Soil Water Balance Module

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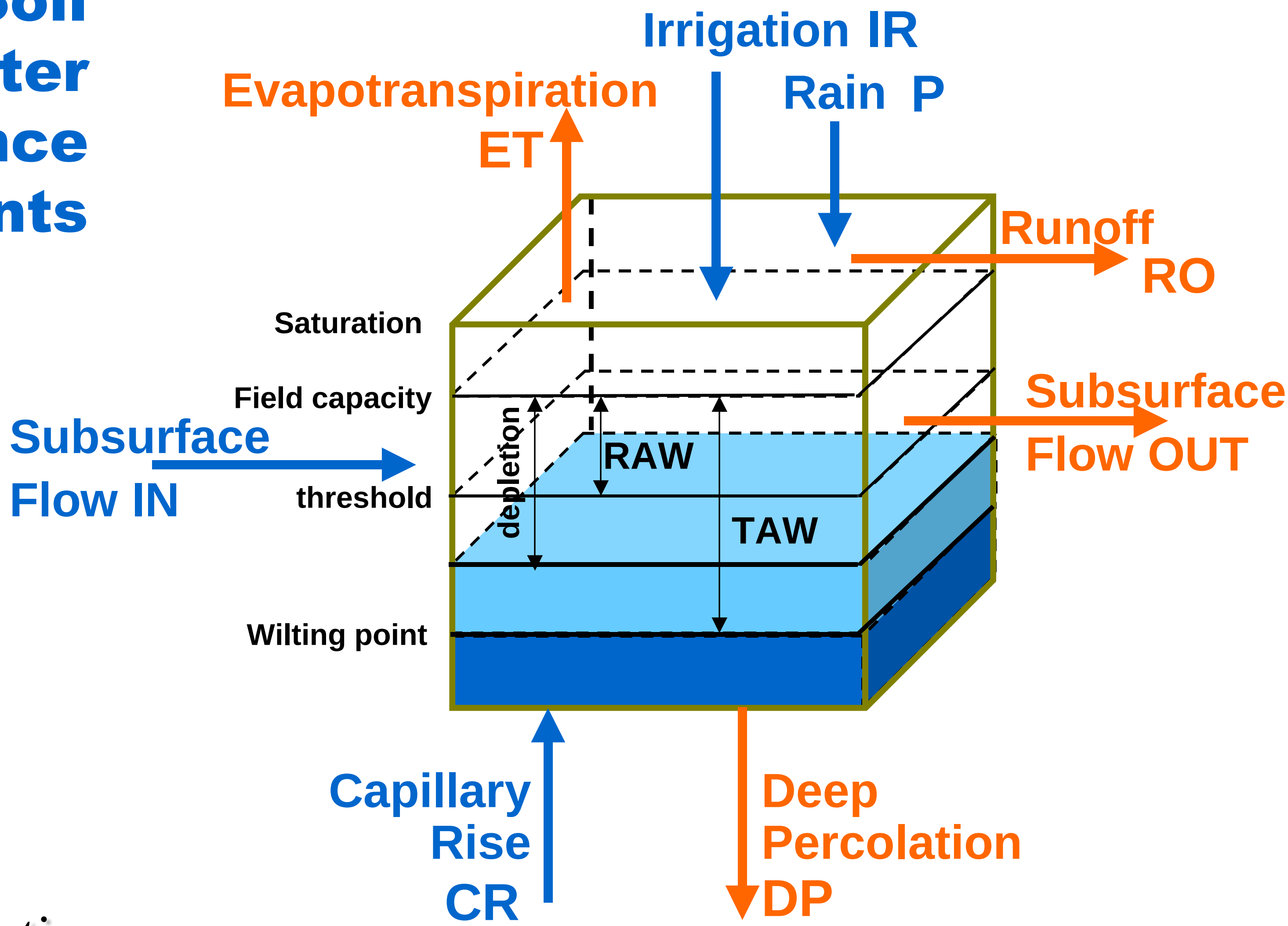
Soil Water Balance – why we need it?

- to asses the root zone soil water depletion/soil water content under different water regimes and soil, climatic and crop conditions;
- to design irrigation scheduling;
- to evaluate irrigation strategies;
- to estimate yield response to water and crop growth;
- to study the building of salt in the root zone under averse irrigation conditions.

Soil Water Balance Components



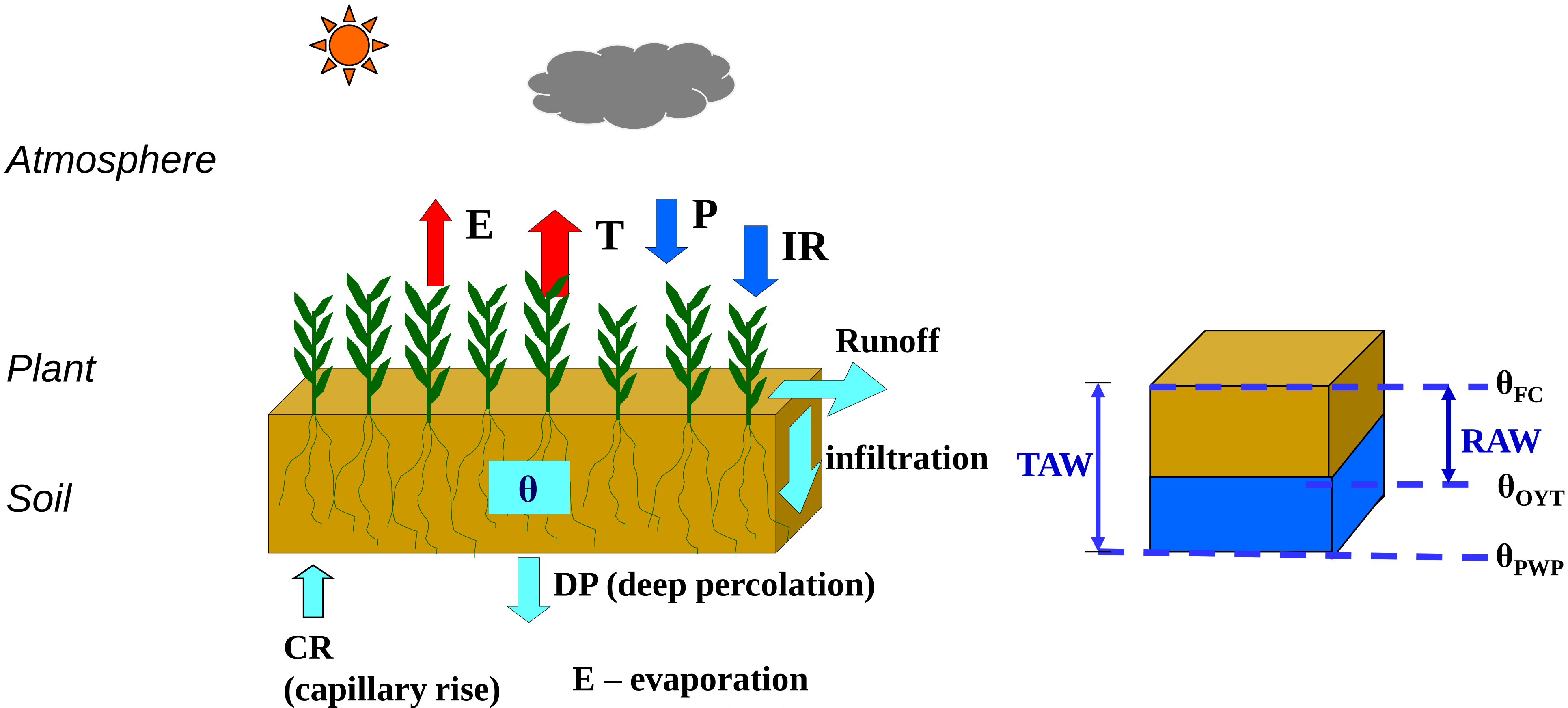
Root zone depletion:

$$D_{r,i} = D_{r,i-1} - P_i - IR_i - CR_i + ET_{c,i} + RO_i + DP_i$$

Soil moisture content:

$$\Theta_{r,i} = \Theta_{r,i-1} + P_i + IR_i + CR_i - ET_{c,i} - RO_i - DP_i$$

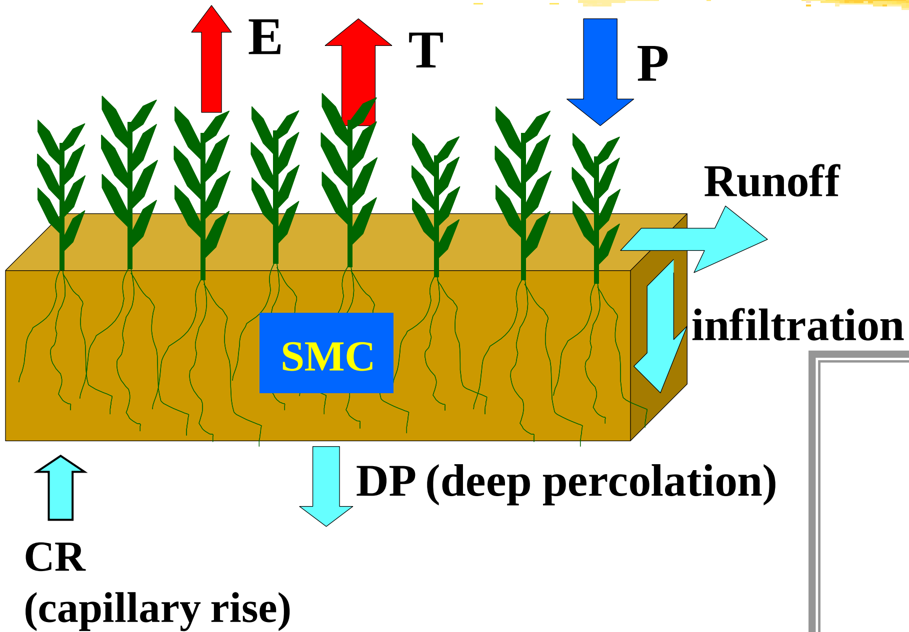
Soil – Plant – Atmosphere Continuum

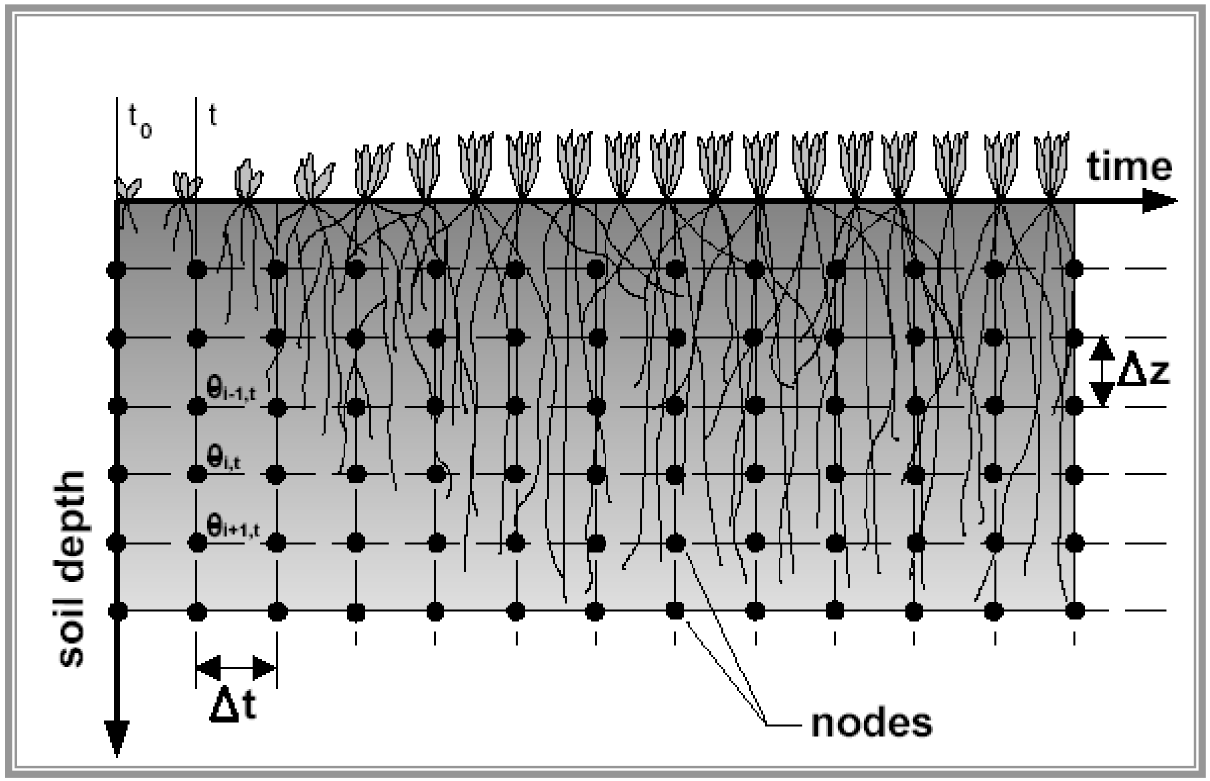


E – evaporation
T – transpiration
P – precipitation
θ – Soil Moisture Content

DYNAMIC SIMULATION MODEL

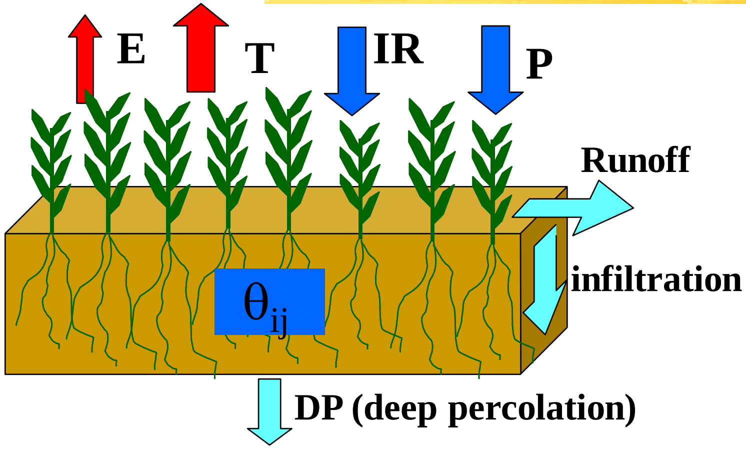
Time (t) – soil depth (z) – space grid





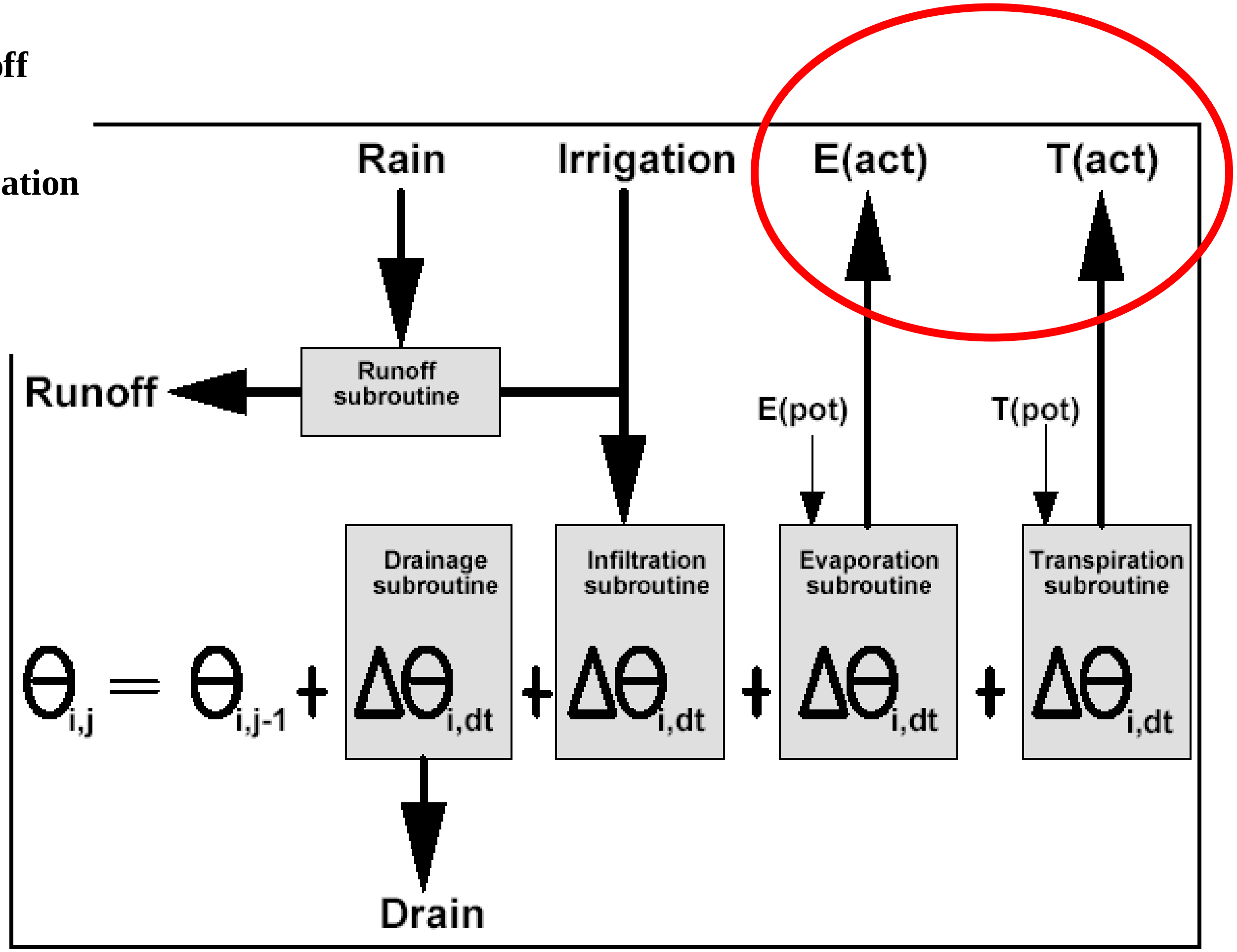
E – evaporation
T – transpiration
P – precipitation
SMC – Soil Moisture Content

Soil Water Balance – common calculation scheme

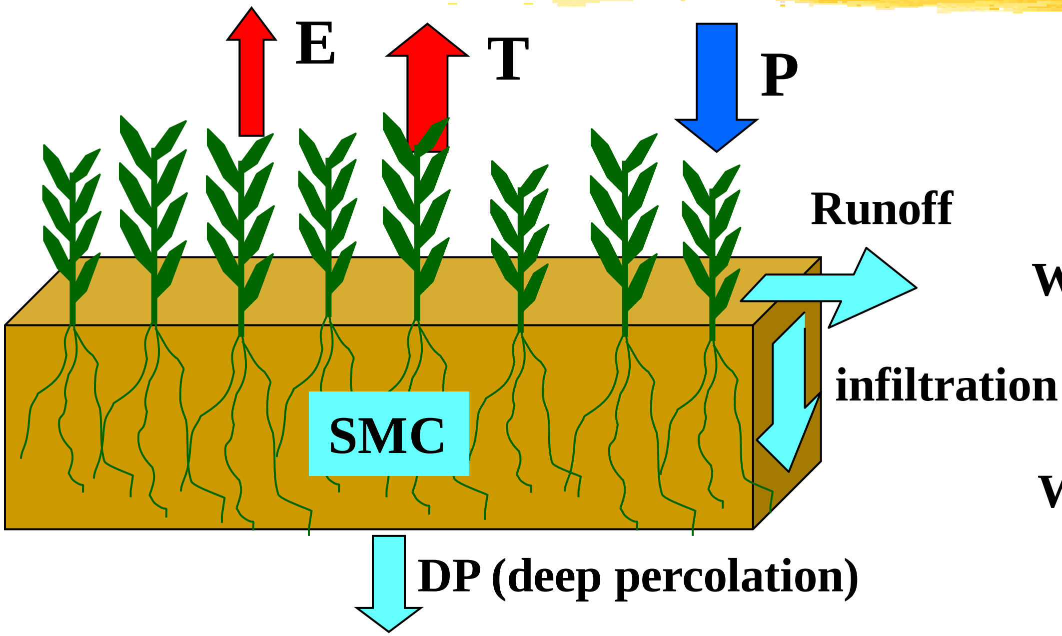


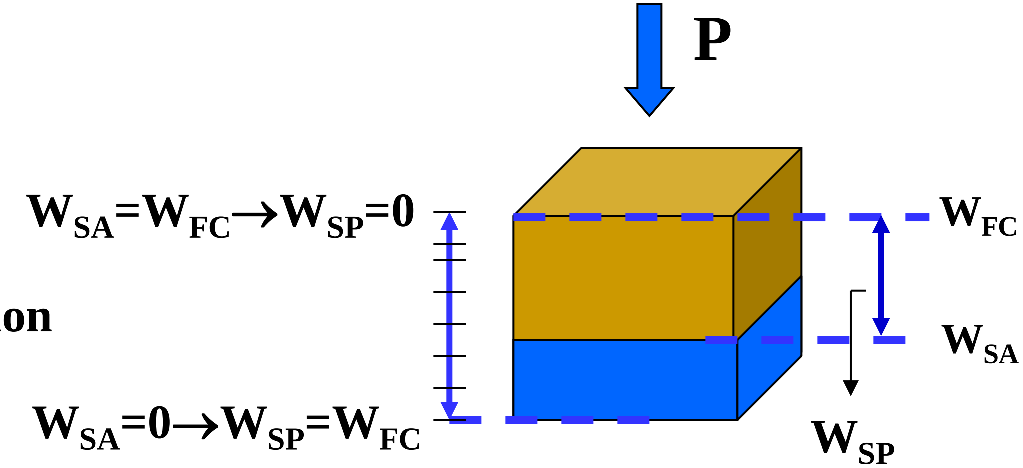
θ_{ij} - soil moisture content at depth z_i and at time level t_j

