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Joint ICTP-IAEA Conference on Coping with Climate Change and Variability in Agriculture through Minimizing Soil Evaporation Wastage and Enhancing More Crops per Drop

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AquaCrop, the FAO simulation model for crop water productivity, irrigation management and hydrologic assessment

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FAO WATER

AquaCrop, the FAO simulation model for crop water productivity, irrigation management and hydrologic assessment

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To downloan AquaCrop: www.fao.org/nr/water/aquacrop.html

ICTP-IAEA Conference, Trieste, May, 2011

Globally, water is a finite resource

Demand and competition for water is increasing

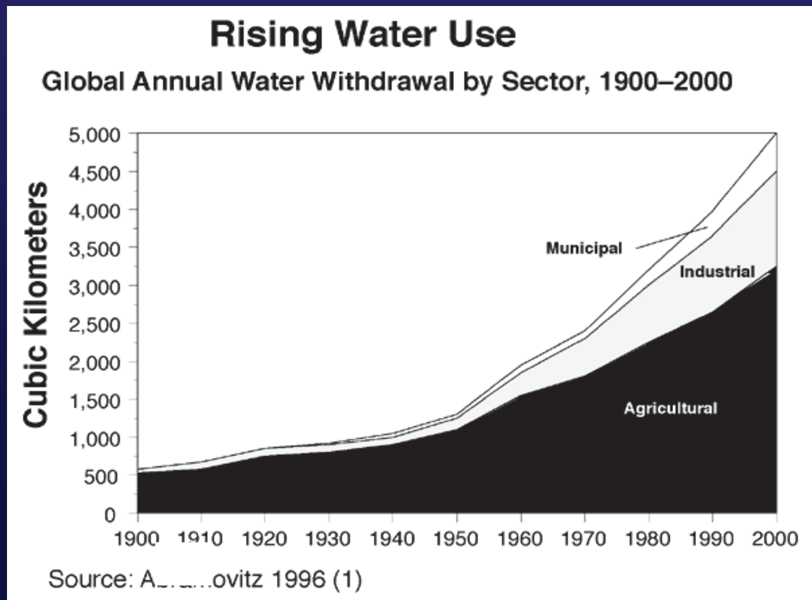
- Rising world population
- Improved living conditions
- Increasing recreational use

