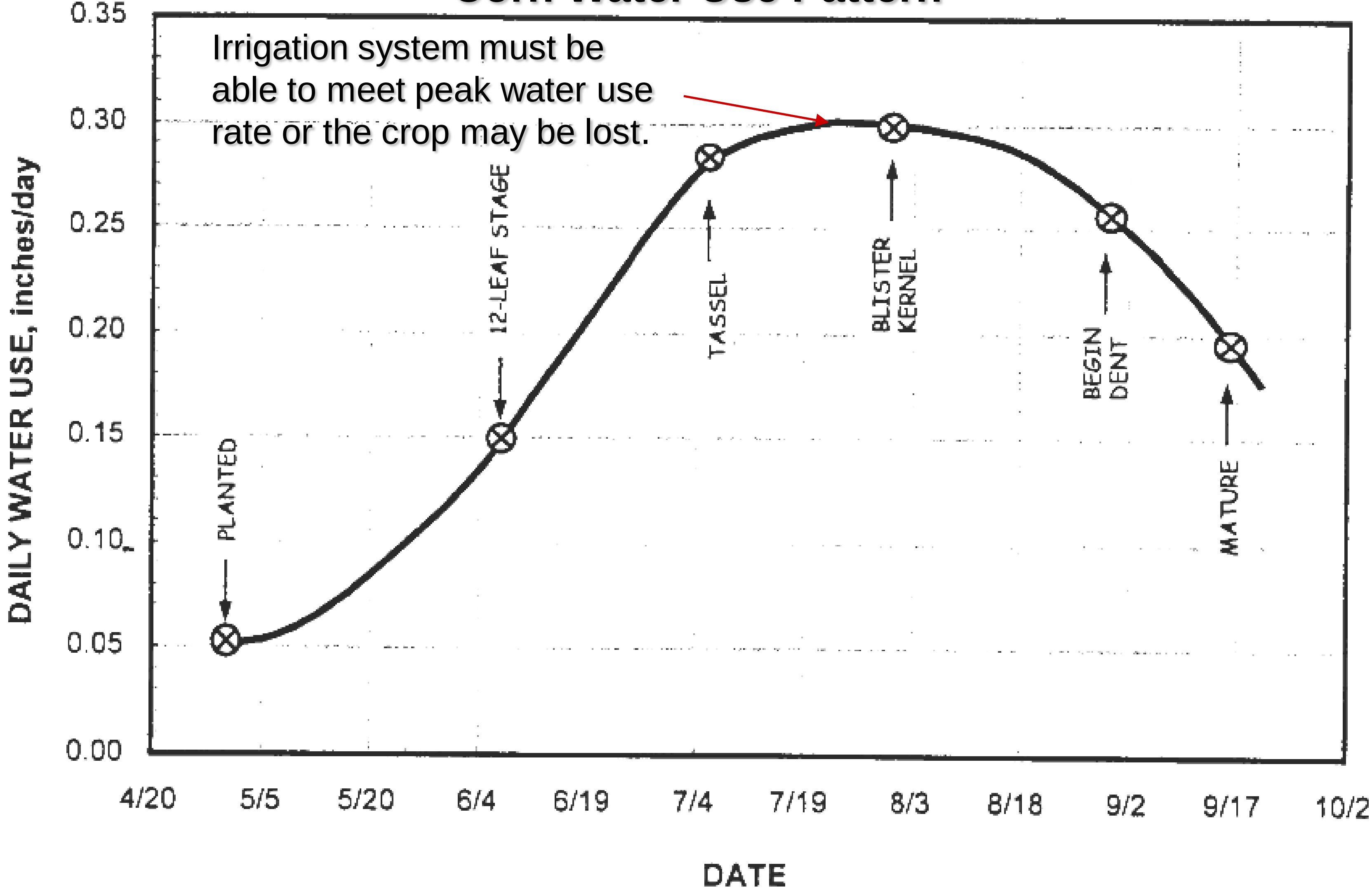
Corn Growth Stage



Plant Water Use Patterns

- Seasonal Use Pattern: Peak period affects design

Corn Water Use Pattern



CROP WATER REQUIREMENTS

The depth of water to meet evapotranspiration of a disease-free crop growing in large fields without restricting conditions on soil profile, soil moisture and fertility, thus achieving full production potential.

$$E_{crop} = K_c \, E_{ref}$$

The specific characteristics of the crop are represented by the crop coefficient k,

and the meteorological conditions by the reference crop evaporation E_{ref}.