The greatest components of SWB in the Mediterranean



Simplified Soil Water Balance for a rainfall event

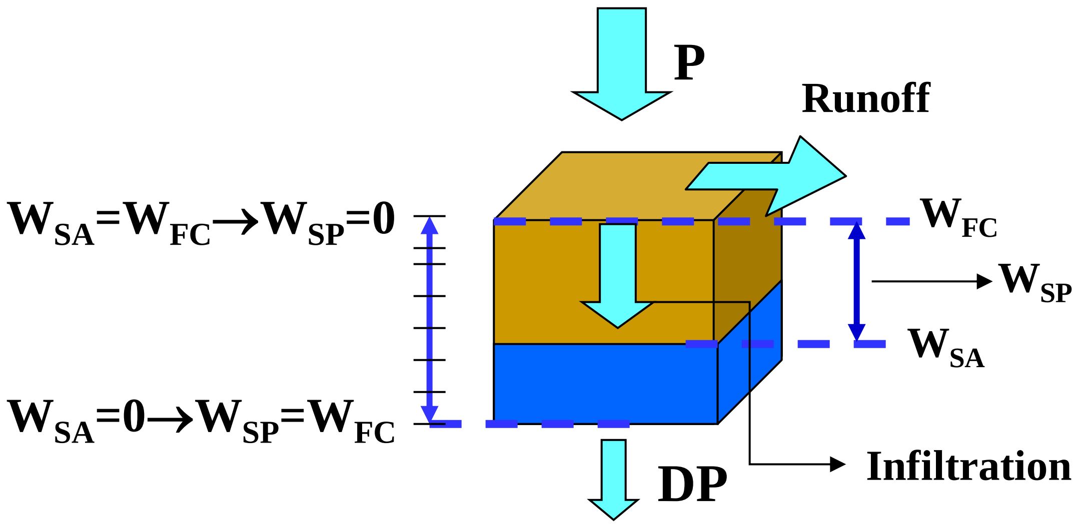




- The opportunity to stored water in the soil root zone, or **potential water storage(W_{SP})**, depends on the **actual water content** in that zone (W_{SA}): $W_{SP} = W_{FC} - W_{SA}$
- For a rainfall event, the **water infiltrated** into the soil (W_{inf}) is given by : $W_{inf}=P - Runoff$
- Thus, water stored in the soil (W_{ST}) is obtained in the following way:
  - if $W_{inf} \leq W_{SP}$ then $W_{ST}=W_{inf}$ and $DP=0$
  - if $W_{inf} > W_{SP}$ then $W_{ST}=W_{SP}$ and $DP=W_{inf}-W_{SP}$

Simplified Soil Water Balance for a rainfall event – an example of calculation

- **Assume:**
  - **P = 50 mm**
  - **W_{SA} = 20 mm**
  - **W_{FC} = 40 mm**
  - **Runoff = 15 mm**
- **Calculate water stored in the soil W_{ST} !**

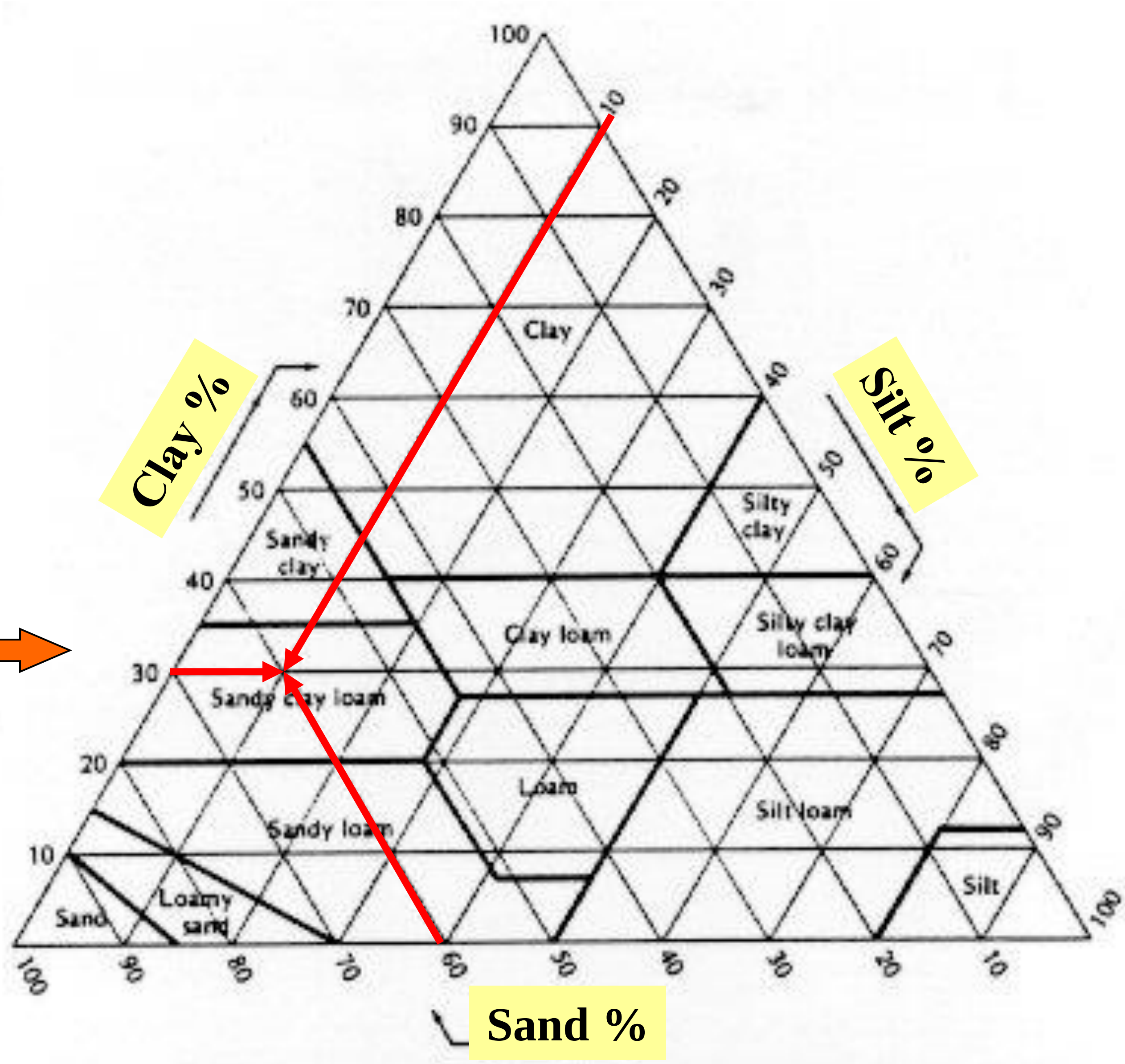


- **Calculation:**
  - **Water infiltrated into the soil is W_{inf} = P - Runoff = 50 – 15 = 35 mm**
  - **Potential water storage is $W_{SP} = W_{FC} – W_{SA}$ = 40 - 20 = 20 mm**
  - **Since $W_{inf} > W_{SP}$, then water stored in the soil is $W_{ST} = W_{SP}$ = 20 mm**
  - **Deep percolation is DP = $W_{inf} – W_{ST}$ = 35 – 20 = 15 mm**

Soil classification – from granulometric soil characteristics & soil triangle

<u>Example:</u>
Sand 60%
Clay 30%
Silt 10%

<u>From the soil triangle</u>
this soil can be classified as
Sandy Clay Loam



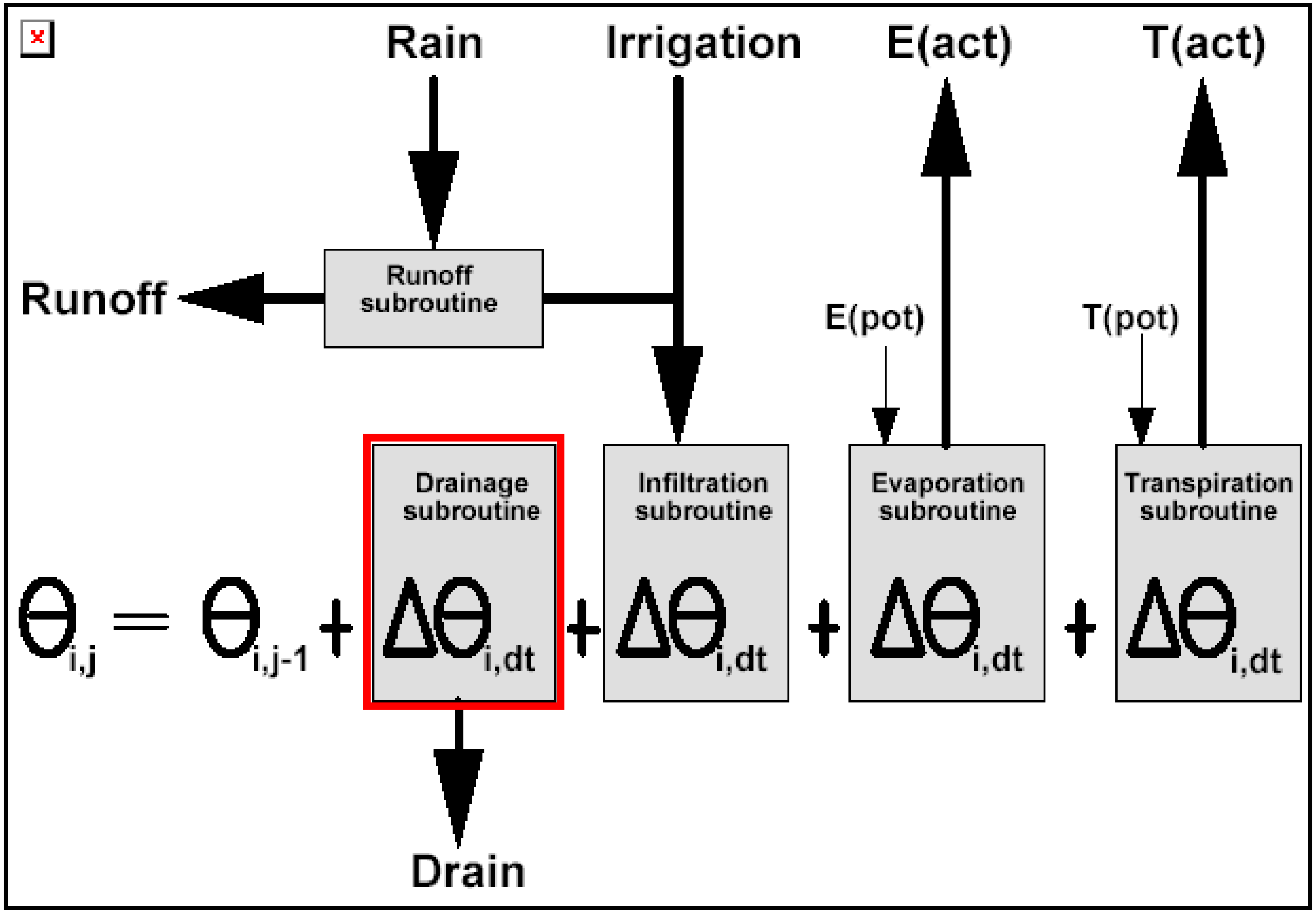
Soil hydraulic properties
- function of soil type

SAT	FC	WP	tau	Ksat	Soil type
vol%	vol%	vol%	-	mm/day	-
36	13	6	1.00	1500	Sand
38	16	8	0.95	800	Loamy sand
41	22	10	0.75	500	Sandy loam
46	31	15	0.60	250	Loam
46	33	13	0.50	150	Silt loam
43	33	9	0.35	50	Silt
47	32	20	0.45	125	Sandy clay loam
50	39	23	0.40	70	Clay loam
52	44	23	0.30	20	Silty clay loam
50	39	27	0.42	75	Sandy clay
54	50	32	0.20	15	Silty clay
55	54	39	0.10	2	Clay

The *characteristics* of the soil layer are the following hydraulic properties:

SAT : soil water content [vol%] at saturation;
FC : soil water content [vol%] at field capacity;
WP : soil water content [vol%] at wilting point;
tau : drainage characteristic (value between 1 and 0);
Ksat : infiltration rate [mm/day] at saturation.

Soil Water Balance – common calculation scheme in crop growth models



θ_{ij} - soil moisture content at depth z_i and at time level t_j

Drainage – amount of water lost by free drainage as a function of time for any SWC between saturation and FC

$$\frac{\Delta\theta_i}{\Delta t} = \tau\left(\theta_{sat} - \theta_{FC}\right)\frac{e^{\theta_i - \theta_{FC}} - 1}{e^{\theta_{sat} - \theta_{FC}} - 1}$$

$\Delta\theta_i/\Delta t$: decrease in soil water content at depth i, during time step Δt [$m^3 m^{-3} day^{-1}$]

τ : drainage characteristics, from 0 to 1, non-dimensional

θ_i : actual soil water content at depth *i* [$m^3 m^{-3}$]

θ_{SAT} : soil water content at saturation [$m^3 m^{-3}$]

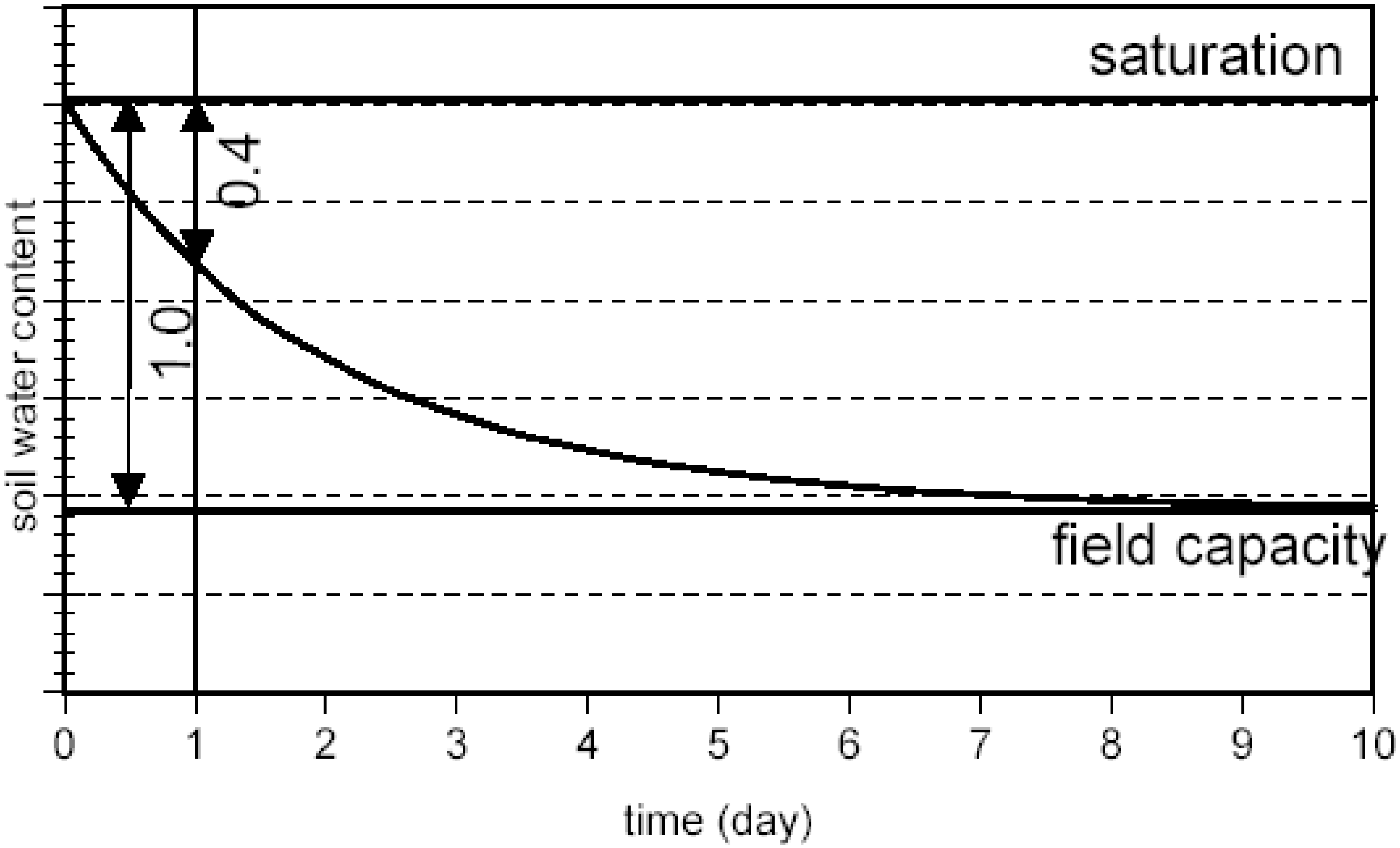
θ_{FC} : soil water content at field capacity [$m^3 m^{-3}$]

Δt : time step

If $\theta_I \leq \theta_{FC}$ than $\Delta\theta_i/\Delta t = 0$

If $\theta_I = \theta_{SAT}$ than $\Delta\theta_i/\Delta t = \tau(\theta_{SAT} - \theta_{FC})$

Variation of soil water content in function of time in a free draining soil layer with a drainage characteristics of τ = 0.4

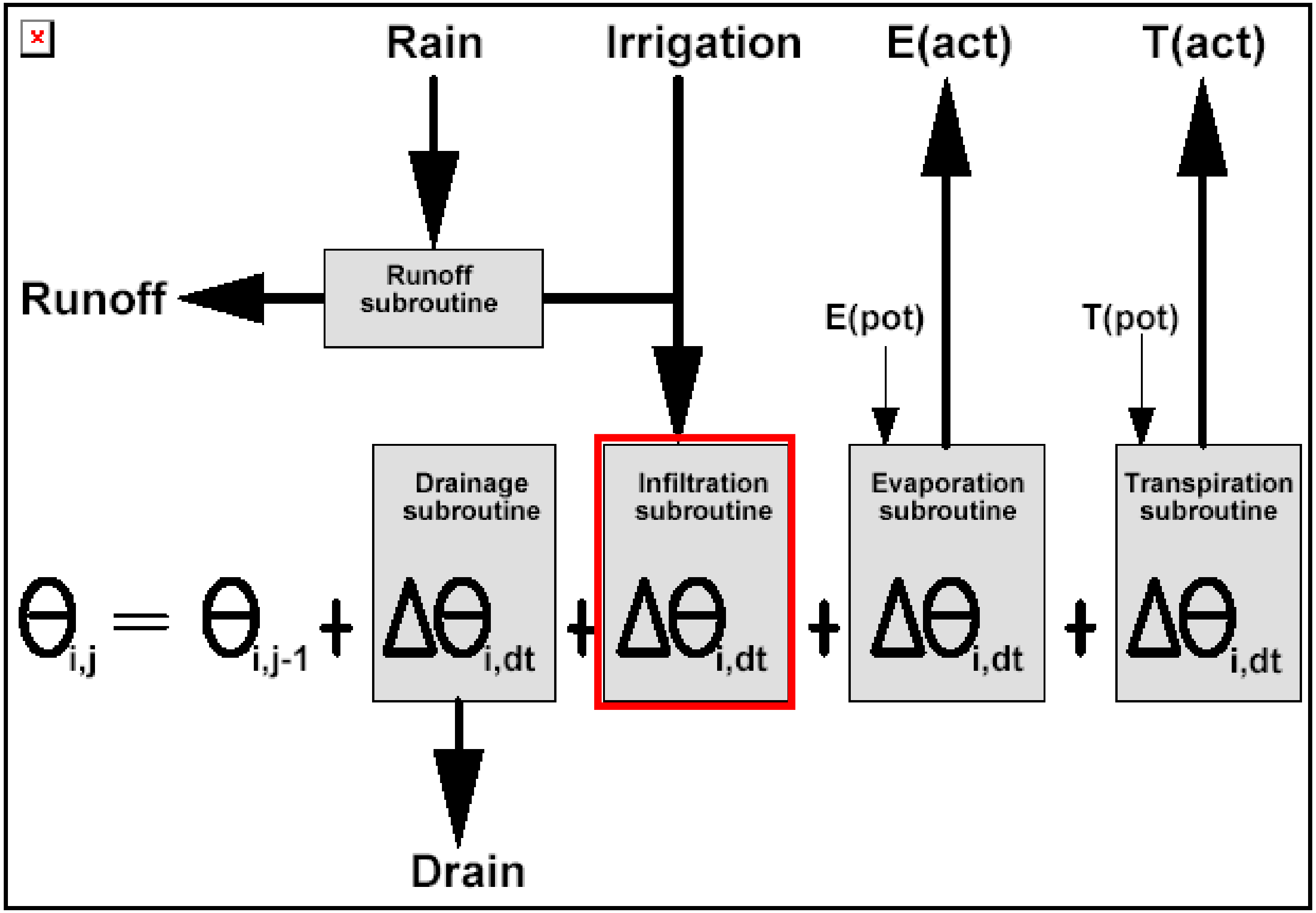


τ : drainage characteristics – expresses the decrease in soil water content of a soil layer, originally at saturation, at the end of the first day of free drainage.