Water use is highly unequal among nations

- Shifting to diets higher in animal products

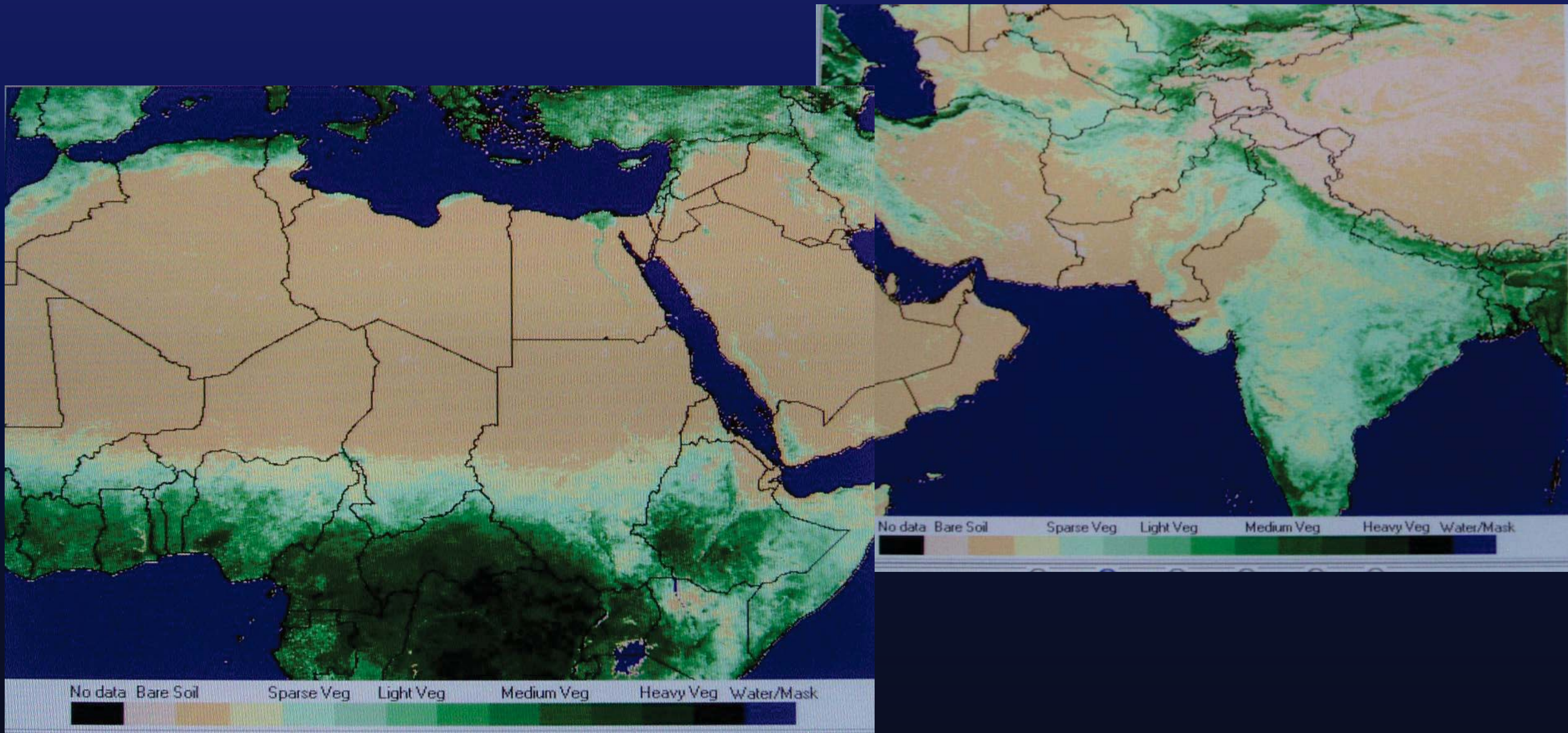
Example in the Mediterranean countries

- Rising world population
- Improved living conditions
- Increasing recreational use
- Shifting to diets higher in animal products