E_{ref} refers to the evapotranspiration of grass and the crop coefficients correspond to this reference evapotranspiration.

Reference crop evapotranspiration (E_{ref}): The rate of evapotranspiration from an extensive surface of an 8 to 15 cm tall green grass cover of uniform height, completely shading the ground and not short of water.

E_{ref} is most accurately computed with the **Penman formula** for grass, but this requires data on wind, humidity, temperature and sunshine or radiation.

If data on wind and humidity are lacking a less accurate estimate of E_{ref} is obtained with the **radiation method**, an empirical equation relating the reference crop evapotranspiration to climatic data.

Blaney & Criddle (1950) provide the least accurate method, but it only requires data on temperature.

Finally, reasonable estimates of E_{ref} may be obtained from evaporation **pans** which are properly sited.

Estimated error in the calculation of E_{ref}

Method	Error (%)
Penman	10
Pan	15
Radiation	20
Blaney & Criddle	25

Evapotranspiration is calculated from Penman formula

$$ET_0 = \frac{0.408 * \Delta * (R_n - G) + \gamma * \left(\frac{900}{T - 273}\right) * U_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 U_2)}$$

R_n = The remain of radiation on the plant surface (M J $m^{-2}day^{-1}$),
G = The adsorbed amount of radiation by the earth (M J $m^{-2}day^{-1}$),
T = The mean temperature at 2 m height (^0C),
U_2 = wind speed at 2 meters height (m s^{-1}),
e_s = Saturated air pressure (kPa),
e_a = vapor pressure (kPa),
Δ = Vapor pressure at temperature (kPa $^0C^{-1}$) and
∂ = constant (kPa $^0C^{-1}$)

Evapotranspiration formulas

$$ET_0 = \frac{0.408 * \Delta * (R_n - G) + \gamma * \left(\frac{900}{T - 273}\right) * U_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 U_2)}$$

$$es = \frac{e^0_{(T\max)} + e^0_{(T\min)}}{2}$$

$$\gamma = 0.665 * 10^{-3} * P$$

$$e_a = \frac{RH_{mean}}{100} * \frac{e^0_{(T\max)} + e^0_{(T\min)}}{2}$$

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

$$e^0(T) = 0.6108 \exp\left(\frac{17.27T}{T + 237.3}\right)$$

$$U_2 = U_Z * \left(\frac{4.87}{\ln(67.8Z - 5.42)}\right)$$

$$R_{ns} = 0.77 * R_s$$

$$P = 101.3 * \left(\frac{293 - 0.0065Z}{293}\right)^{5.26}$$

$$R_s = \left(0.25 + 0.5 * \left(\frac{n}{N}\right)\right) * R_a$$

$$\Delta = 4098 \frac{e^0_{(T)}}{(T + 237.3)^2}$$

$$G_{month} = 0.07 * (T_{month(i+1)} - T_{month(i-1)})$$

$$R_{nl} = \sigma * \left(\frac{T_{\max} - T_{\min}}{2}\right)\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right)$$

Crop coefficients (K_c): Tall crops like maize have a crop coefficient greater than one while others may, for different reasons, (e.g. waxy leaves of citrus) transpire less than the reference (grass) crop ($K_c < 1$).

To establish the crop coefficient curve the growing season is divided into four stages:

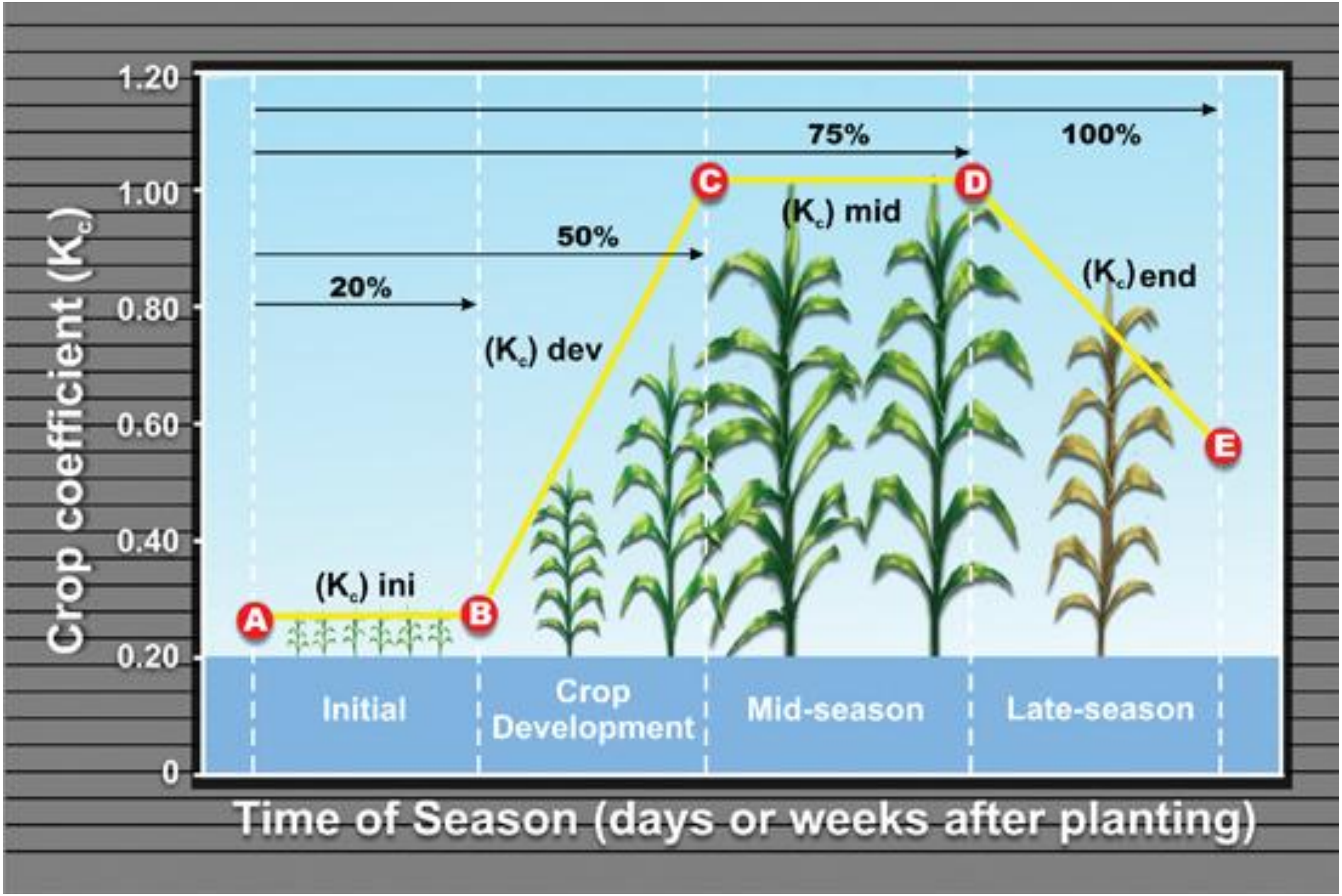
I. initial stage from sowing/planting date until the percentage of the soil covered by the crop S_c is 10%.