τ = 0 : when soil layer is impermeable

τ = 1 : when complete drainage happens after one day

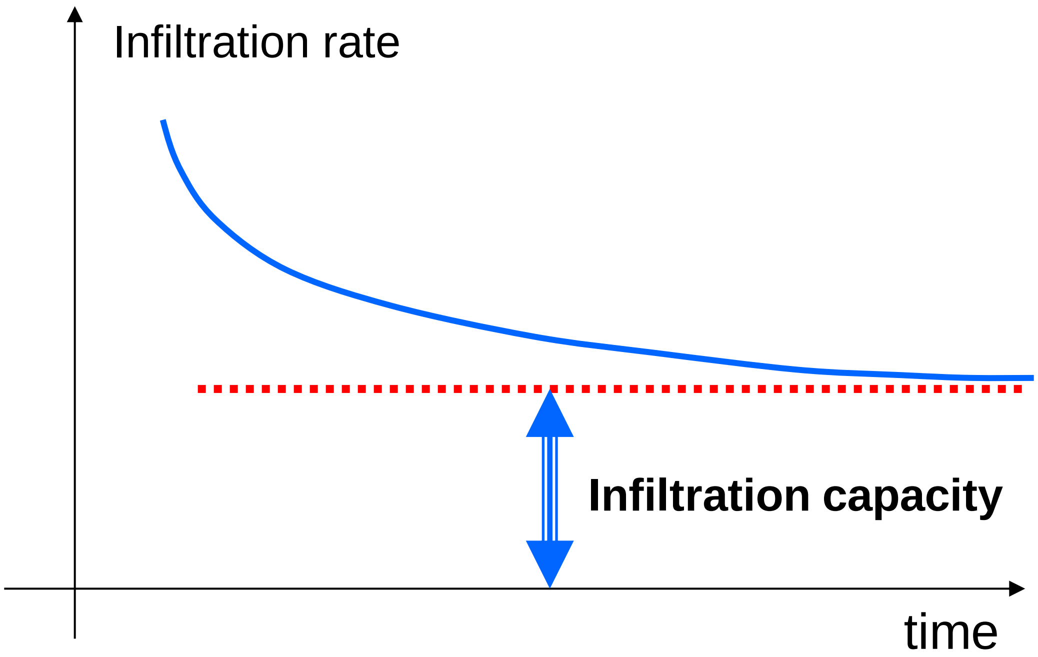
Soil Water Balance –
common calculation scheme in crop growth models



θ_{ij} - soil moisture content at depth z_i and at time level t_j

Infiltration

- Infiltration refers to the downward flow of water from surface into the soil.
- Percolation refers to the movement of water through the soil profile



Indicative values of infiltration capacity [mm/hr] as a function of soil texture and vegetation cover

Texture	Vegetative soil	Bare soil
Loamy sand	50	25
Loam	25	13
Silt loam	15	8
Clay loam	5	3

Source: Khonkeo, 1968

Runoff – basic considerations

- From the hydrological (engineering) point of view, the runoff from a drainage basin can be considered as a product (gain) in a hydrological cycle.
- Main climatic factors affecting runoff:
  - precipitation: form, duration, intensity, time and areal distribution, frequency of occurrence, antecedent precipitation, antecedent soil moisture, interception (vegetation species, composition, age, density of canopy, season of the year) …
- Main physiographic factors affecting runoff:
  - basin characteristics: size, shape, slope, orientation, elevation, stream density
  - physical factors: land use and cover, soil type, infiltration conditions, permeability conditions, capacity of groundwater formations …
- From the agronomic point of view, the runoff can be considered as precipitation losses in a rainfall-runoff analysis.

Runoff – SCS-USDA Curve Number (CN) method

- A Curve Number is an empirical value assigned to each watershed or portion of watershed based on:
  - Soil type;
  - Land use and treatment;
  - Antecedent moisture conditions (AMC).
- Antecedent moisture conditions are divided into:
  - AMC-I – soils are dry close to the wilting point, and satisfactory plowing or cultivation takes place;
  - AMC-II – average soil moisture conditions and management practices
  - AMC-III – the soil is nearly saturated – heavy rainfall or light rainfall and low temperatures occurred during the five days previous to the given storm

SCS-USDA method – CN values

Description	Average % Impervious	Curve Number by Hydrologic Soil Group				Typical Land Uses
		A	B	C	D	
Residential (High Density)	65	77	85	90	92	Multi-family, Apartments, Condos, Trailer Parks
Residential (Med. Density)	30	57	72	81	86	Single-Family, Lot Size ¼ to 1 acre
Residential (Low Density)	15	48	66	78	83	Single-Family, Lot Size 1 acre and Greater
Commercial	85	89	92	94	95	Strip Commercial, Shopping Ctrs, Convenience Stores
Industrial	72	81	88	91	93	Light Industrial, Schools, Prisons, Treatment Plants
Disturbed/Transitional	5	76	85	89	91	Gravel Parking, Quarries, Land Under Development
Agricultural	5	67	77	83	87	Cultivated Land, Row crops, Broadcast Legumes
Open Land – Good	5	39	61	74	80	Parks, Golf Courses, Greenways, Grazed Pasture
Meadow	5	30	58	71	78	Hay Fields, Tall Grass, Ungrazed Pasture
Woods (Thick Cover)	5	30	55	70	77	Forest Litter and Brush adequately cover soil
Woods (Thin Cover)	5	43	65	76	82	Light Woods, Woods-Grass combination, Tree Farms
Impervious	95	98	98	98	98	Paved Parking, Shopping Malls, Major Roadways
Water	100	100	100	100	100	Water Bodies, Lakes, Ponds, Wetlands

SCS-USDA Curve Number (CN) method

Soil hydrological groups by means of infiltration rate

- ***A*** Soils having **high infiltration rates**, even when thoroughly wetted and consisting chiefly of deep, well to excessively-drained sands or gravels. These soils have a high rate of water transmission.
- ***B*** Soils having **moderate infiltration rates** when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
- ***C*** Soils having **slow infiltration rates** when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
- ***D*** Soils having **very slow infiltration rates** when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay-pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

SCS-USDA Curve Number (CN) method

Soil hydrological groups by means of potential runoff

- **A** **Lower Runoff Potential –** Includes deep sands with very little silt and clay, also deep, rapidly permeable loess.
- **B** **Moderately Low Runoff Potential –** Mostly sandy soils less deep than A, and less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting.
- **C** **Moderately High Runoff Potential –** Comprises shallow soils and soils containing considerable clay and colloids, though less than that of group D. The group has below-average infiltration after thorough wetting.
- **D** **Highest Runoff Potential –** Includes mostly clays of high swelling percentage, but the group also includes some shallow soils with nearly impermeable sub-horizons near the surface.

Runoff – SCS-USDA Curve Number (CN) method

Range of variation (possible error?!)

CN values for Antecedent Moisture Classes (AMC) II and their corresponding values for AMC I (dry) and III (wet).

AMC	Soil water content	CN value			
I	Wilting point	45	56	63	70
II	**Default value**	**65**	**75**	**80**	**85**
III	Field capacity	84	88	91	93

$$S = 254\left(\frac{100}{CN} - 1\right)$$

$$RO = \frac{(P - 0.2S)^2}{P + S - 0.2S}$$

S : potential maximum storage (soil retention)

(0.2)*S : initial abstraction [mm] – the amount of water that can infiltrate before runoff occurs

CN : curve number

RO : amount of water lost by surface runoff [mm]

P : precipitation [mm]

Initial abstraction 0.2S

$CN45 \rightarrow 62$ mm	**Initially dry soil**
$CN65 \rightarrow 27$ mm	**Initially moderately wet soil**
$CN85 \rightarrow 9$ mm	**Soil is nearly saturated**

Runoff starts when P>0.2S

Runoff – SCS-USDA Curve Number (CN) method
Example of calculation

- **Assume:**
  - **P = 50 mm**
  - **CN = 75 (agricultural land, moderate infiltration rate)**

- **Calculate runoff and initial water abstraction in the soil !**

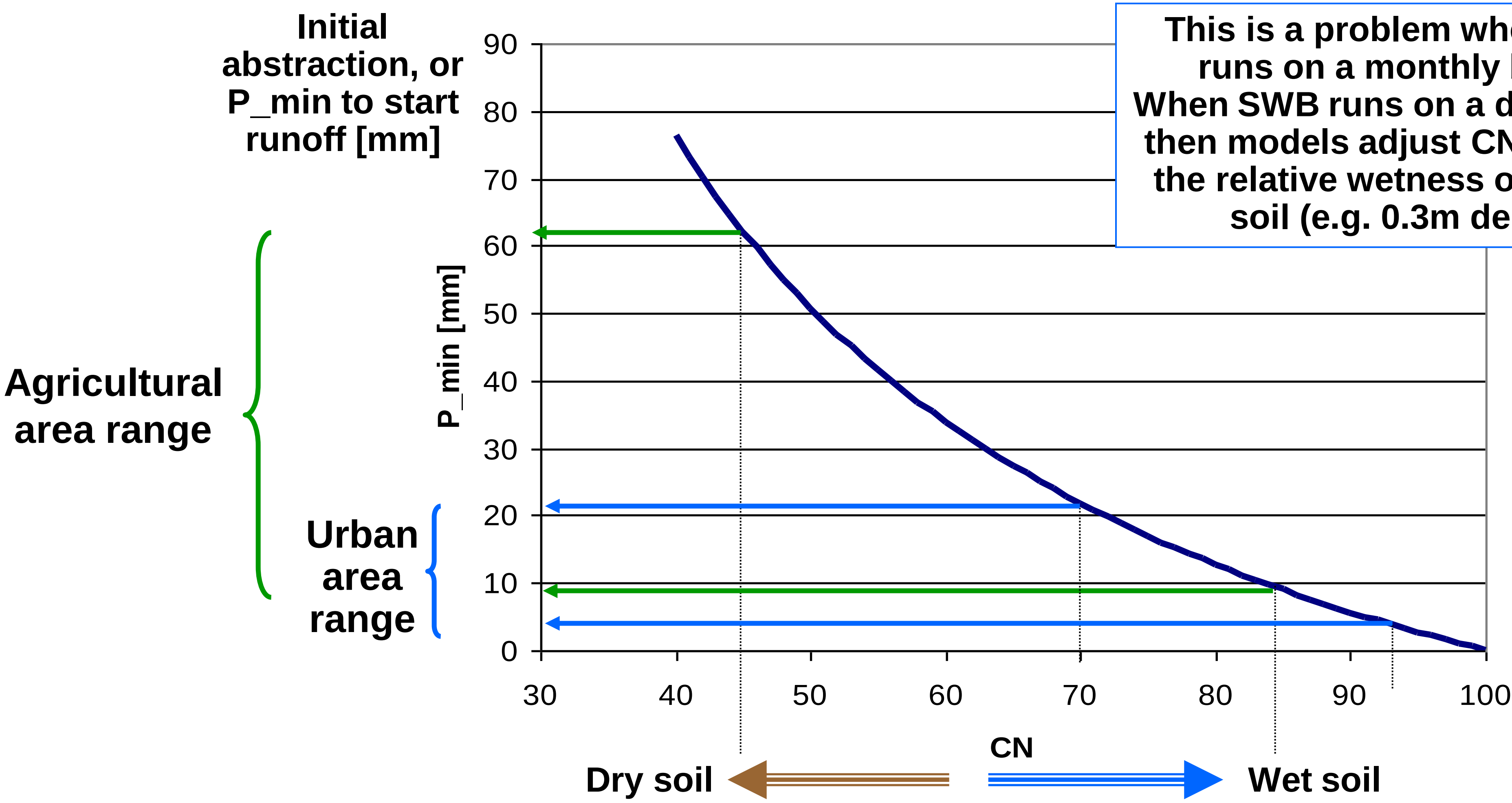
$$S = 254\left(\frac{100}{CN} - 1\right)$$ = 84.7 mm – potential maximum storage

*Initial abstraction 0.2*S = 16.9 mm*

$$RO = \frac{(P - 0.2S)^2}{P + S - 0.2S}$$ = 9.2 mm – runoff

Runoff – SCS-USDA Curve Number (CN) method

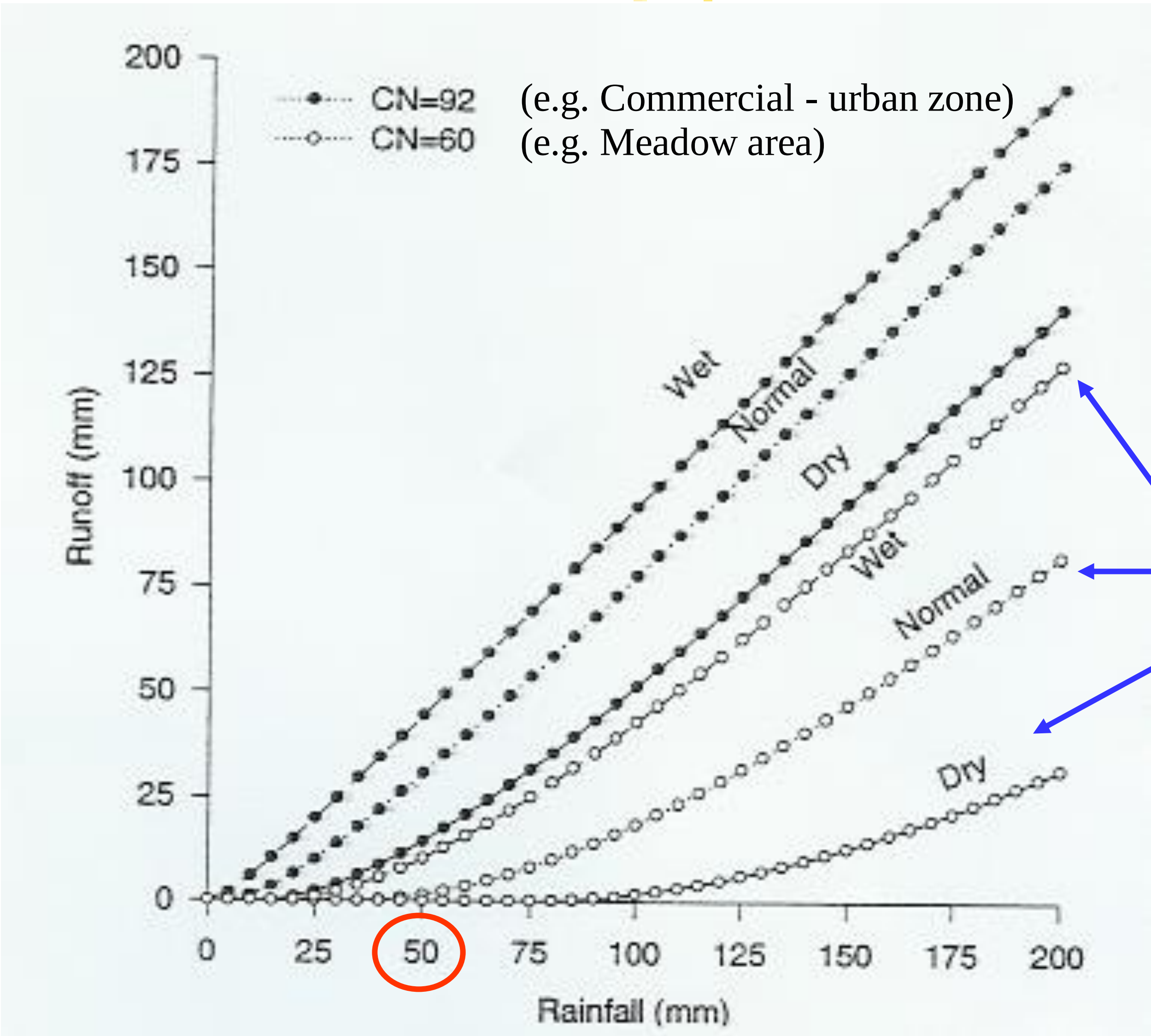
Range of variation as a function of AMC (possible error?!)



This is a problem when SWB runs on a monthly basis. When SWB runs on a daily basis then models adjust CN value to the relative wetness of the top soil (e.g. 0.3m depth)

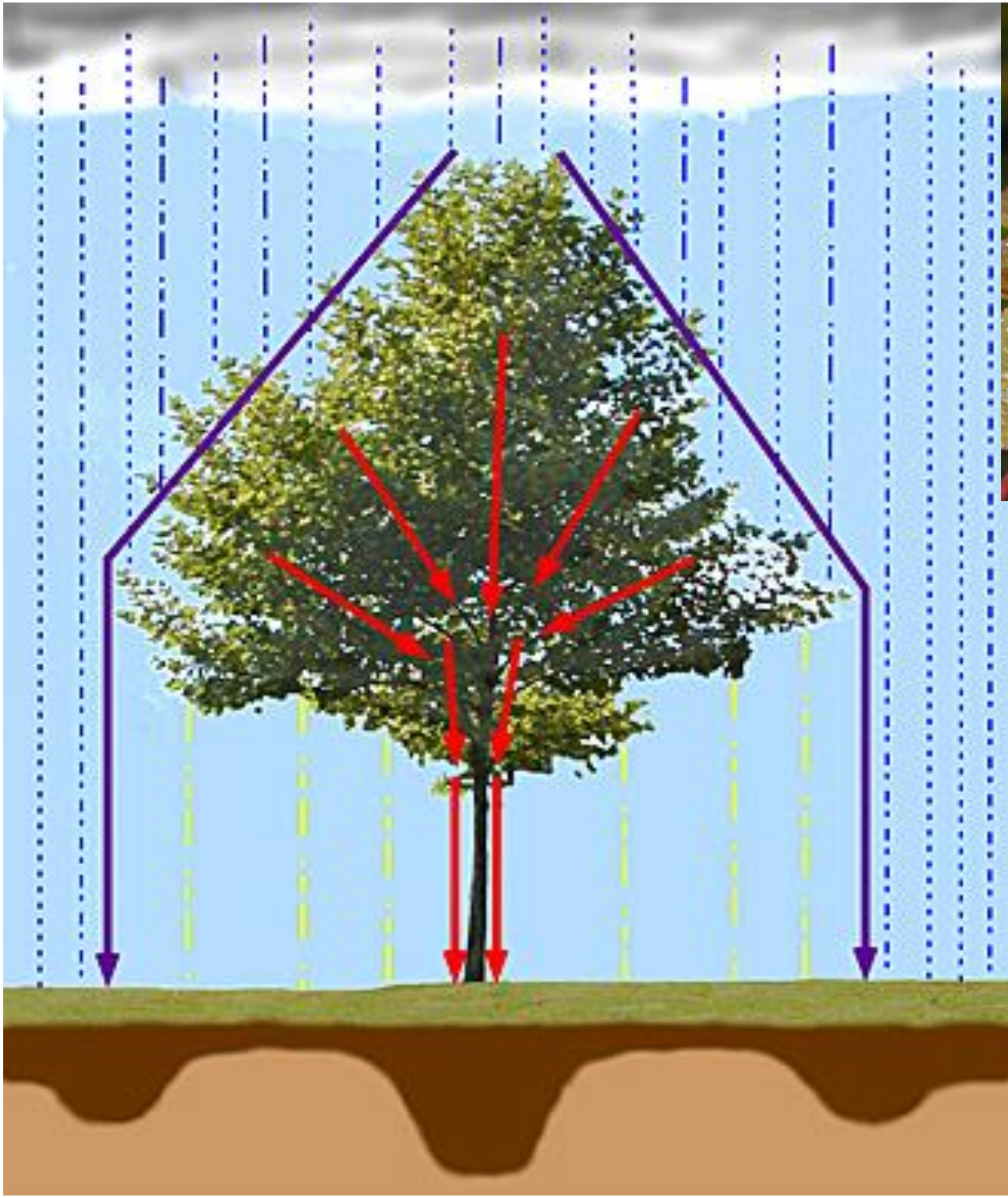
Higher CN → smaller S → greater runoff (smaller infiltration)

SCS USDA Curve number method – discussion



Wetness of the soil near the surface before precipitation

However, sometimes runoff can represents almost 100% of P even from agricultural fields

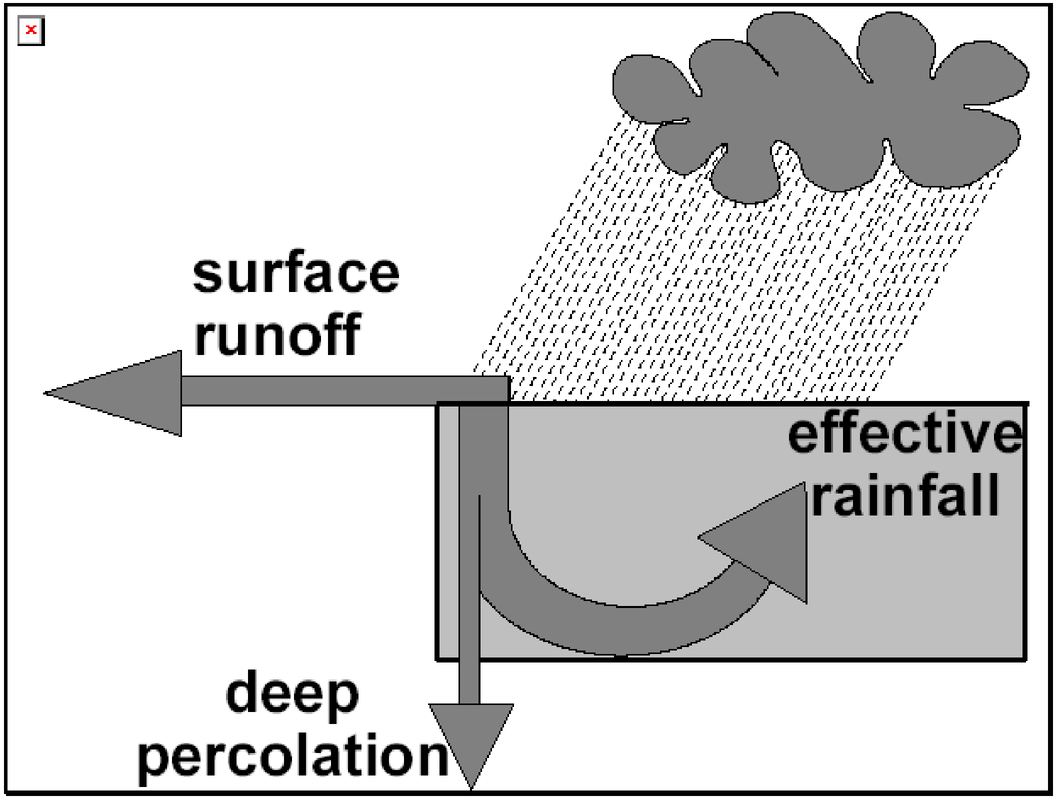


Interception and Effective Rainfall Concept

Effective Rainfall (P_{eff})

a part of P stored in the root zone and not lost by surface runoff or deep percolation

(to be used over the total growing season, or on a monthly basis)



- Fixed % of P

$$P_{eff} = P_{coeff} * P$$

- FAO/AGL Empirical Equation for design purposes where 80% probability of exceedance is required

$$P_{eff}=0.6*P_{tot}-10 \quad \text{for } P_{tot}<70mm$$

$$P_{eff}=0.8*P_{tot}-24 \quad \text{for } P_{tot}>70mm$$

- USDA Soil Conservation Method

$$P_{eff}=P_{tot}(125-0.2P_{tot})/125 \quad \text{for } P_{tot}<250mm$$

$$P_{eff}=125+0.1P_{tot} \quad \text{for } P_{tot}>250mm$$

Total rainfall is used (and not P_{eff}) in the water balance calculations for irrigation scheduling on a daily basis - the intake of rain into soil is determined and rainfall losses due to deep percolation and surface runoff are estimated according to actual soil moisture content in the root zone.