Where there is rain, there is food production

NDVI—indicator of green biomass, May 2005

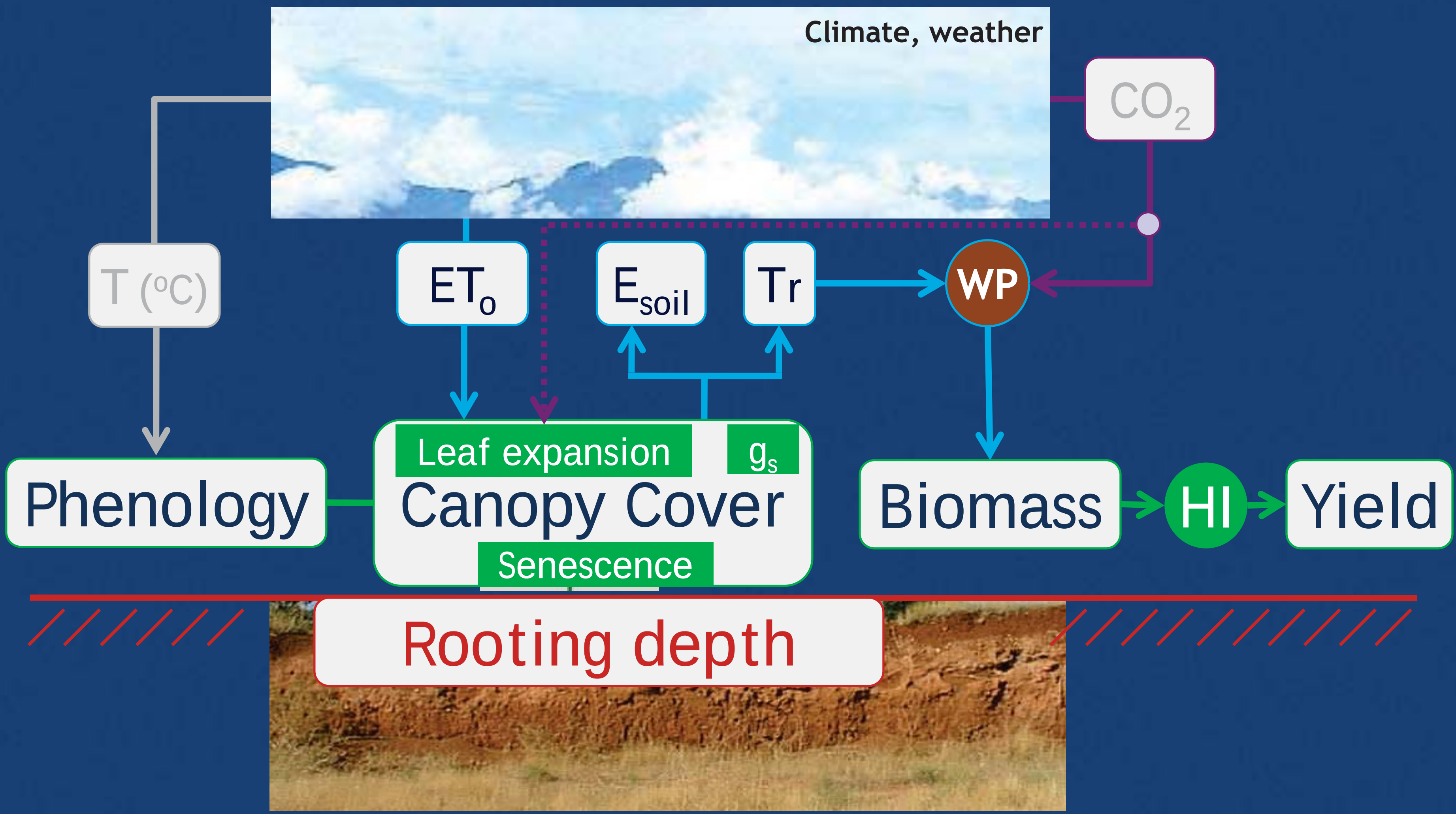


To ameliorate the problem of water scarcity for agriculture, need to quantify water availability