II. crop development stage from $S_c >= 10$ to $S_c = 70$- 80%,

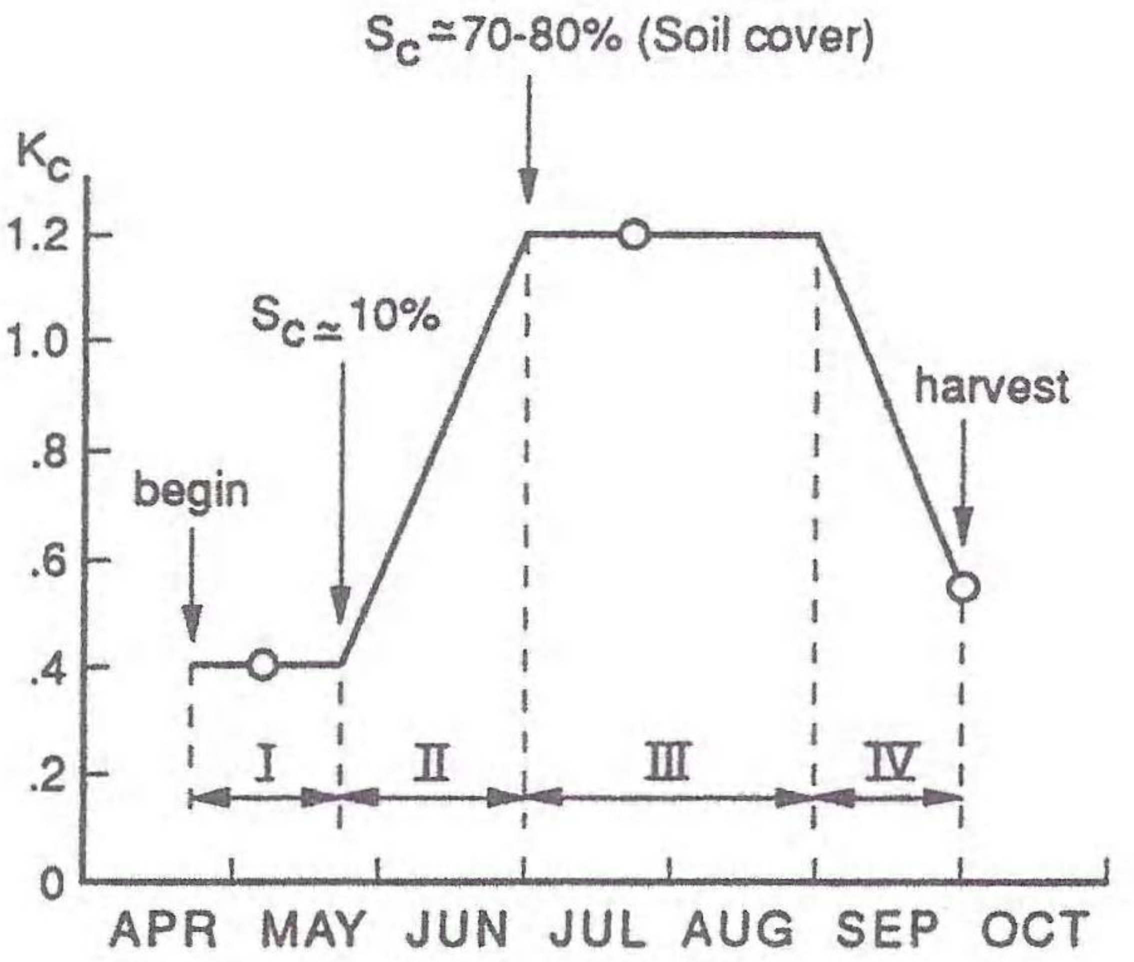
III. mid-season stage from $S_c = 70$- 80% to start of maturing.

IV. late season stage from start of maturing to full maturity or harvest.

Crop coefficients



Example of crop coefficient (K_c) curve



Examples of crop development stages

Cotton: March planting Egypt, April-May planting Pakistan, etc. 30/50/60/55 and (195); etc.

Maize: Spring planting East Africa high lands 30/50/60/40 and (180); late cool season planting, warm desert climates 24/40/45/30 and (140); etc.

Suger beet: Coastal Lebanon, mid-November planting 45/75/80/30 and (230); early summer planting 25/35/50/50 and (160); etc.

Table 1. Examples of crop coefficient K_c

	Humidity	$RH_{min} > 70\%$		$RH_{min} < 20\%$	
	Wind $m.s^{-1}$	0–5	5–8	0–5	5–8
crop	*crop stage*				
cotton	3	1.05	1.15	1.20	1.25
	4	0.65	0.65	0.65	0.70
maize	3	1.05	1.10	1.15	1.20
	4	0.55	0.55	0.60	0.60
sugar beet	3	1.05	1.10	1.15	1.20
	4	0.90	0.95	1.00	1.00

Leaching of salts

Leaching requirements

An annual application of 1000 mm of irrigation water containing only 250 mg/l dissolved salts will add 2,500 kg salts to each ha each year. To prevent Stalinization of the top soil salts have to be washed down which is known as leaching.

LEACHING: Leaching is the process of removal of soluble material by the passage of water through soil.

The leaching requirement is the ratio between the drainable excess and the quantity of irrigation water applied to keep the salt content in the root zone below the crop tolerance level.

The tolerance level is found from relations between crop yield and the salt concentration of the saturation extract.

The saturation extract is obtained by mixing a soil sample with distilled water until it glistens. The solution is extracted from the paste with a suction filter after which the electrical conductivity ECe is measured.

Consider for the computation of the leaching requirement the water balance of the root zone. Neglecting storage effects the equation may be written as:

$$P_e + I = D + E_{crop}$$

where

P_e : is the effective precipitation.