Interception and Effective Rainfall

27 January

2 March

17 March

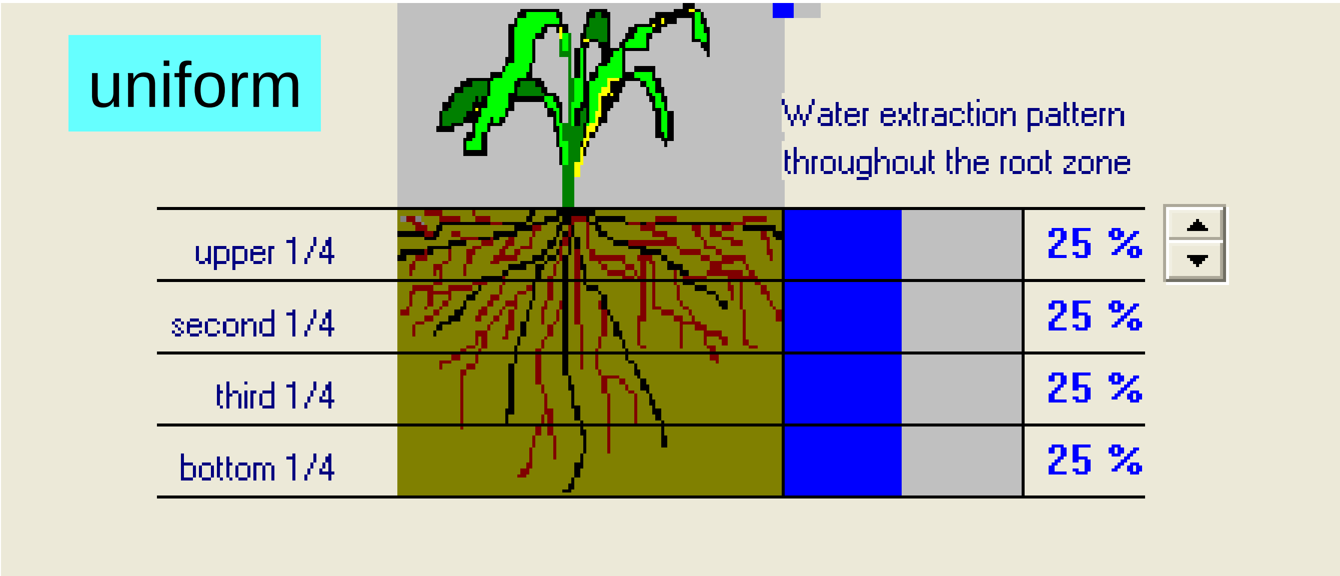
Percentage of ground cover estimation in the field

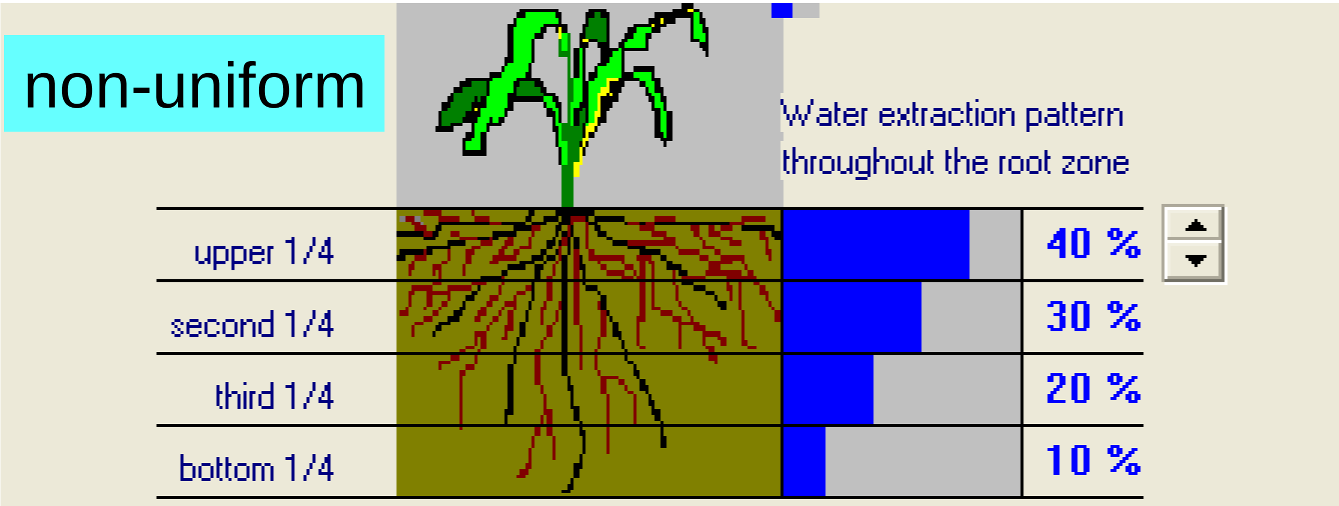
27 January

2 March

17 March

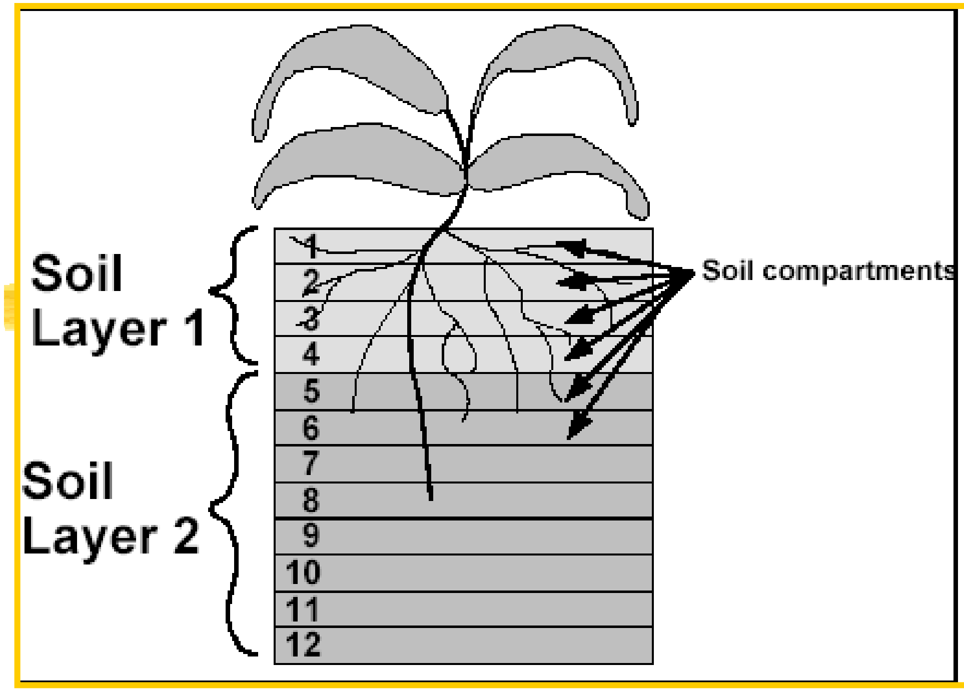
Water extraction pattern throughout the root zone



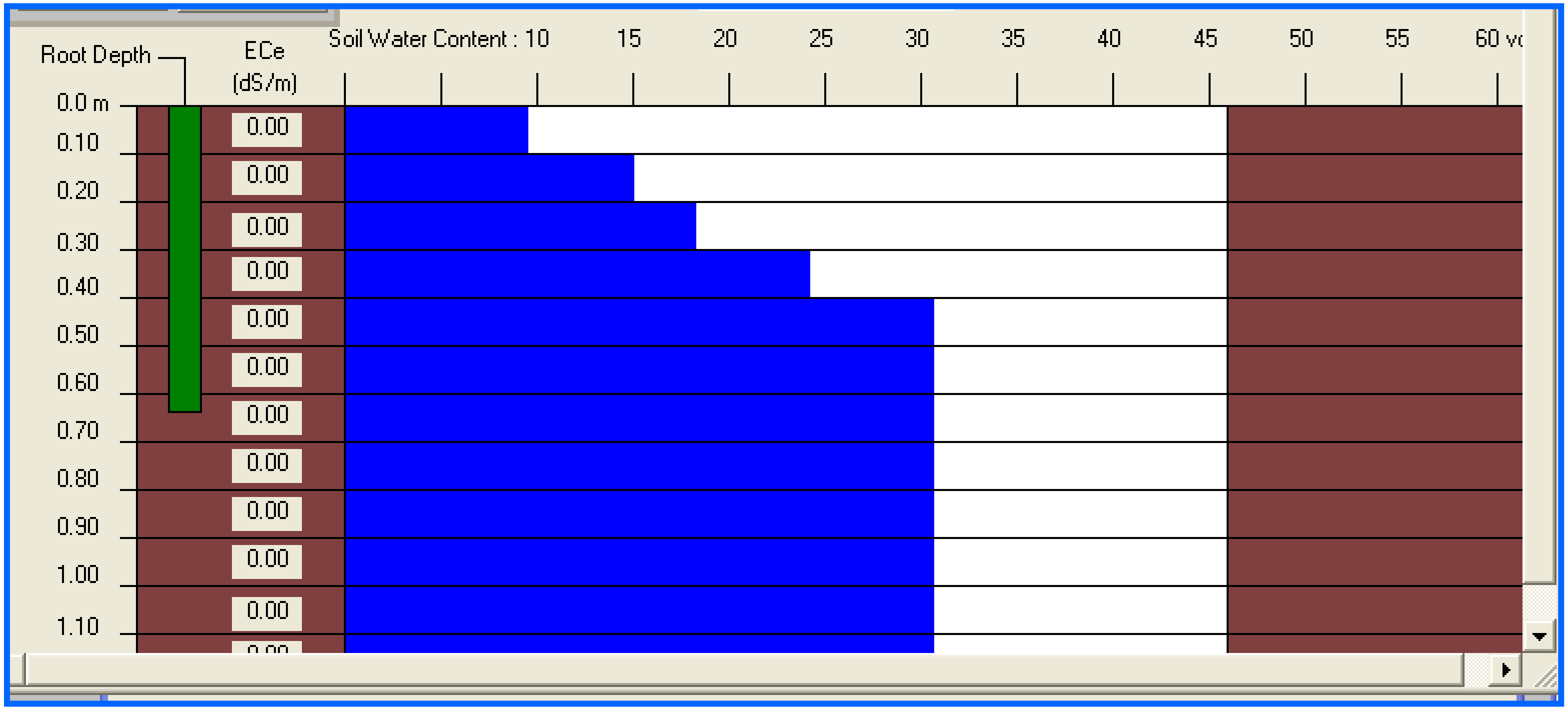


Typical water extraction pattern

Soil layers and soil compartments



Soil water content



Source: Raes, 2002

Soil Water Balance
and Irrigation scheduling considerations

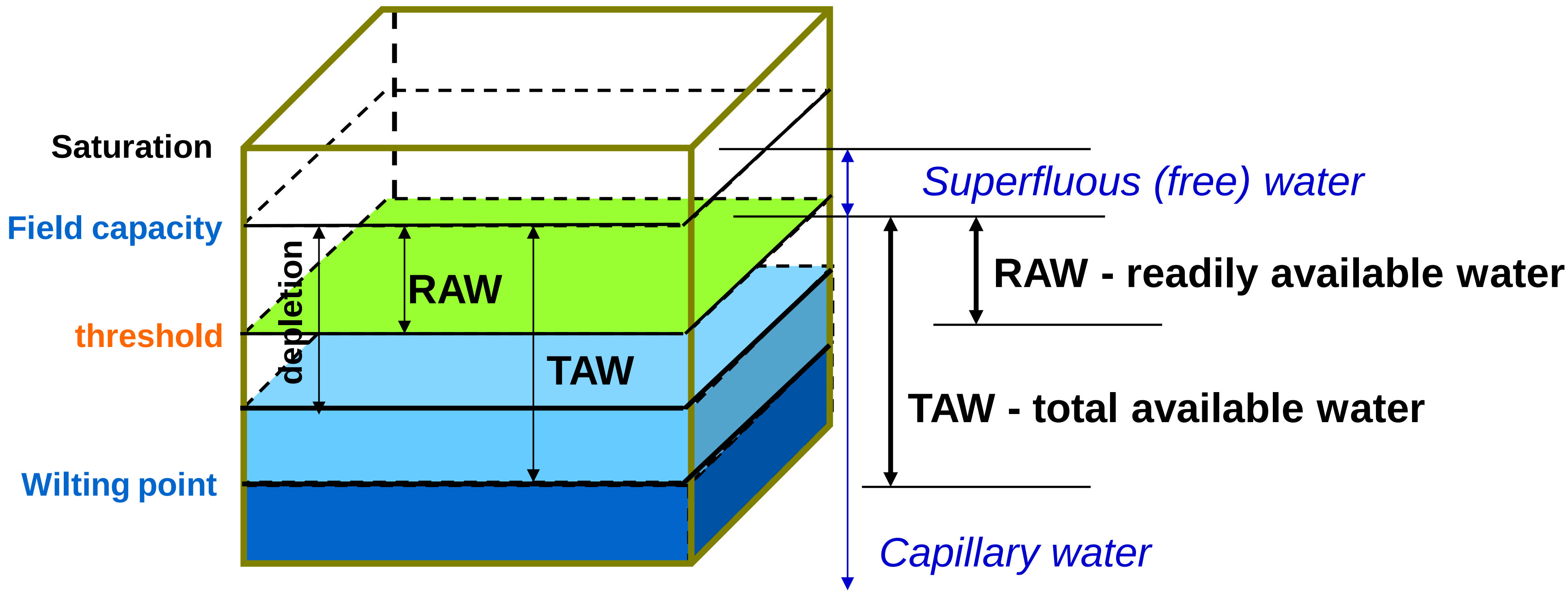
Knowing the soil water content (depletion) in the root zone we are able to decide the amount of water to supply. However, there are many other parameters to take into consideration...

Field application efficiency of irrigation methods

Irrigation method	APPLICATION PRACTICES	Field application efficiency in %		Average deep percolation as fraction of irrigation water applied to the field	
		Soil texture		Soil texture	
		fine	coarse	fine	Coarse
Sprinkler	*Daytime application, moderately strong wind*	60	60	0.3	0.3
	Nighttime application	70	70	0.25	0.25
Trickle		80-85	80-85	0.10-0.15	0.10-0.15
Basin	*Poorly leveled and shaped*	60	45	0.30	0.40
	Well leveled and shaped	75	60	0.20	0.30
Furrow	*Poorly graded and sized*	55	40	0.30	0.40
Border	*Well graded and sized*	65	50	0.25	0.35

Source: FAO 38, 1980

Soil Water Retention



Irrigation Scheduling Management Terms

- TAW - total available water
  - water stored in the root zone between the field capacity and wilting point:

$$TAW=1000*(\theta_{FC}- \theta_{WP})*Rz$$

where TAW is in *mm* , θ_{FC} and θ_{WP} are given in $m^3\ m^{-3}$, and the effective root depth Rz in *m*

- RAW - readily available depletion
  - a fraction (p) of TAW that can be extracted by crops without suffering water stress:

$$RAW=p*TAW$$

Root depth concept in irrigation scheduling

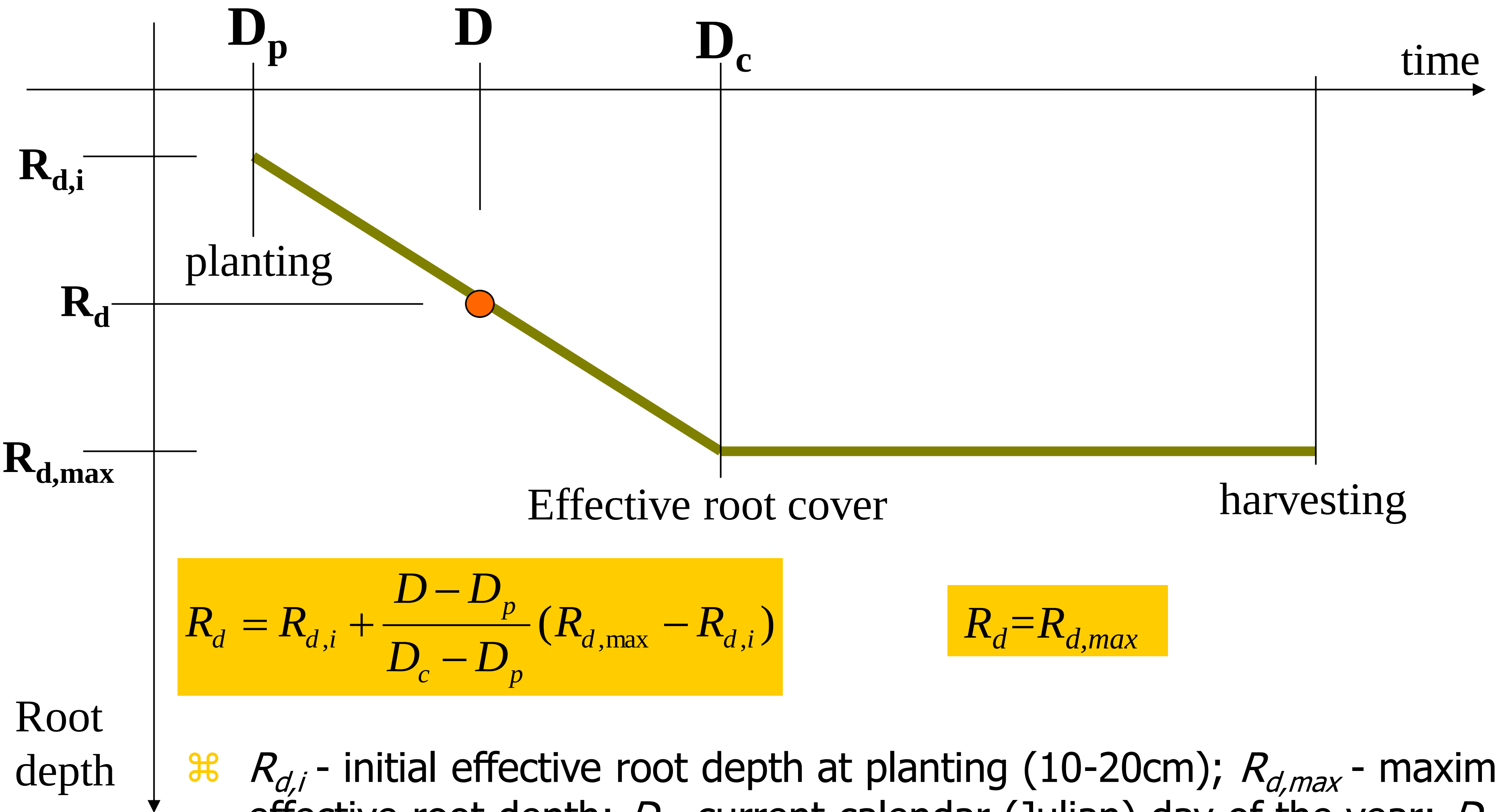
- Root depth is affected by:
  - soil texture, soil water management, and plant nutrient and oxygen availability
- Effective root depth
  - used in irrigation scheduling for estimates of TAW and RAW
  - assumed to be less than maximum since 80-90% of plant's feed roots are contained in the upper 60-75% of the root zone

$$R_z = R_{z,i} + \frac{D - D_p}{D_c - D_p}(R_{z,\max} - R_{z,i}) \qquad D<D_c$$

$$R_z=R_{z,max} \qquad D=D_c \text{ or } D>D_c$$

- $R_{z,i}$ - initial effective root depth at planting (4-10cm); $R_{z,max}$ - maximum effective root depth; D - current calendar (Julian) day of the year; D_p - planting day; D_c - day of effective root cover