and use for food production, and seek improvements in water use efficiency through management changes

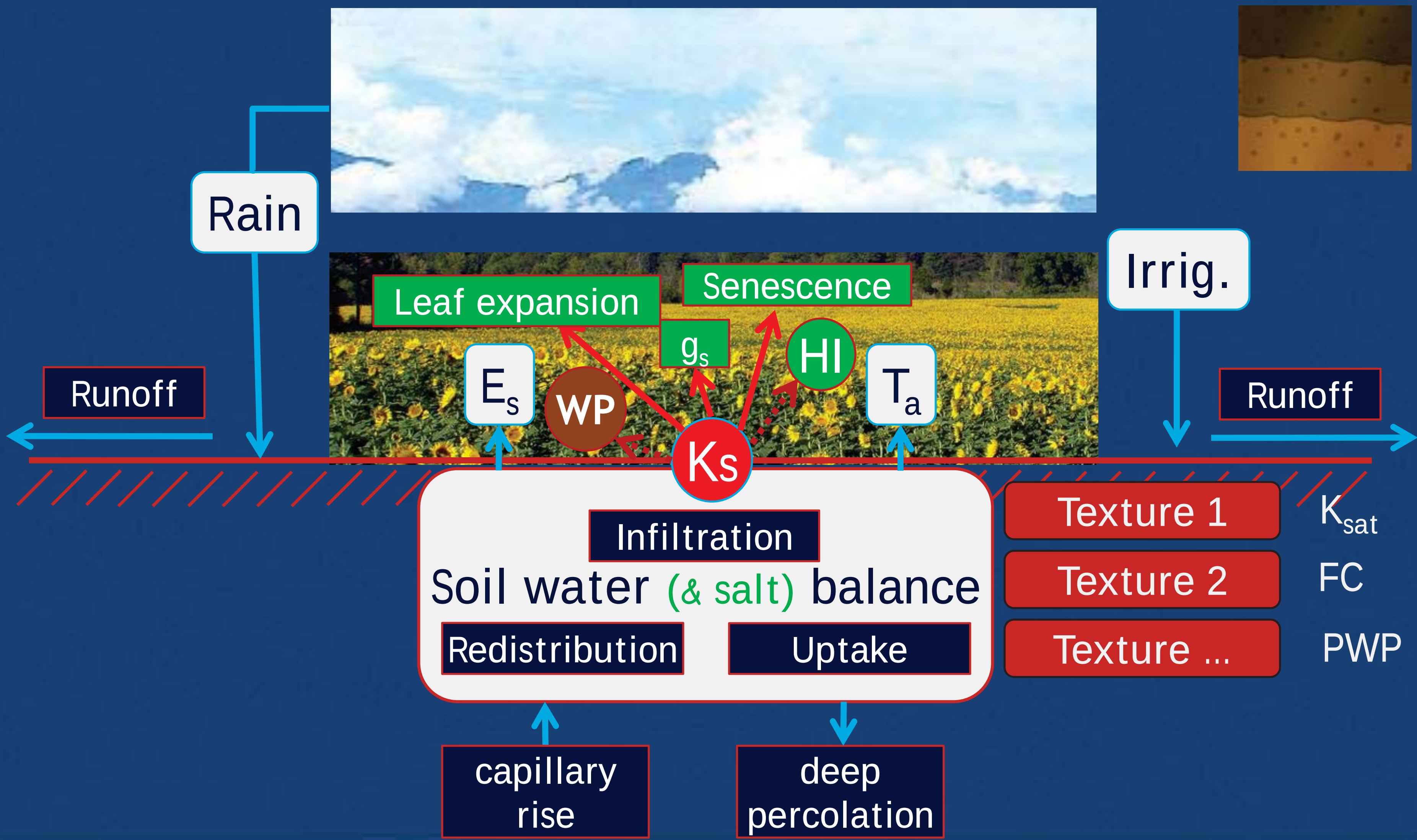
AquaCrop is designed by FAO with those purposes in mind for the potential use to:

- Improve irrigation management by reducing water use while maintaining crop productivity, i.e., improve water use efficiency
- Quantify crop ET and production from field to landscape scale in the hydrological analysis of water resources
- Develop water production functions for economical analysis to optimize water use and farm income
- Predict crop water use and productivity for climate change scenarios

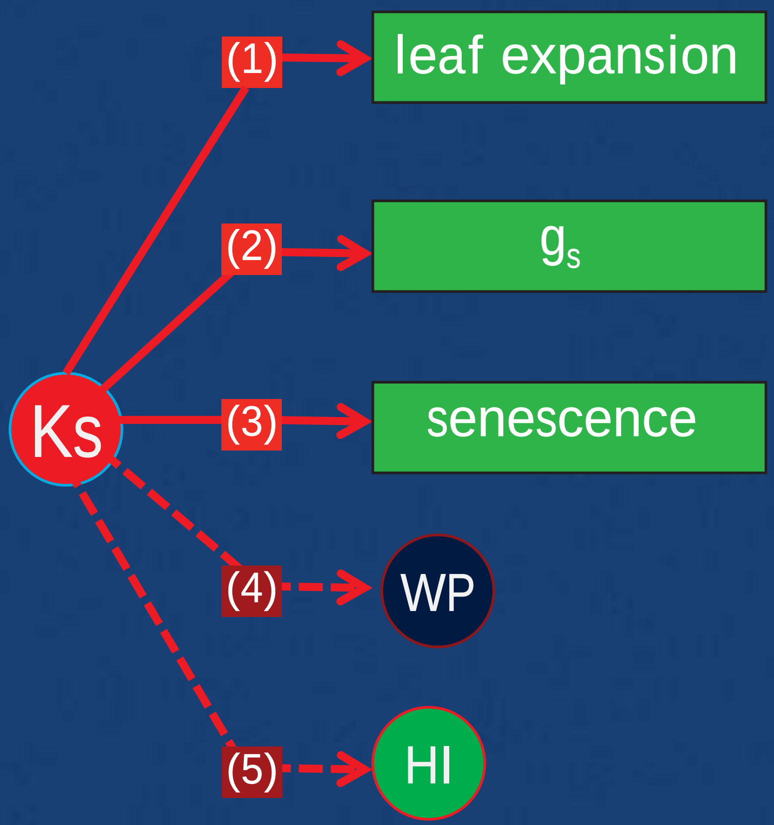
AquaCrop Conceptual Framework | Crop and Climate