I : is the irrigation.

D: is the net drainage (percolation from the root zone minus capillary rise).

Neglecting the accumulation of salts in the root zone, the salt balance can be expressed as:

$$I\ C_i = D\ C_d$$

where C_i and C_d are the salt concentrations of the irrigation and drainage water, respectively.

Changes in salt content due to fertilizer, crop growth or salty rainwater are not taken into consideration. Since the electrical conductivity EC of a solute is a reliable

Leaching requirements calculation

For surface irrigation method including sprinkler

$$LR = \frac{EC_i}{5EC_e - EC_i}$$

For drip irrigation method

$$LR = \frac{EC_i}{(2\max)\, xEC_e}$$

Where:

LR is the leaching requirements

EC_i is the electrical conductivity of irrigation water

EC_e is the electrical conductivity of the root zone- soil extraction.

Max.EC_e =Maximum tolerable Electrical conductivity of the soil saturation extract for a given crop

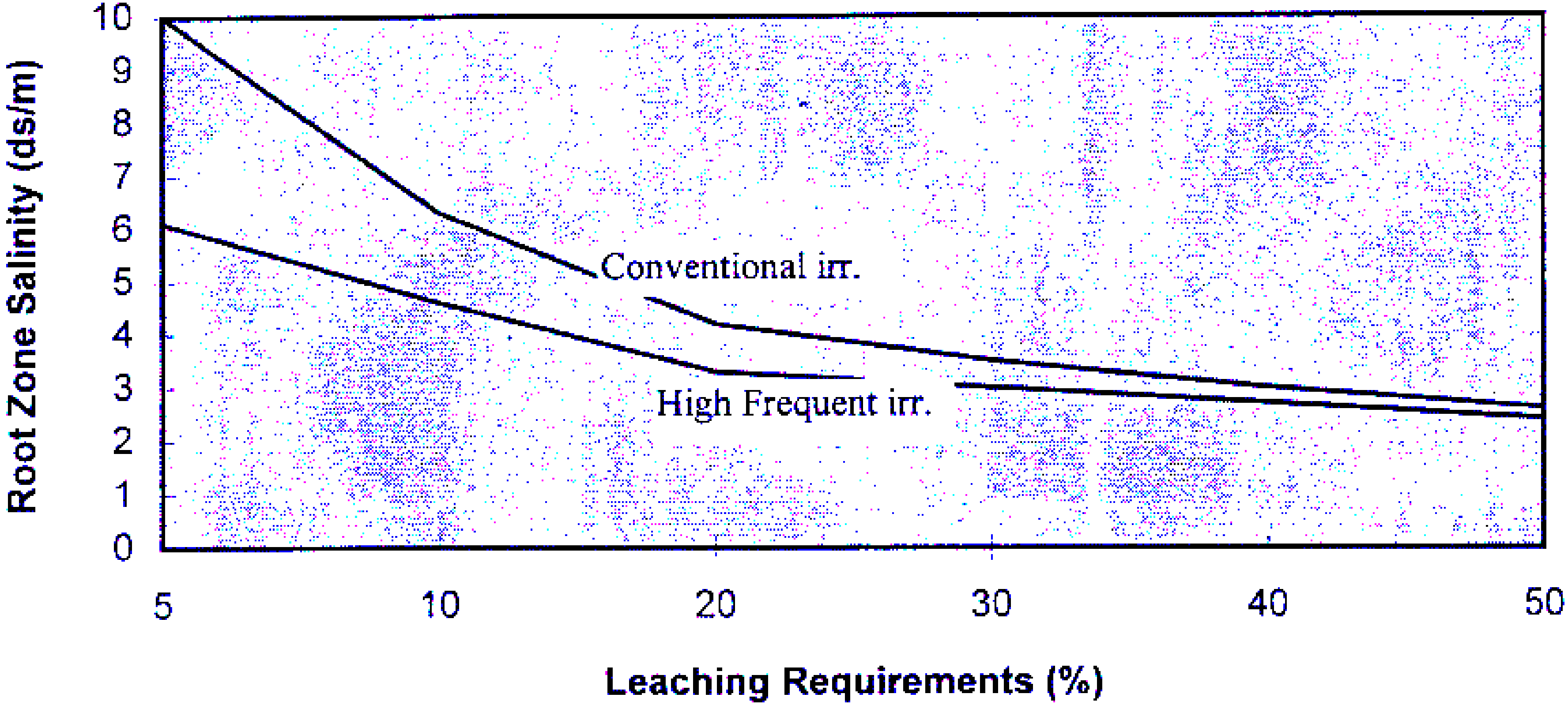
Examples of crop salt tolerance levels EC_e in mmho/cm