Management (Effective) Root Depth (R_d)



$$R_d = R_{d,i} + \frac{D - D_p}{D_c - D_p}(R_{d,\max} - R_{d,i})$$

$$R_d = R_{d,max}$$

- $R_{d,i}$ - initial effective root depth at planting (10-20cm); $R_{d,max}$ - maximum effective root depth; D - current calendar (Julian) day of the year; D_p - planting day; D_c - day of effective root cover

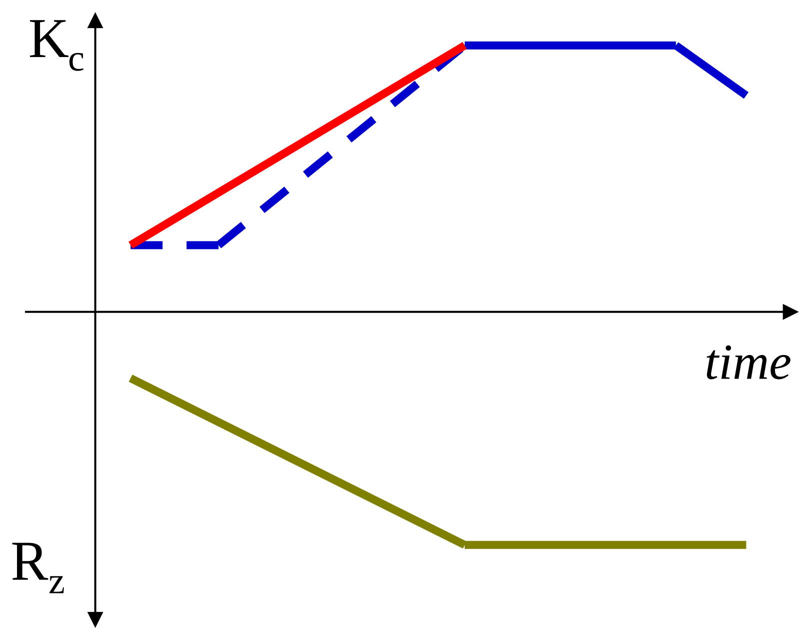
Management (Effective) Root Depth Calculation

- <u>Using the Kc values</u>

$$R_d = R_{d,i} + R_f \left(R_{d,\max} - R_{d,i}\right)$$

- where R_f is the root factor $0 \leq R_f \leq 1$

$$R_f = \frac{K_c - K_{c,ger}}{K_{c,max} - K_{c,ger}}$$



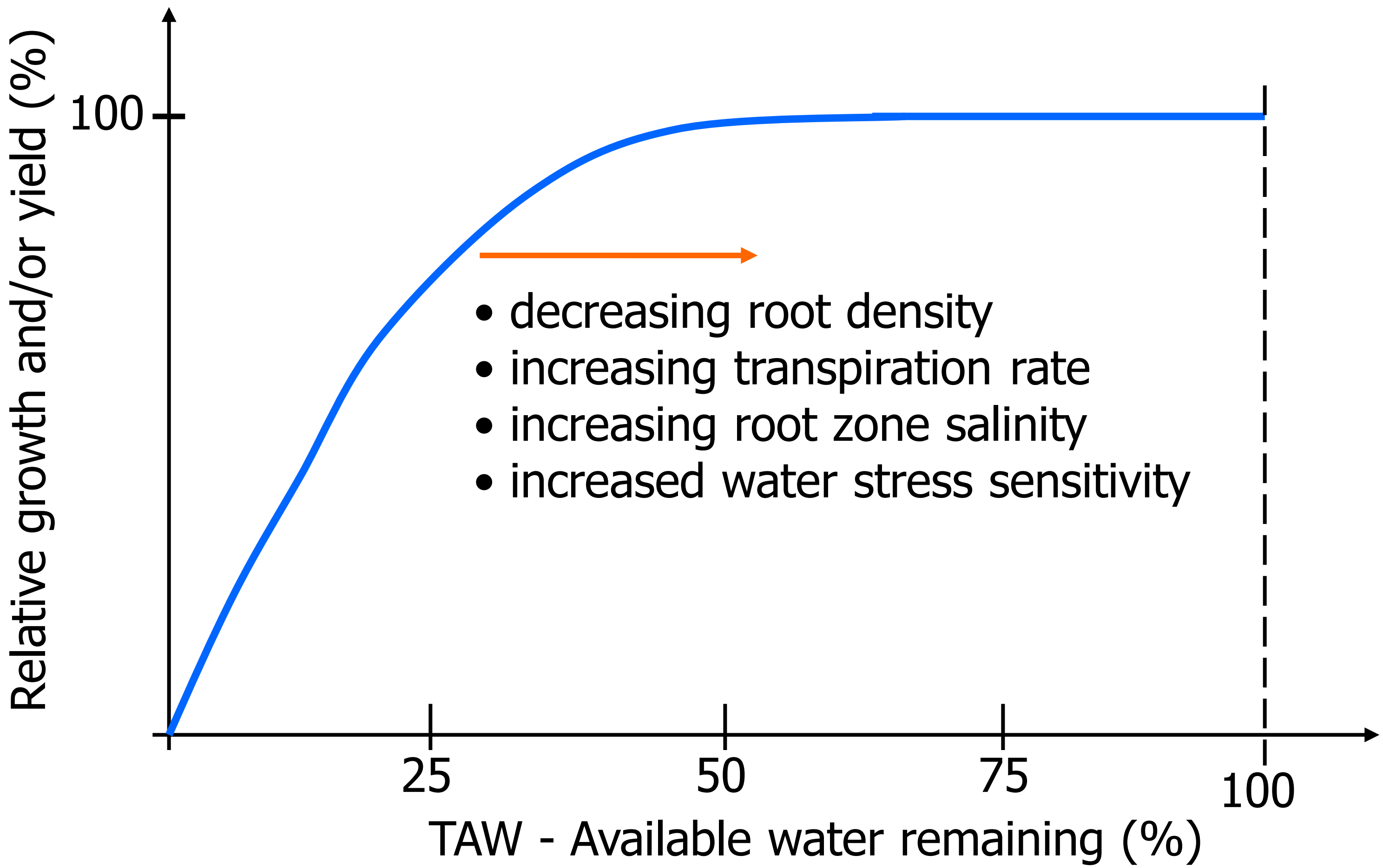
- Kc - crop coefficient for the growing stage under consideration
- Kc,max - maximum crop coefficient
- Kc,ger - crop coefficient for the germination stage
- $R_{z,i}$ - initial effective root depth at planting 20 cm;

Readily allowable water depletion (RAW)

- The percentage of available soil water which can be depleted between irrigations without serious water stress
- Values of RAW (as percentage of TAW) are typically:
  - 25-40% for high-value, shallow or sparsely rooted crops
  - 50% for deep-rooted crops
  - 60-65% for low-value, deep-rooted crops
  - may decreased by 5-10% when ETo>6 mm/day
- FAO 33 recommended:
  - 50% of TAW as an average “safe” level
  - increase/decrease of 15% in when ETo<3mm/day or ETo>8mm/day

Range of root zone available water

that can be utilized before growth and/or yield is reduced



Allowable root zone water depletion

for various crops according to sensitivity to water stress

Crop groups	Maximum evapotranspiration rate ET_m [mm/day]								
	2	3	4	5	6	7	8	9	10
1	0.50	0.43	0.35	0.30	0.25	0.23	0.20	0.20	0.18
2	0.68	0.58	0.48	0.40	0.35	0.33	0.28	0.25	0.23
3	0.80	0.70	0.60	0.50	0.45	0.43	0.38	0.35	0.30
4	0.88	0.80	0.70	0.60	0.55	0.50	0.45	0.43	0.40

Group	Crops
1	Onion, pepper, potato
2	Banana, cabbage, pea, tomato
3	Alfalfa, bean, citrus, groundnut, pineapple, sunflower, watermelon, wheat
4	Cotton, sorghum, olive, grape, safflower, maize, soybean, sugarbeet, tobacco

Source: FAO 33, 1986

Management allowable depletion (MAD)

- The percentage of available soil water which can be depleted between irrigations
- MAD should be less than or equal to RAW except when deficit irrigation is applied
- MAD may change during the season
  - to account for sensitivity to water stress during critical developmental periods and for changes in rooting depth and evaporative demand
  - Some crops require greater soil-water depletion directly before harvest to enhance the quality of fruit or grain
- MAD may depend also on irrigation method, water delivery...
  - it is lower for drip than for sprinkler irrigation method

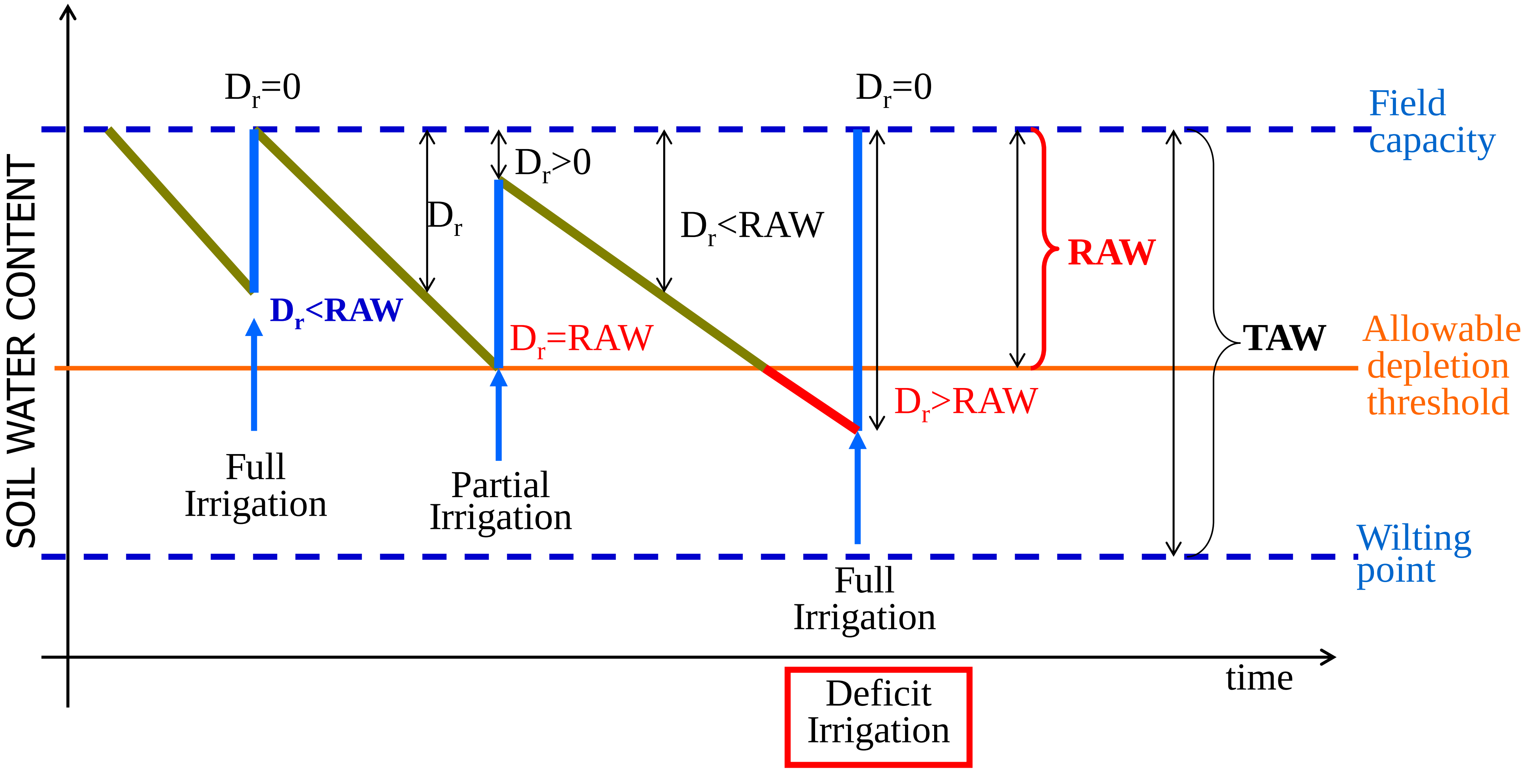
Timing Irrigation Criteria

- Allowable depletion of TAW (fraction)
  - irrigation is applied whenever Dr drops below a predetermined fraction of TAW
- Allowable depletion of RAW (fraction)
  - irrigation is applied whenever Dr drops below a predetermined fraction of RAW
- Allowable daily stress
  - irrigation is applied whenever the actual ET rate drops below a predetermined fraction of potential ET rate
- Allowable depletion amount
  - irrigation is applied whenever a predetermined amount of water below field capacity is depleted
  - particularly useful in the case of high frequency irrigation systems (drip)
- Fixed/variable calendar
  - irrigation is applied 4 days, every week, etc. depending on growing stage

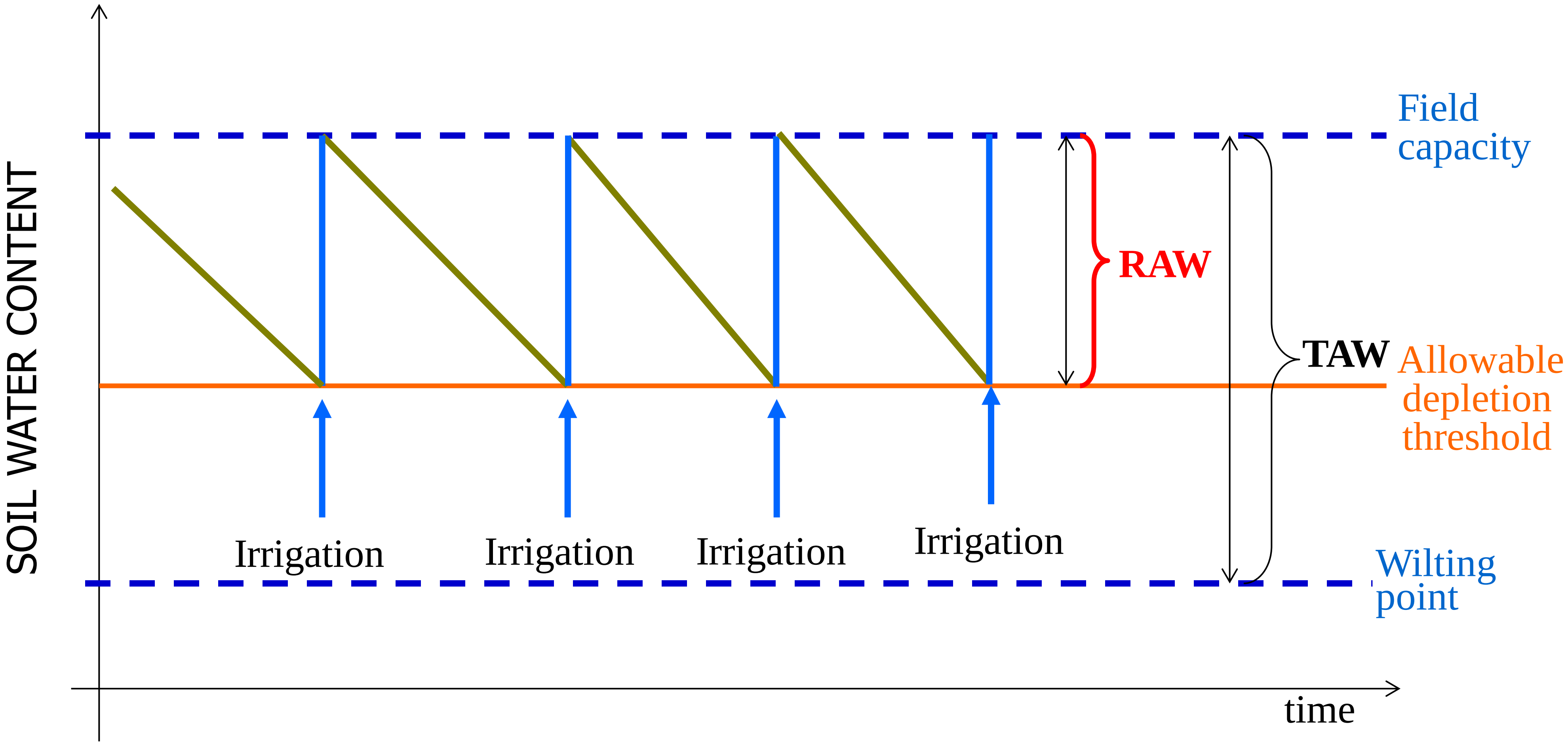
Depth Irrigation Criteria

- Back to field capacity (+/-)
  - the soil water content in the root zone is brought back to field capacity plus or minus a specified depth for salt leaching purposes or rainfall allowance respectively.
- Fixed depth
  - a predetermined amount of water is applied (adapted to specific irrigation method)
  - for high frequency irrigation there is no water stress risk but there is water excess risk (aeration problems)

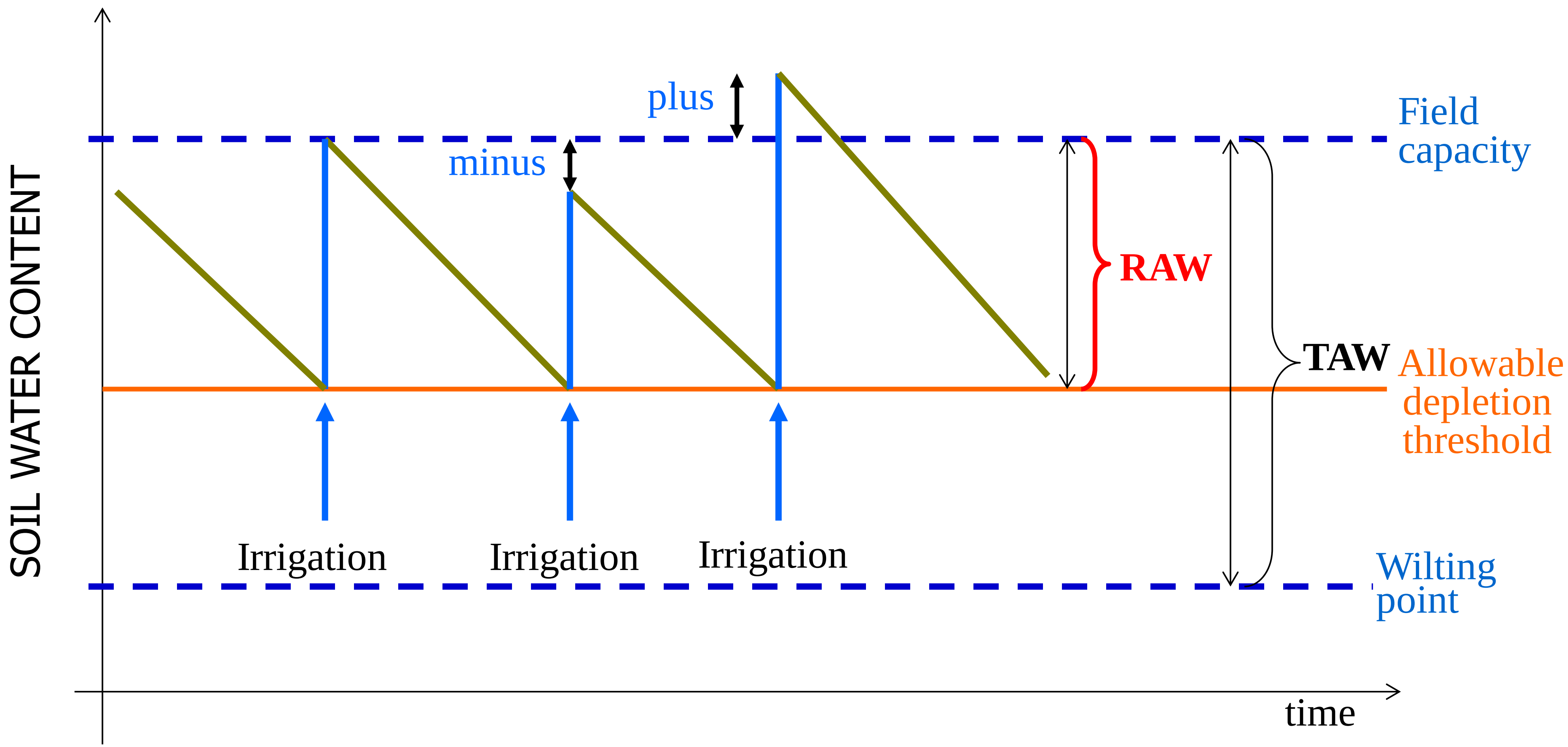
Root zone water depletion (Dr) and irrigation water supply strategies