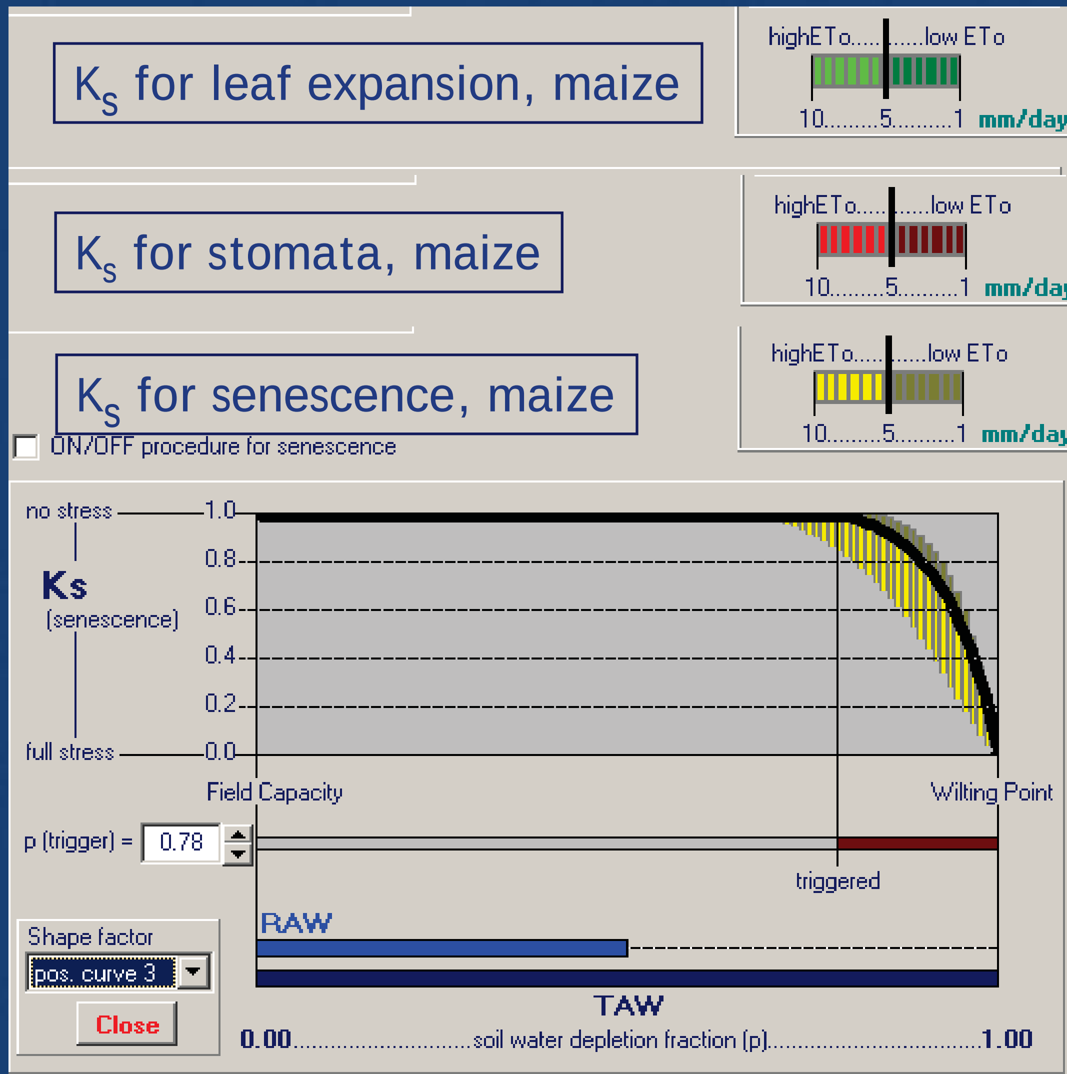


AquaCrop Conceptual Framework | Soil and Water



Stresses


Ks
(1)
leaf expansion
(2)
g_s
(3)
senescence
(4)
WP
(5)
HI

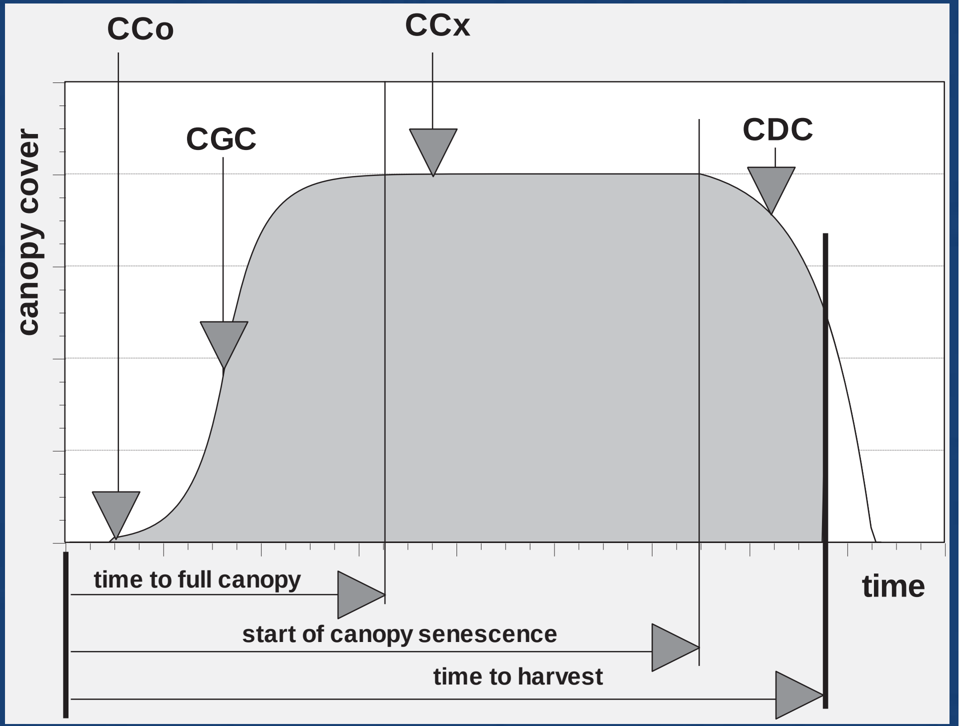

K_s for leaf expansion, maize
highETo.........low ETo
10.........5.........1 mm/day
K_s for stomata, maize
highETo.........low ETo
10.........5.........1 mm/day
K_s for senescence, maize
highETo.........low ETo
10.........5.........1 mm/day
ON/OFF procedure for senescence
no stress
Ks
(senescence)
full stress
1.0
0.8
0.6
0.4
0.2
0.0
Field Capacity
Wilting Point
p (trigger) = 0.78
triggered
Shape factor
pos. curve 3
Close
RAW
TAW
0.00.........................soil water depletion fraction (p)...............................1.00

Key steps of AquaCrop

- Uses growing degree day as driver (can switch to calendar time)
- Calculates canopy cover (CC) first, daily, and not use LAI
- Transpiration is calculated from CC, daily ET_o and a crop coef. for full CC, but with empirical adjustment for daily integral and for interrow advection
- Soil evaporation is calculated from CC, daily ET_o based on Stage 1 & 2 drying, and ET is obtained as the sum
- Water productivity normalized for atmosphere evaporative demand & CO_2, a constant, is used to convert transpiration to biomass production, daily
- Yield is calculated from biomass and harvest index (HI)
- HI is assumed to increase from anthesis onward, linearly after a lag phase
- Water stress is dependent on fractional depletion of available soil water, via several water stress functions, each with its own sensitivity threshold
- The stress functions are: leaf growth, stomata, early canopy senescence, and changes in HI
- Impact of transpiration rate on plant water status are indirectly accounted for by adjusting the sensitivity thresholds according to the daily ET_o

Canopy Cover (CC)