Yield potential	100%	90%	75%	50%
Cotton	7.7	9.6	13.0	17.0
Maize	1.7	2.5	3.8	5.9
Suger beet	7.0	8.7	11.0	15.0

The efficiency of leaching depends on:

1. The amount of water applied,
2. Uniformity of water distribution, and
3. The adequacy of drainage

Leaching requirements based on irrigation frequency for irrigation water EC= 3.5 ds/m



Net irrigation requirements

$$I_n = E_{crop} - (G_e + W_b + P_e)$$

irrigation requirements

$$I = \frac{E_{crop} - (G_e + W_b + P_e)}{1 - LR}$$

Where:

G_e is the groundwater contribution

P_e is the effective precipitation

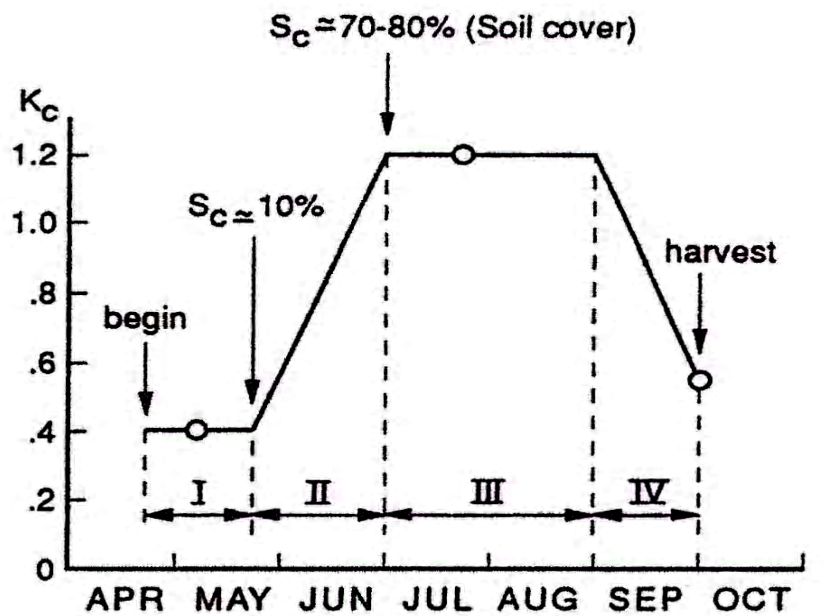
Effective precipitation empirical formula

P_e. = 0.8 * P - 25 for average rainfall (P) > 75 mm/month
P_e. = 0.6 * P - 10 for average rainfall (P) < 75 mm/month

W_b is stored soil water at the beginning of the account period. For preliminary planning net irrigation requirements are usually computed for monthly or 10-day periods.

Assignment No. 6: Maize is cultivated in Gaza Strip at the Mid of April and harvested at the end of September. The following table and figure show the $ET_{ref.}$, rainfall and crop coefficient diagram. Assuming the electrical conductivity of irrigation water 3.0 ds/m and the irrigation period 30 days.

Month	ET_{ref}	Total rain
	----mm/Month----	
Jan.	77	108.23
Feb.	68	56.88
March	106	32.26
April	131	2.24
May	154	0.00
June	170	0.00
July	174	0.00
Aug.	165	0.00
Sept.	146	1.92
Oct.	121	25.39
Nov.	097	54.89
Dec.	080	92.54
Total	1494	374.34



a) Calculate the crop water requirement.
b) Calculate the irrigation water requirement.
c) Calculate the leaching requirements, the maximum tolerable electrical conductivity of the soil saturation extract for maize is 4.2 ds/m.
d) Summarize the results in abstract form (not more than one page).

$$E_{crop} = K_{crop} \text{ X } E_{reference} \qquad LR = \frac{EC_i}{2 Max. EC_e}$$

$P_e. = 0.8 \text{ x } P_r – 25$ for average rainfall (P_r) >75 mm/month
$P_e. = 0.6 \text{ x } P_r - 10$ for average rainfall (P_r) < 75 mm/month