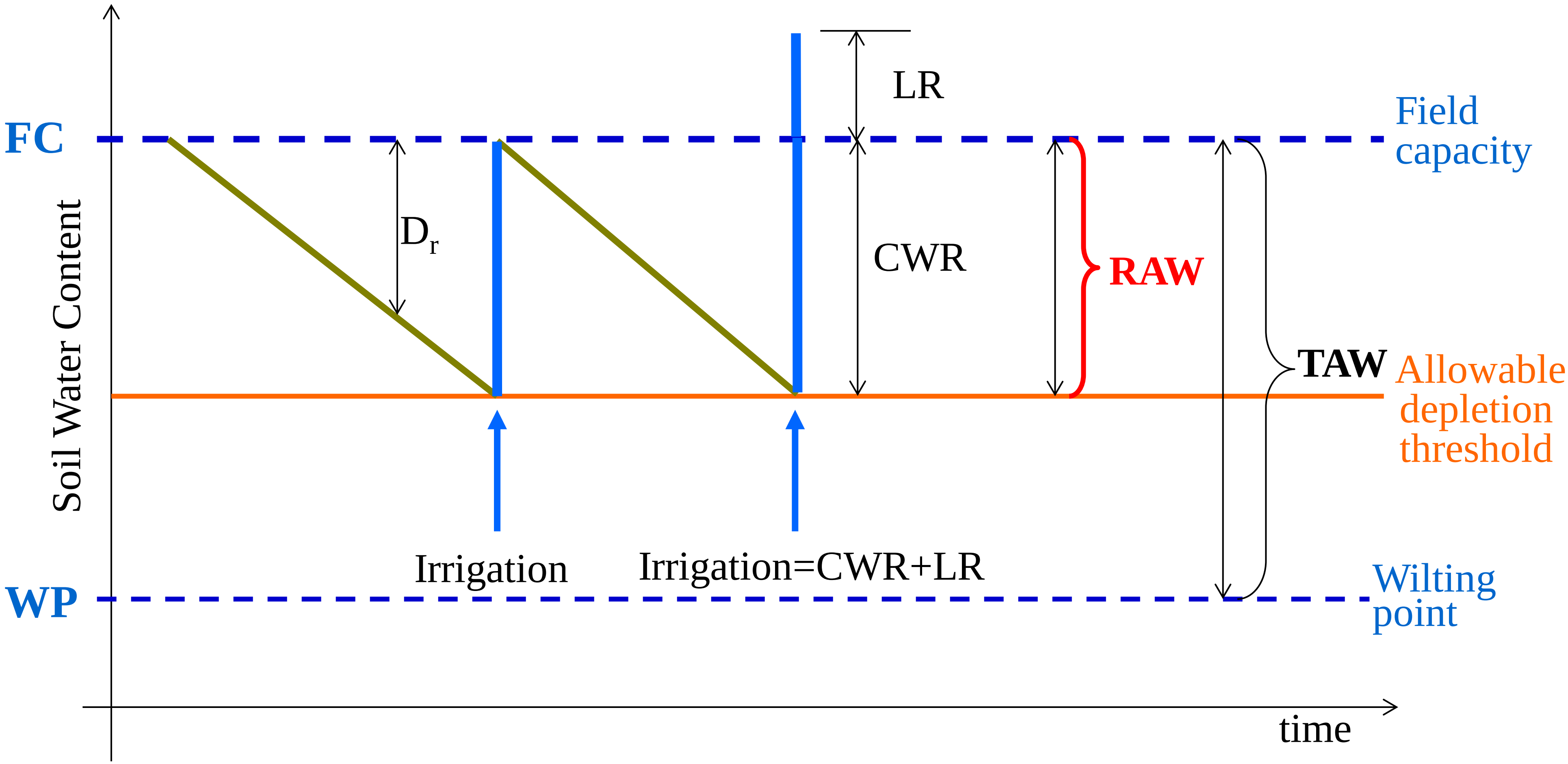
Fixed depth irrigation



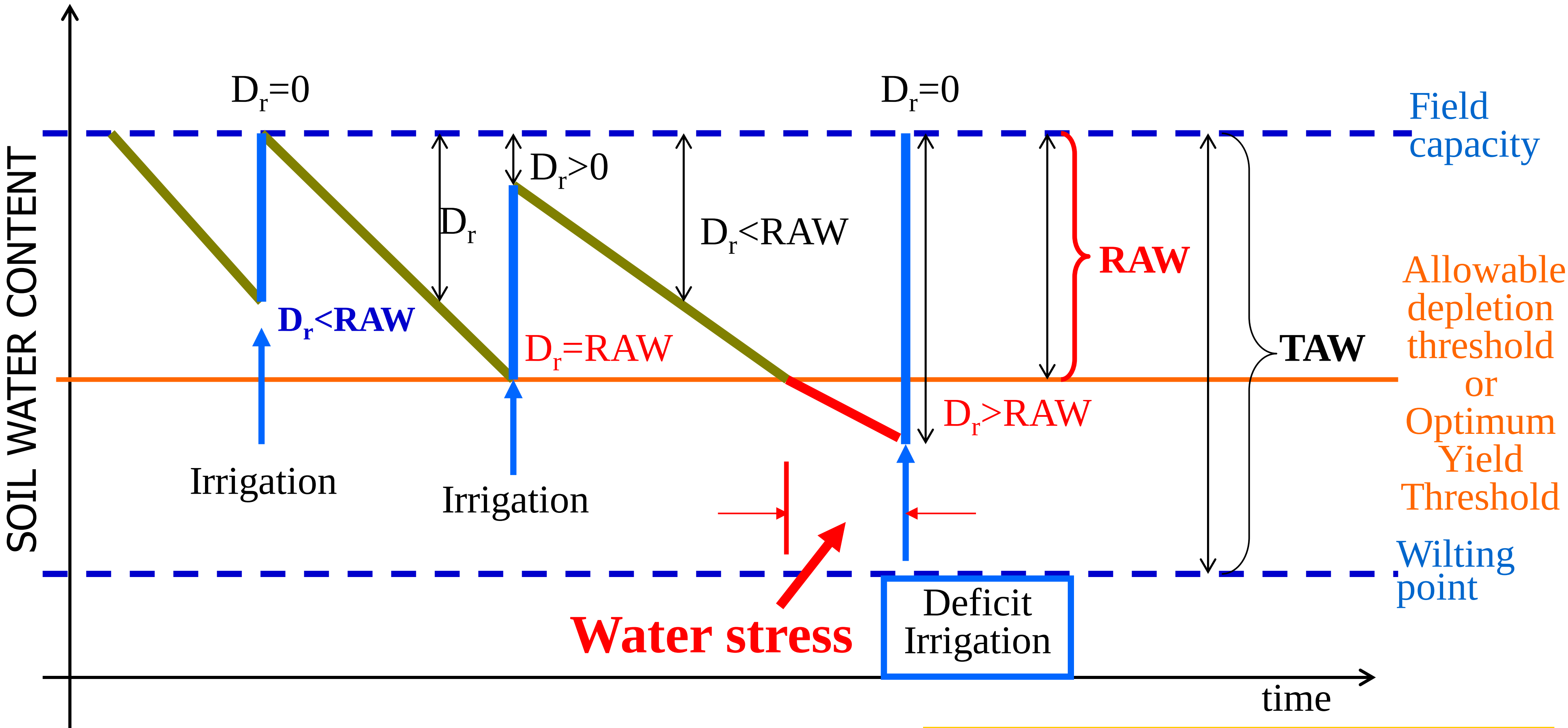
Back to field capacity (+/-) irrigation



Irrigation with leaching



Root zone water depletion (Dr) and irrigation water supply strategies

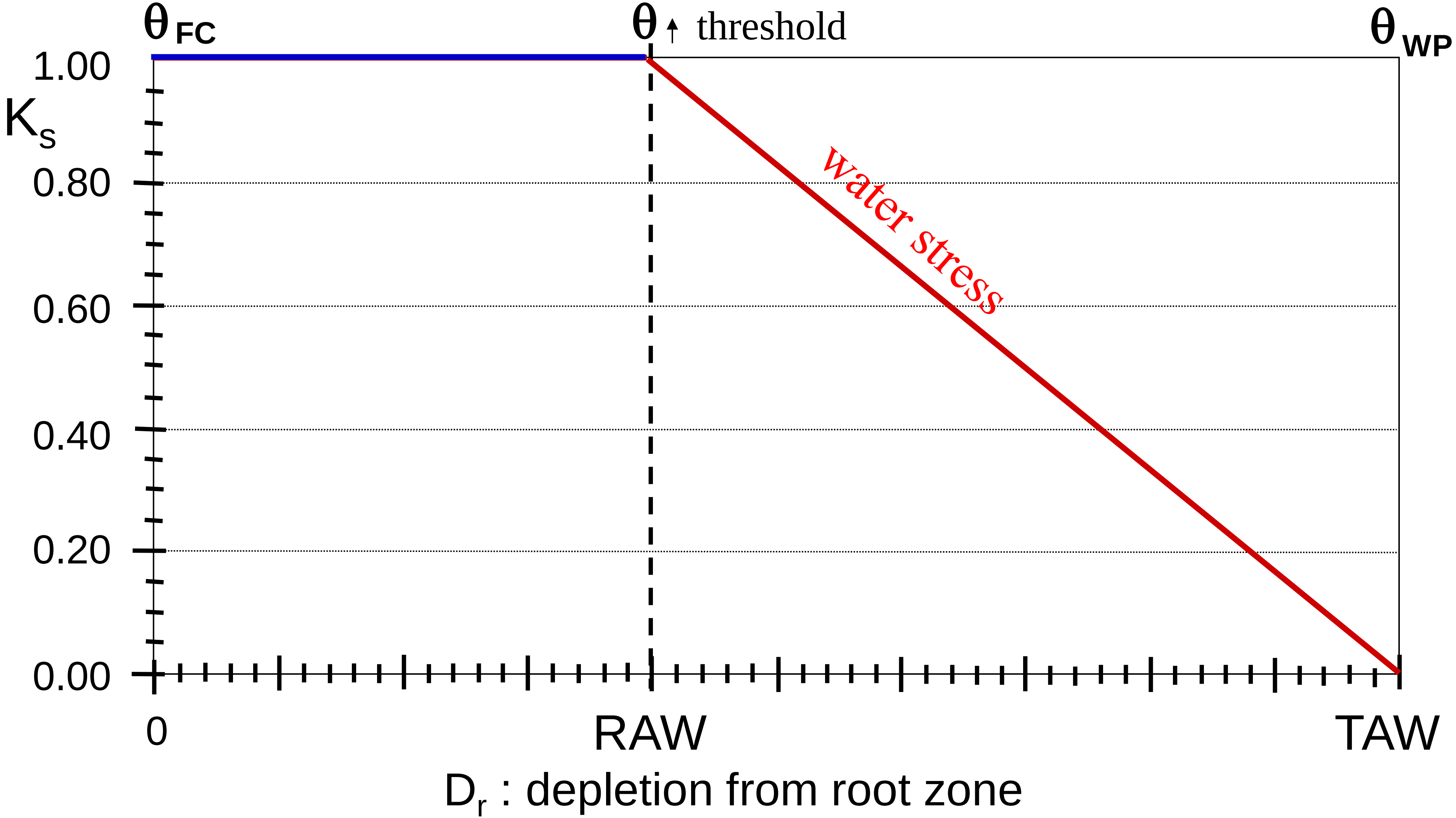


Ks – reduction coefficient for ETc :

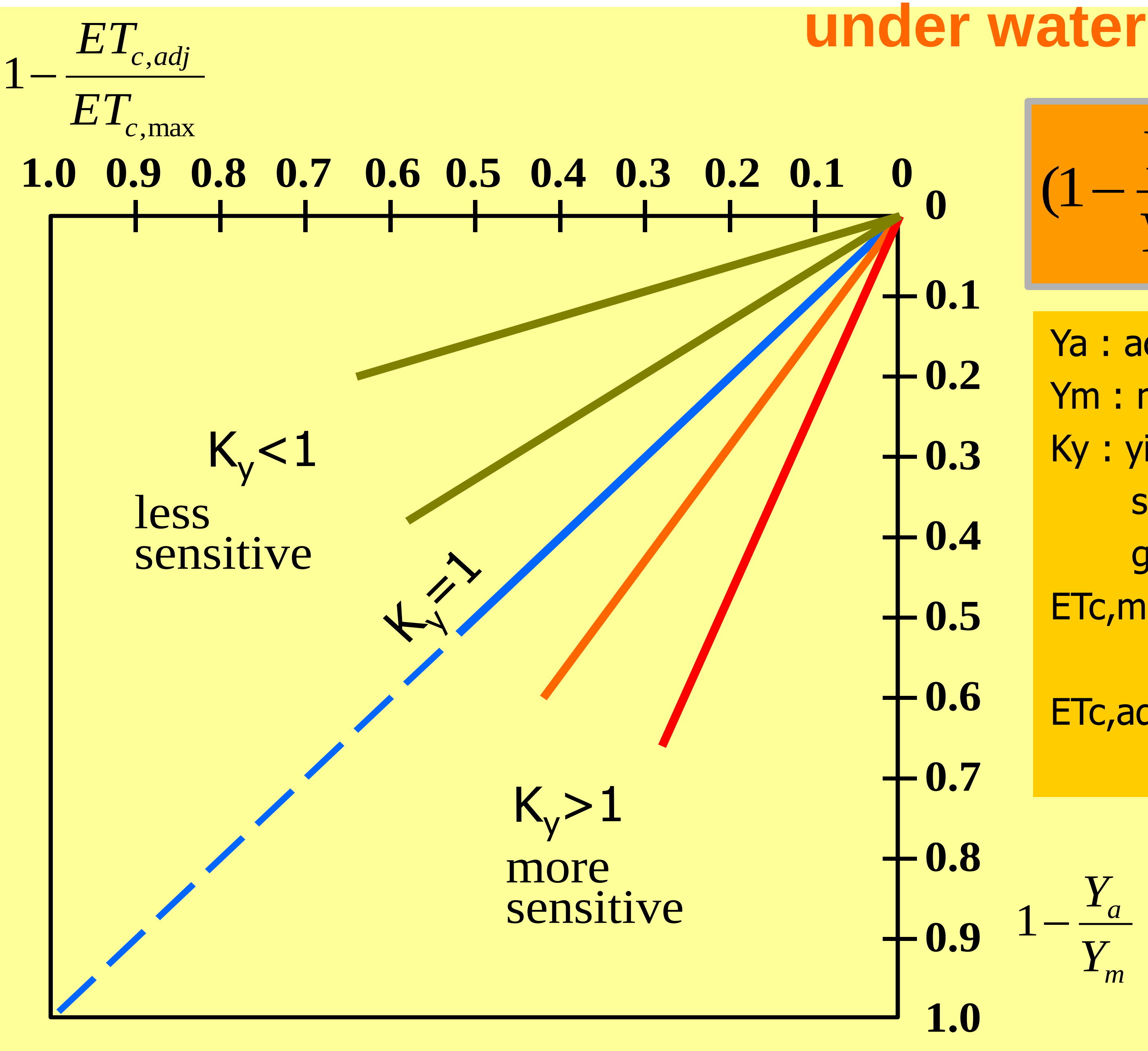
$$K_s = \frac{TAW - D_r}{TAW - RAW} = \frac{TAW - D_r}{(1-p)TAW}$$

ETc adjusted for water stress :

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



Relative yield estimation for the whole growing season under water stress conditions



$$\left(1-\frac{Y_a}{Y_m}\right) = K_y\left(1-\frac{ET_{c,adj}}{ET_{c,\max}}\right)$$

Ya : actual yield;

Ym : maximum expected yield;

Ky : yield response factor (crop specific and varies during the growing season);

ETc,max : ETc for optimal water supply

ETc,adj : actual crop ET adjusted for water stress

Source: Stewart et al., 1977

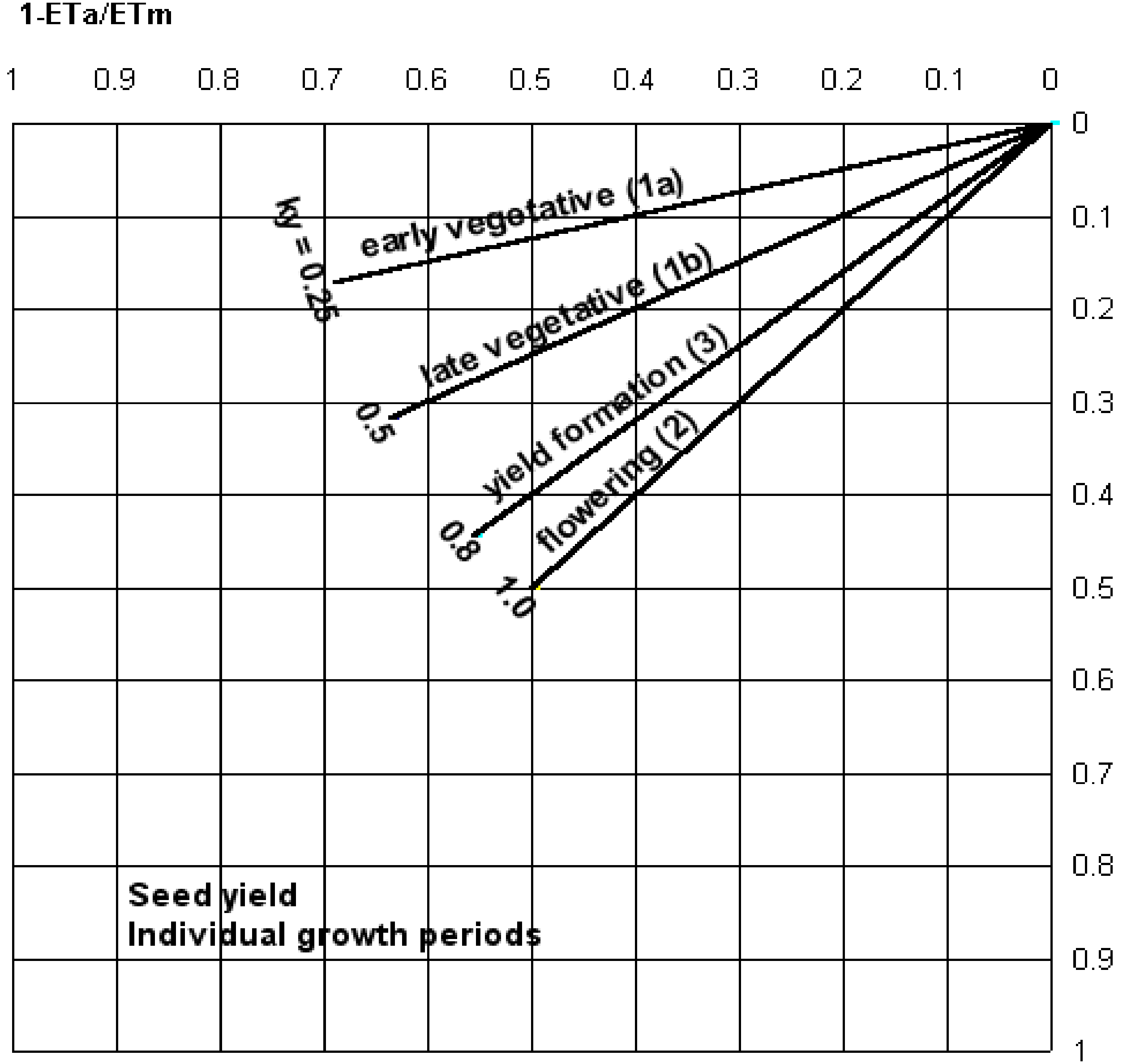
Ky (yield response factor to water stress) values for some crops

Crop	K_y
Alfalfa	1.1
Beans	1.2-1.35
Cabbage	0.95
Citrus	1.1-1.3
Cotton	0.85
Grape	0.85
Maize	1.25
Onion	1.1
Peas	1.15
Pepper	1.1

Crop	K_y
Potato	1.1
Sorghum	0.9
Soybean	0.85
Spring Wheat	1.15
Sugarbeet	1.0
Sugarcane	1.2
Sunflower	0.95
Tomato	1.05
Watermelon	1.1
Winter Wheat	1.05

Source: FAO, 1998

Relative yield estimation for individual growth periods : a multiplicative approach