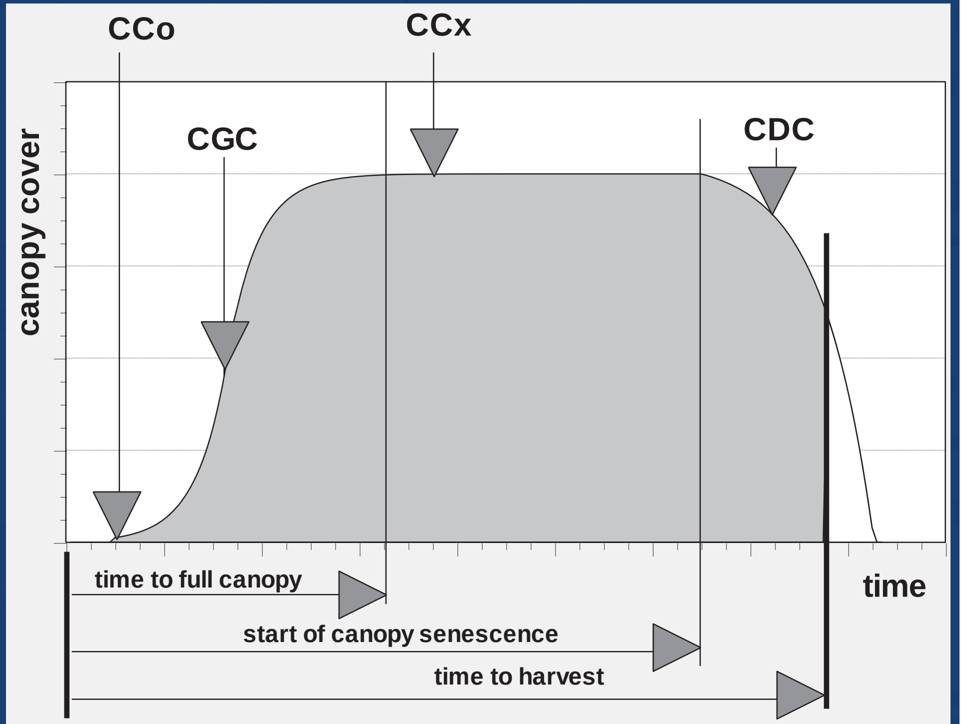
- Canopy cover (CC) follows the exponential growth during the first half of its development (Eq. 1), and an exponential decay during the second half of its development (Eq. 2)



$$CC = CC_o e^{CGC \cdot t} \quad (1)$$

Canopy Cover (CC)

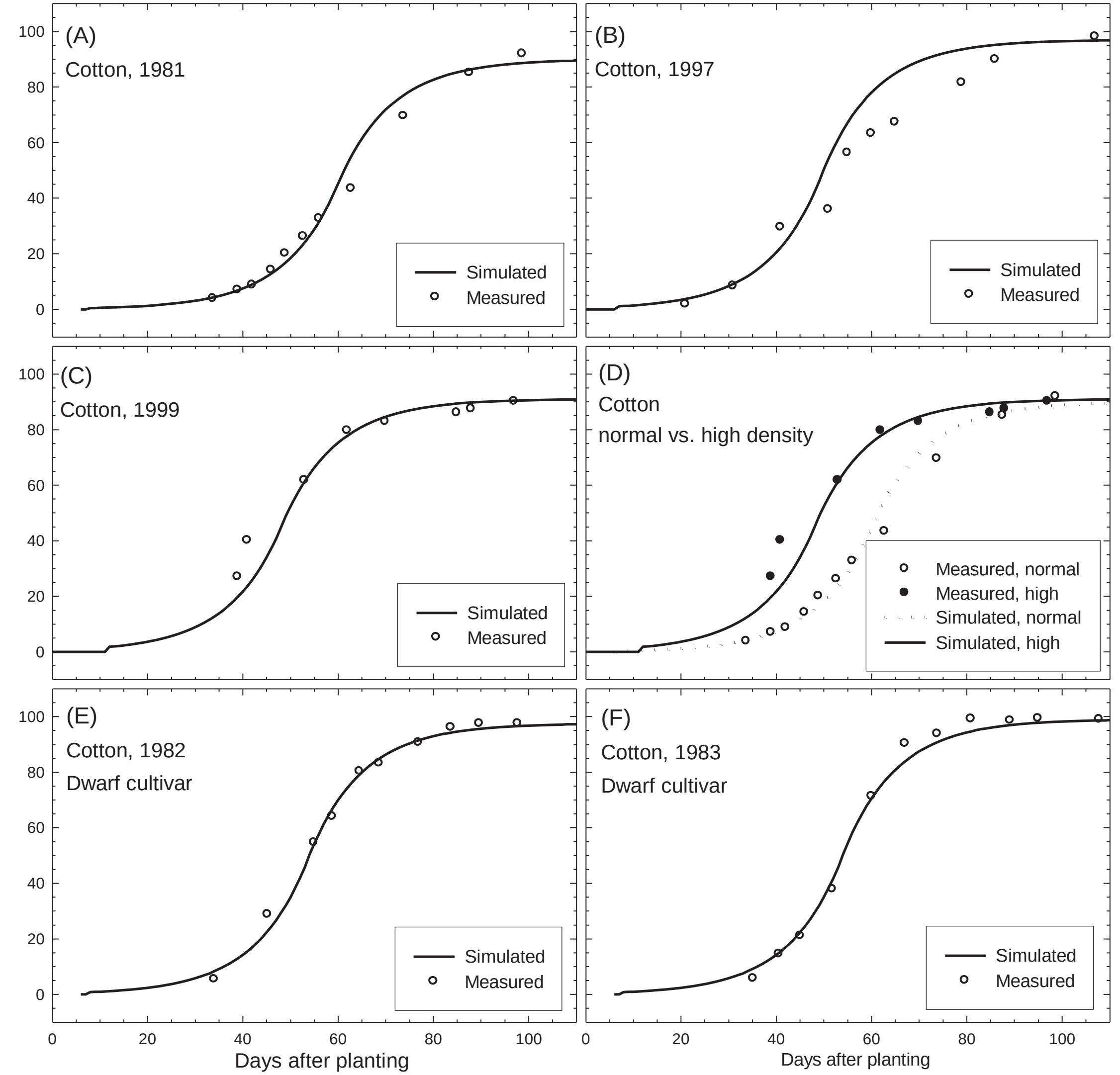
- AquaCrop calculates soil evaporation (E_{soil}) and crop transpiration (Tr) separately
- Canopy cover (CC) is calculated first as it affects the separation between E_{soil} and Tr
- Initial canopy cover (CC_o) is calculated from plant density and CC per seedling