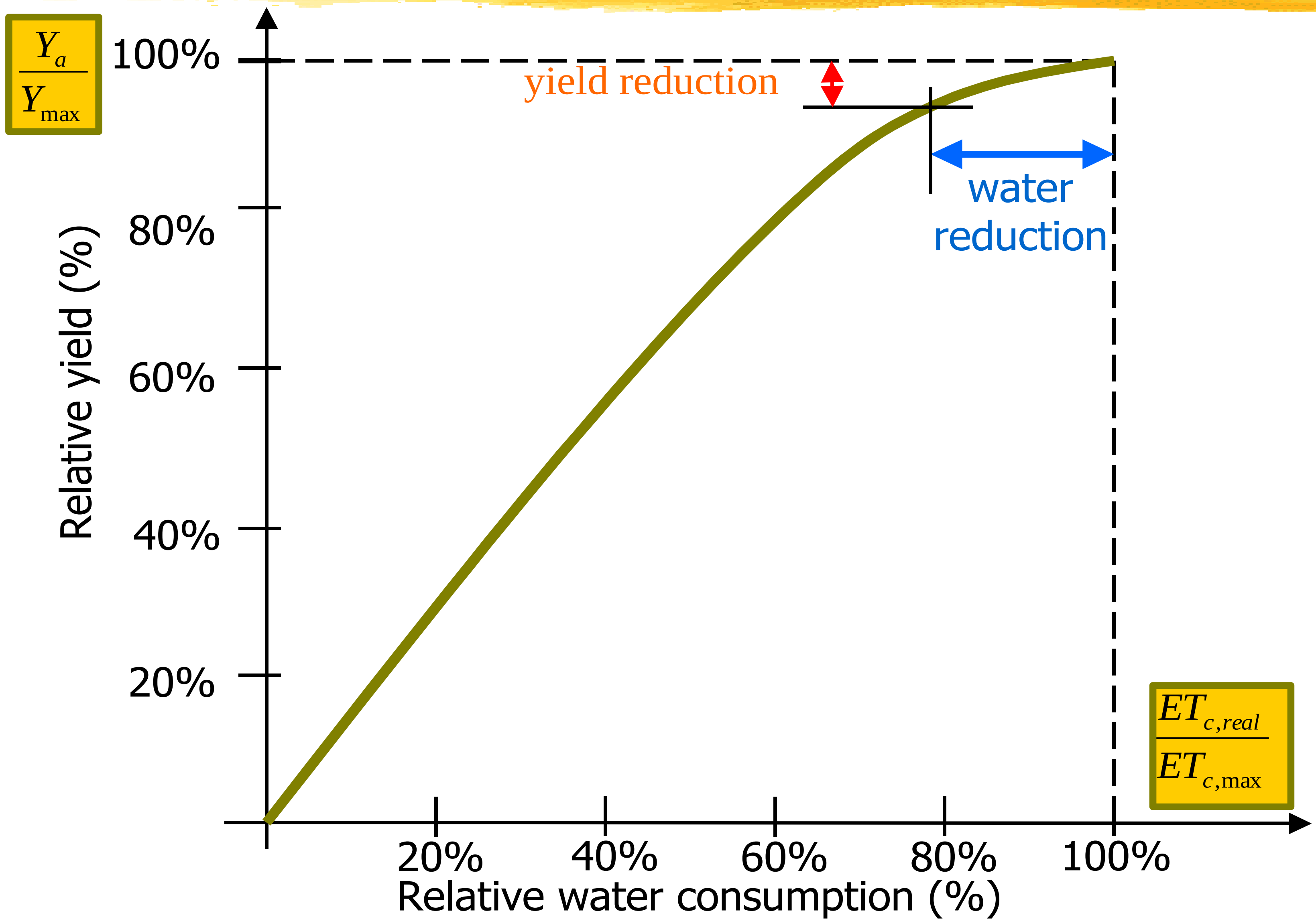


Multiplicative approach for N growing (sensitivity) stages:

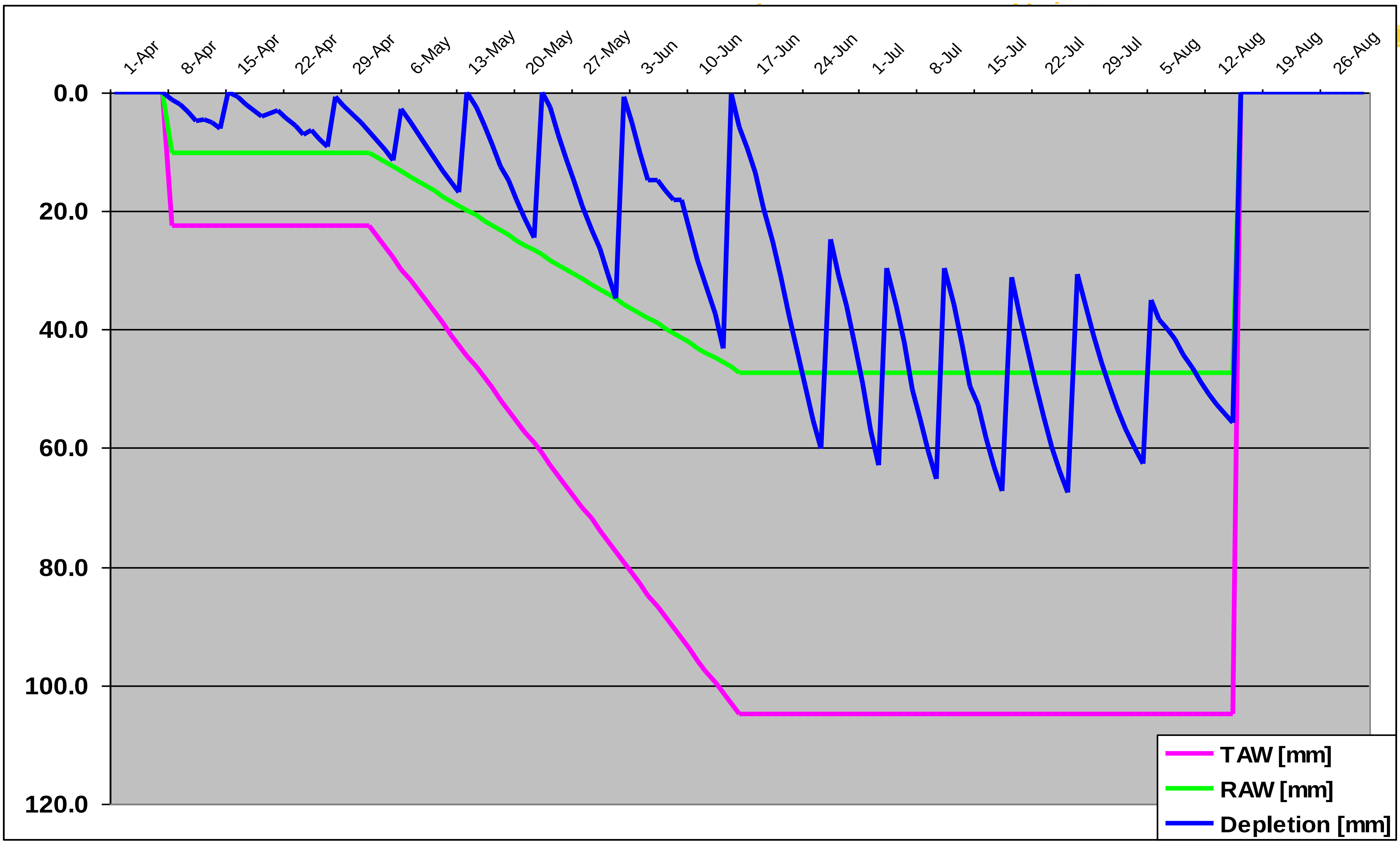
$$\frac{Y_a}{Y_m} = \prod_{i=1}^{N} \left[1 - K_{y,i} \left(1 - \frac{ET_{c,adj,i}}{ET_{c,i}} \right) \right]$$

Source: FAO 33, 1979; Rao et al., 1988

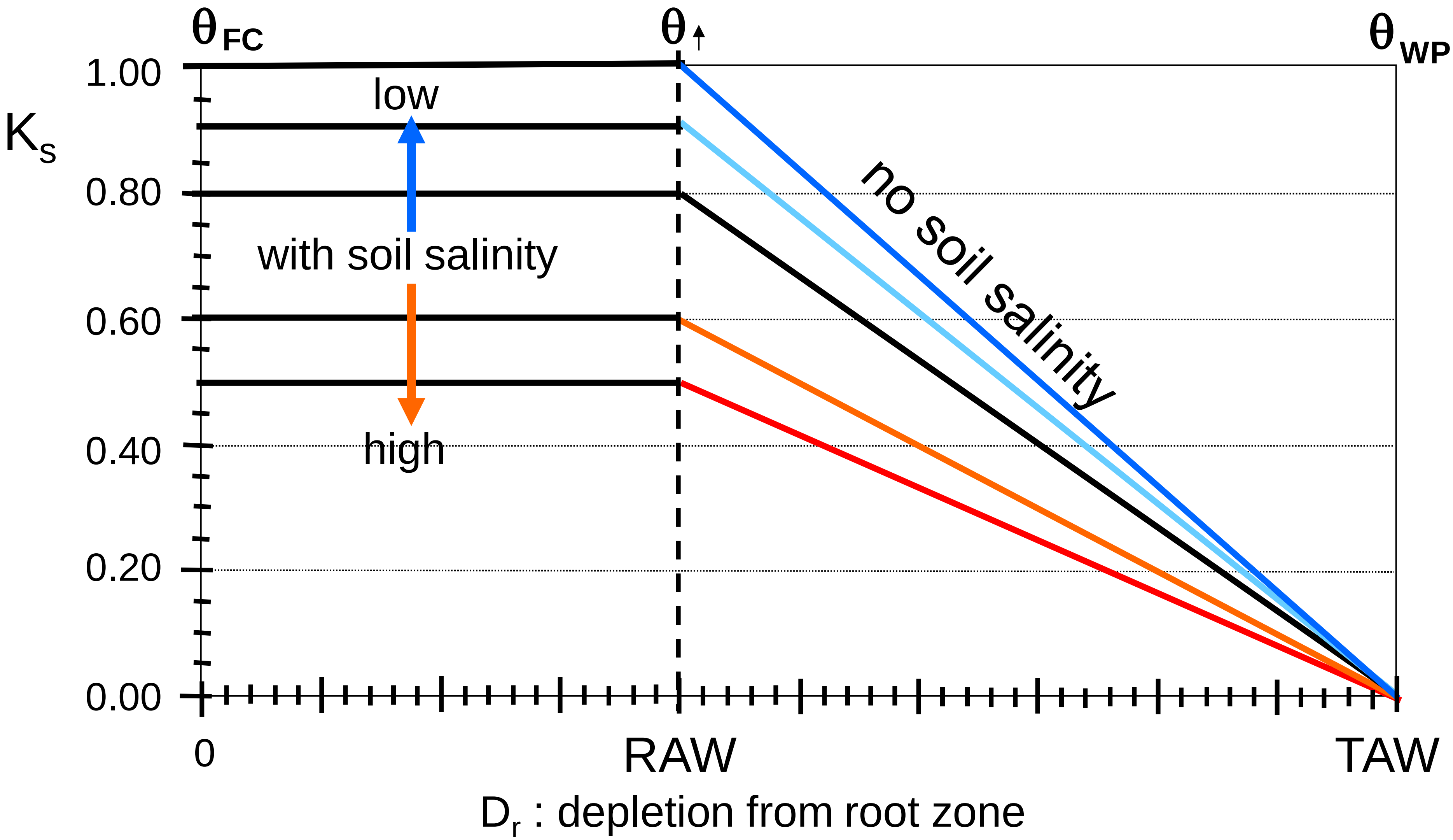
Deficit Irrigation Strategy:
minimizing Yield reduction while
maximizing ET reduction (water saving)



Example of RDI applied on a field crop during the phase tolerant to water stress



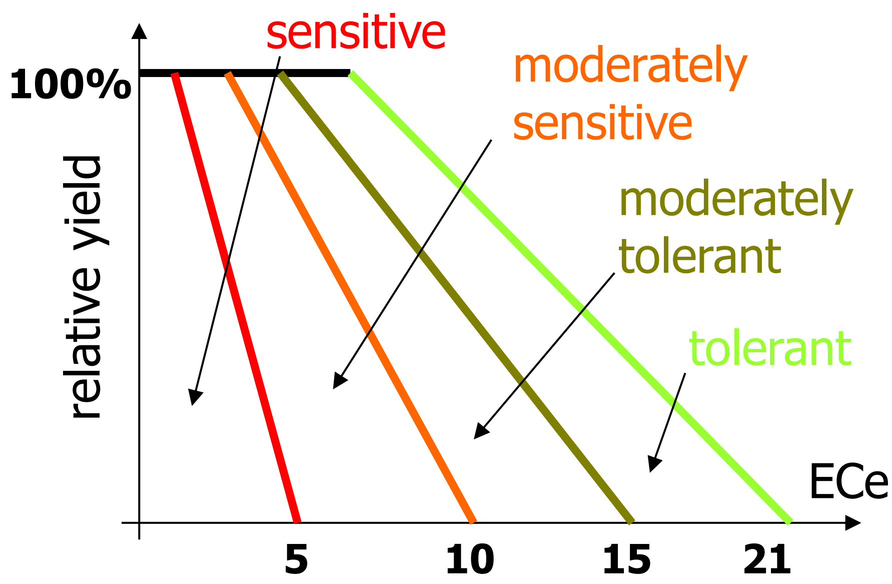
The effect of soil salinity on the Ks and reduction of ETc



Yield-salinity relationship and salinity-ET reduction relationship

- Assumption:
  - crop yield decreases linearly with salinity increase which may be expressed through ECe

$$\frac{Y_a}{Y_m} = 1 - (EC_e - EC_{e,thres})\frac{b}{100}$$



- Y_a - the actual crop yield,
- Y_m - the maximum crop yield expected when there is no salt stress,
- EC_e is the mean electrical conductivity of the saturation extract for the root zone,
- $EC_{e,thres}$ - the threshold value of EC_e when yield reduction occurs;
- b is the is the factor of yield reduction (slope of the curve) in respect to increase of EC_e (%/dS m^{-1})

Salinity stress without water stress

- $EC_e > EC_{e,threshold}$ and Dr<RAW
- Salinity stress

$$\frac{Y_a}{Y_m} = 1 - (EC_e - EC_{e,thres})\frac{b}{100}$$

↓

- The reduction of yield

$$(1 - \frac{Y_a}{Y_m}) = K_y(1 - \frac{ET_{c,adj}}{ET_{c,\max}})$$

$$K_s = \frac{ET_{c,adj}}{ET_{c,\max}}$$

↓

$$1 - 1 + (EC_e - EC_{e,thres})\frac{b}{100} = K_y(1 - K_s)$$

↓

- Reduction coefficient Ks

$$K_s = 1 - \frac{b}{K_y 100}(EC_e - EC_{e,thres})$$

Water and salinity stress

- Water stress Dr>RAW

$$K_s = \frac{TAW - D_r}{TAW - RAW} = \frac{TAW - D_r}{(1-p)TAW}$$

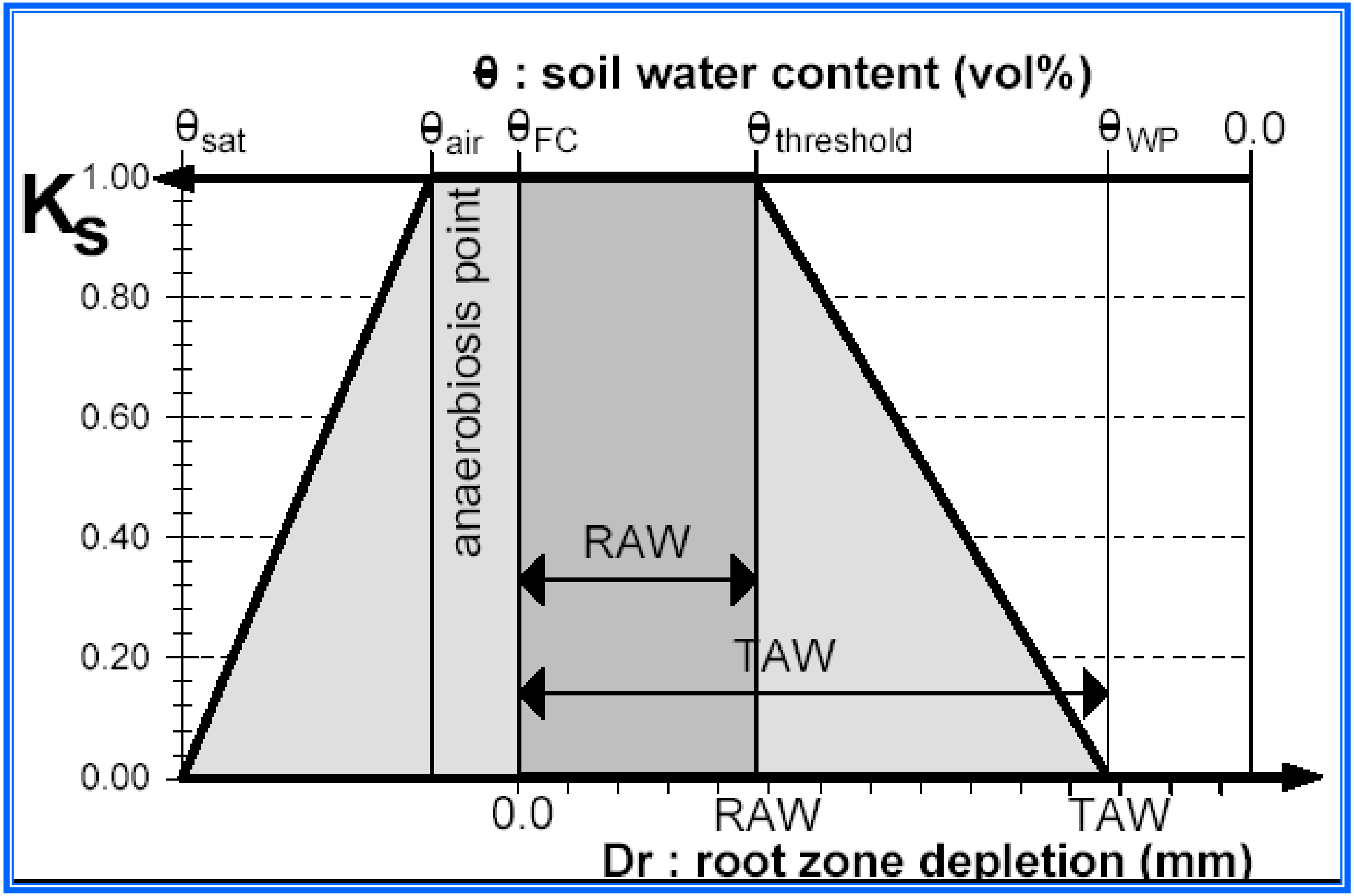
- Salinity stress $EC_e > EC_{e,threshold}$

$$K_s = 1 - \frac{b}{K_y 100}(EC_e - EC_{e,thres})$$

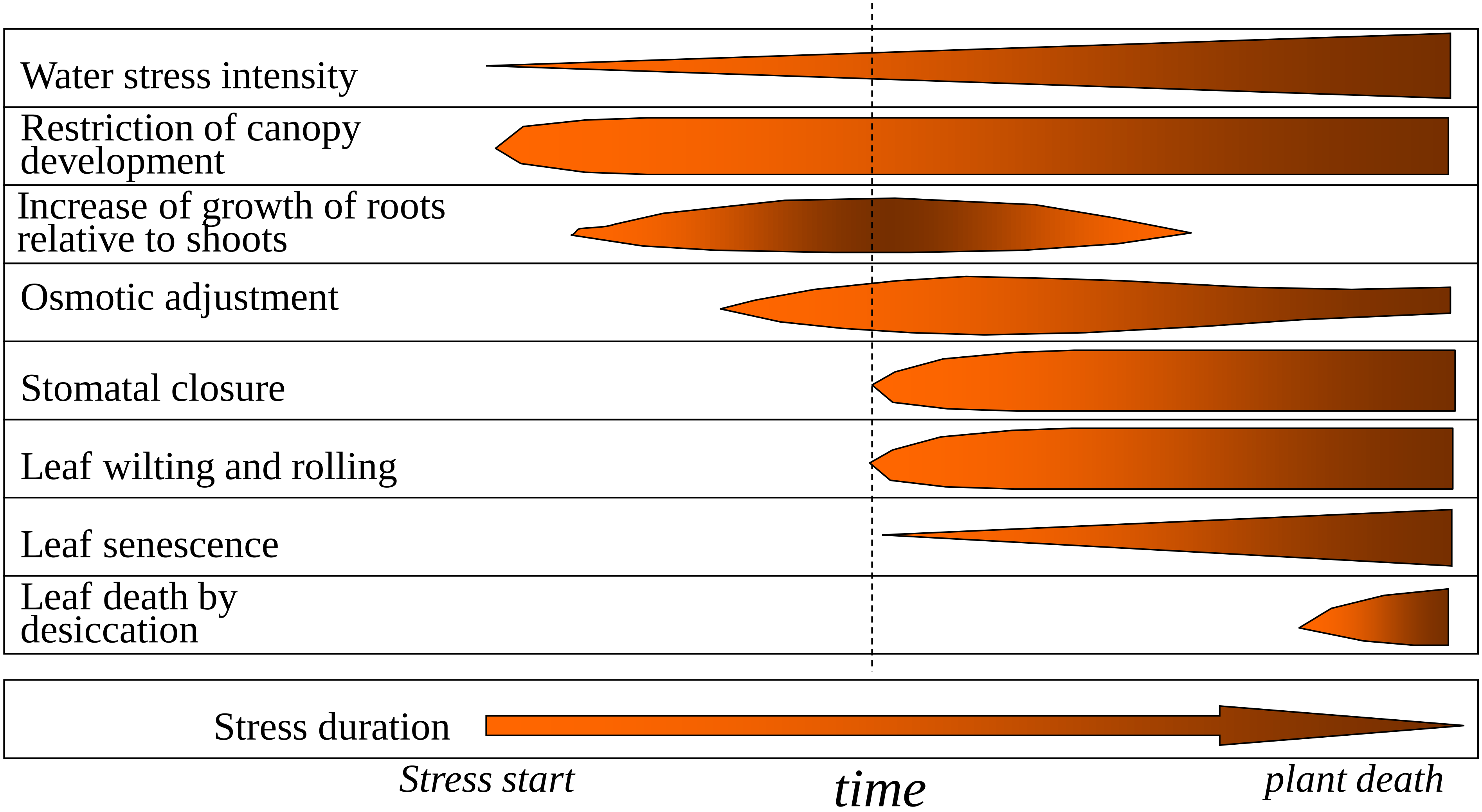
- Both, water (Dr>RAW) and salinity stress ($EC_e > EC_{e,threshold}$)

$$K_s = (1 - \frac{b}{K_y 100}(EC_e - EC_{e,thres}))\frac{TAW - D_r}{TAW - RAW}$$

Ks : Water stress and aeration stress
(accounting for excess of water in the root zone)

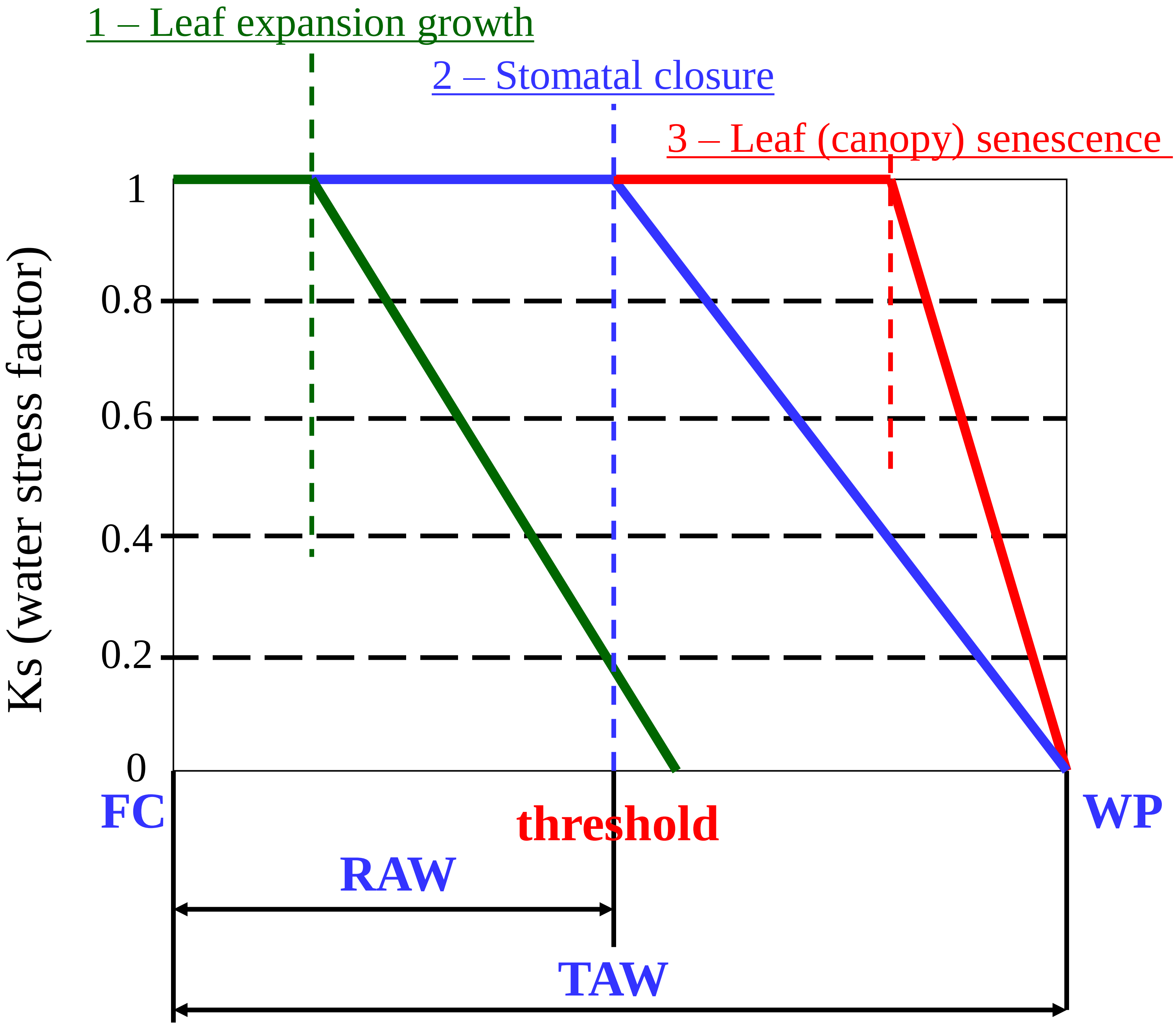


Response of key processes to gradual development of water stress in the field

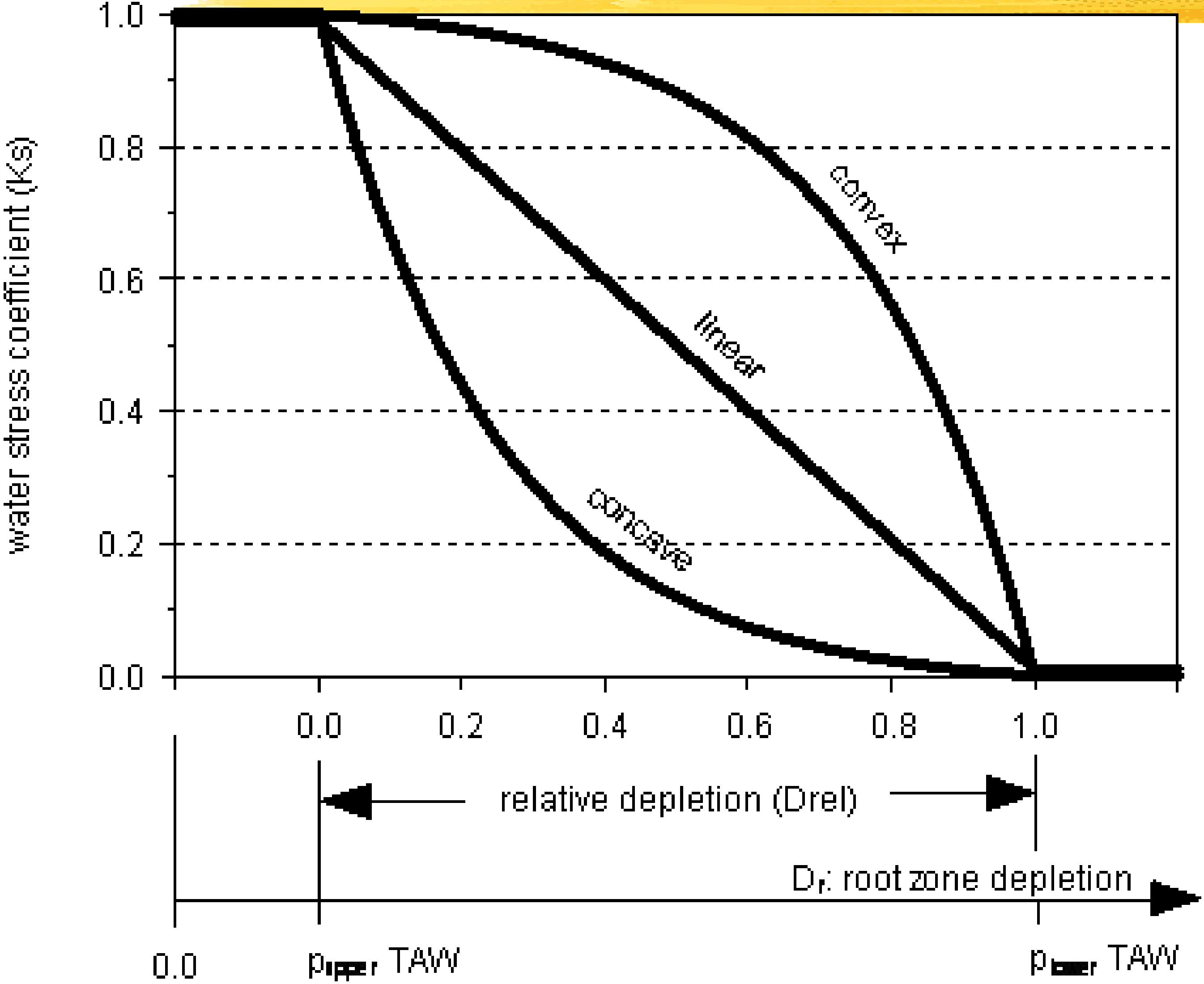


Source: adapted after Bradford and Hsiao, 1982

WATER STRESS THRESHOLDS – AquaCrop Approach



AquaCrop approach:
Convex, linear and concave shapes for the water stress coefficient

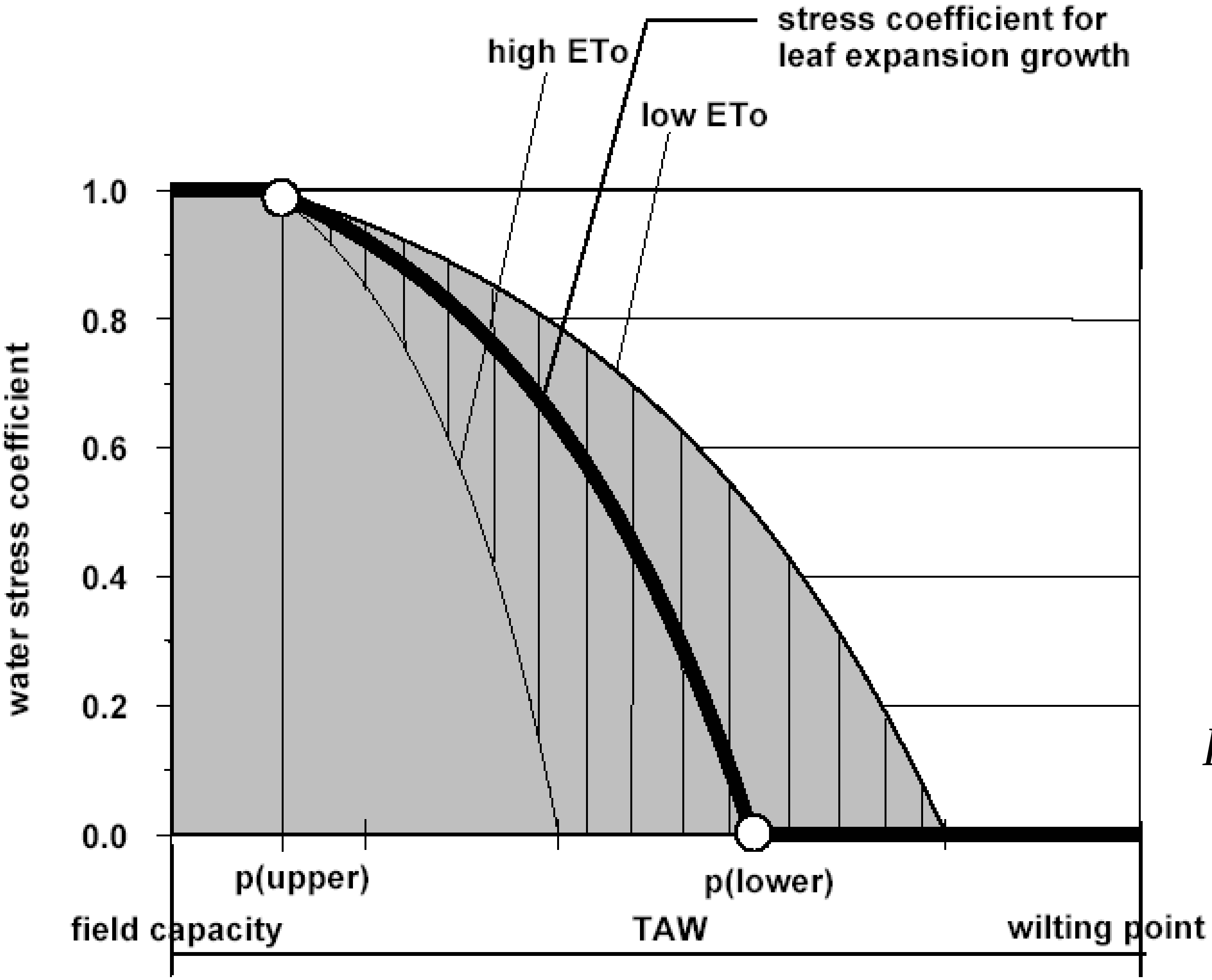


$$Ks = 1 - \frac{e^{Drel\ f_{shape}} - 1}{e^{f_{shape}} - 1}$$

If $f_{shape} < 0$ then Ks function is concave

If $f_{shape} > 0$ then Ks function is convex

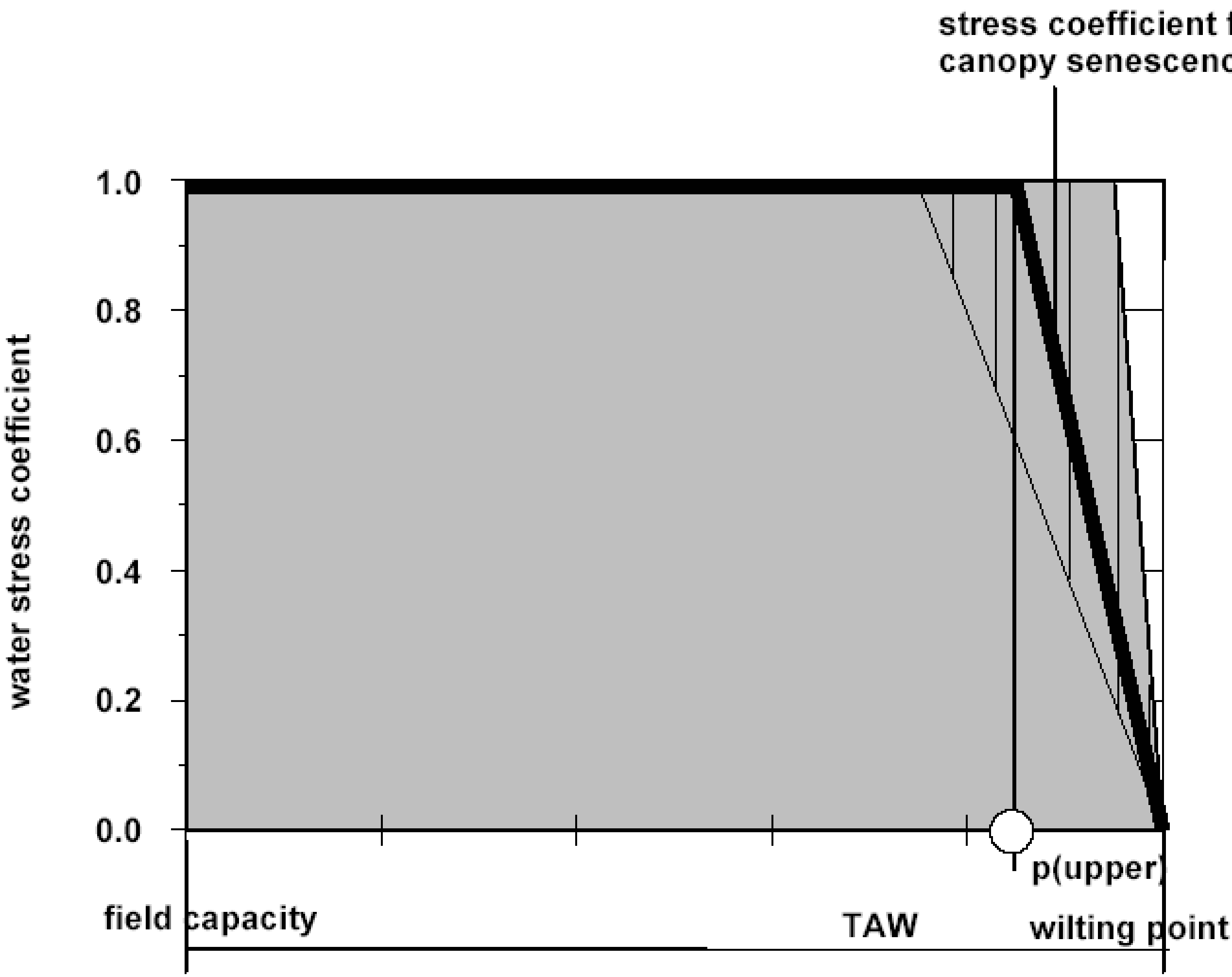
AQUACROP approach –
Water stress coefficient for leaf expansion growth



$$p_{adj} = p_{lower} + C_a \left[0.04 \left(5 - ET_{crop} \right) \right]$$

Ca – adjustment coefficient for ETcrop≠5mm/day

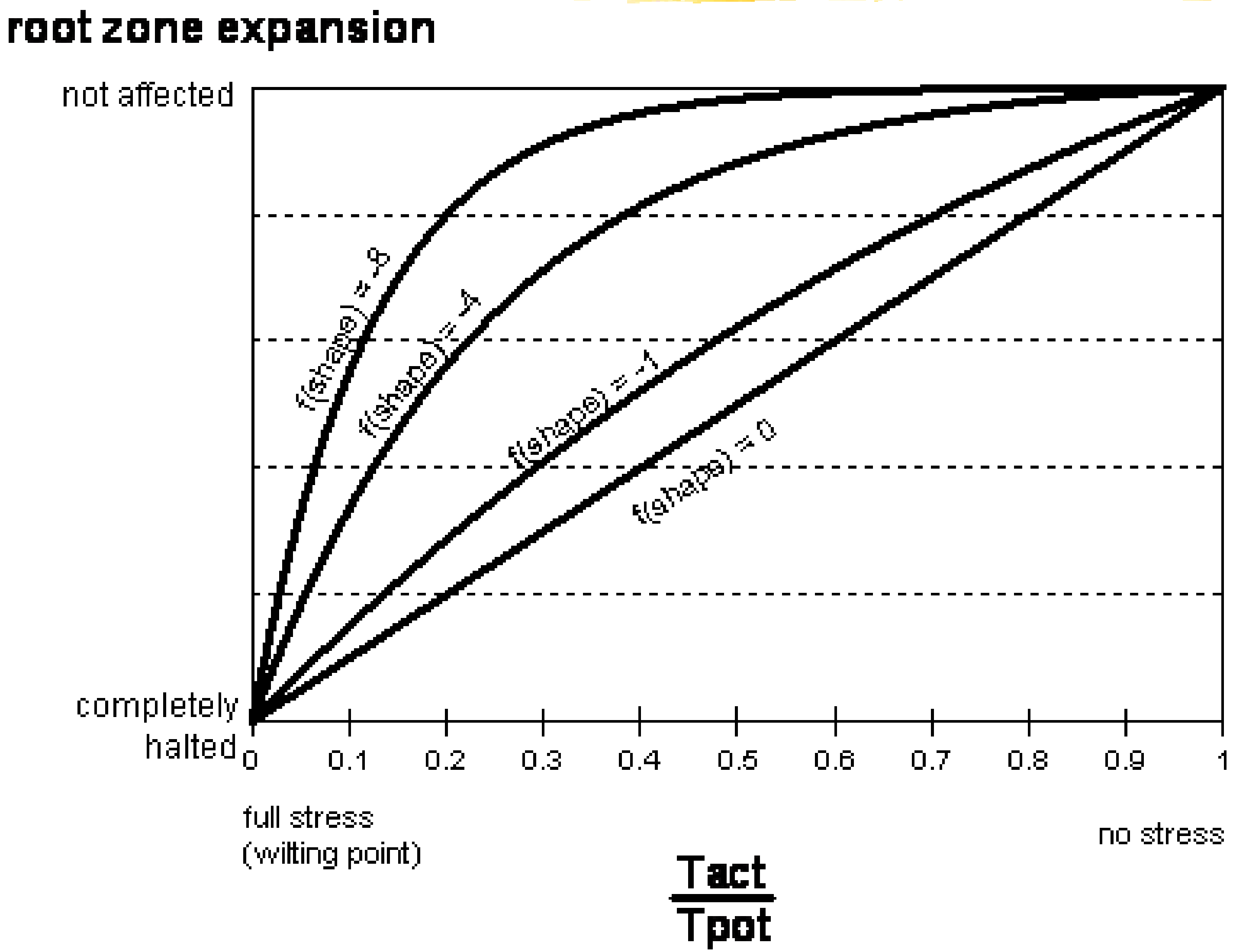
AQUACROP approach –
Water stress coefficient for canopy senescence



$$p_{adj} = p_{upper} + C_a \left[0.04\left(5 - ET_{crop}\right)\right]$$

Ca – adjustment coefficient
for ETcrop≠5mm/day

The effect of water stress on the reduction of **root zone expansion** for various shape factors fshape and relative crop transpiration (Tact/Tpot)



Instead of conclusions

- Certain:
  - measured climatic variables
  - measured average soil characteristics
  - quality of irrigation water
  - quantity of water applied and timing
  - irrigation method (and its performances)
  - some crop parameters (crop height, development stage, DAP, LAI, root depth…)
- Uncertain:
  - estimate of reference evapotranspiration and Kc values
  - estimate of crop water requirements
  - readily available water (total available water)
  - crop water uptake pattern
  - crop response function to deficit irrigation and/or excessive salt accumulation
  - spatial and temporal variability