$$CC = CC_o e^{CGC \cdot t} \quad (1)$$

$$CC = CC_x - (CC_x - CC_o) \cdot e^{-CGC \cdot t} \quad (2)$$

CC simulation using the same CGC and initial CC per seedling



Hsiao et al unpublished

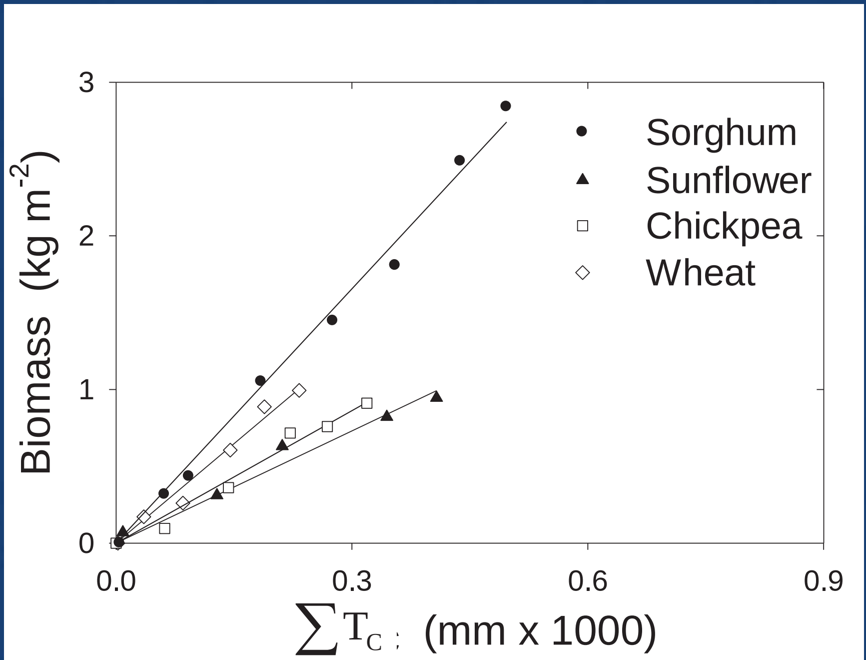
Water Productivity WP

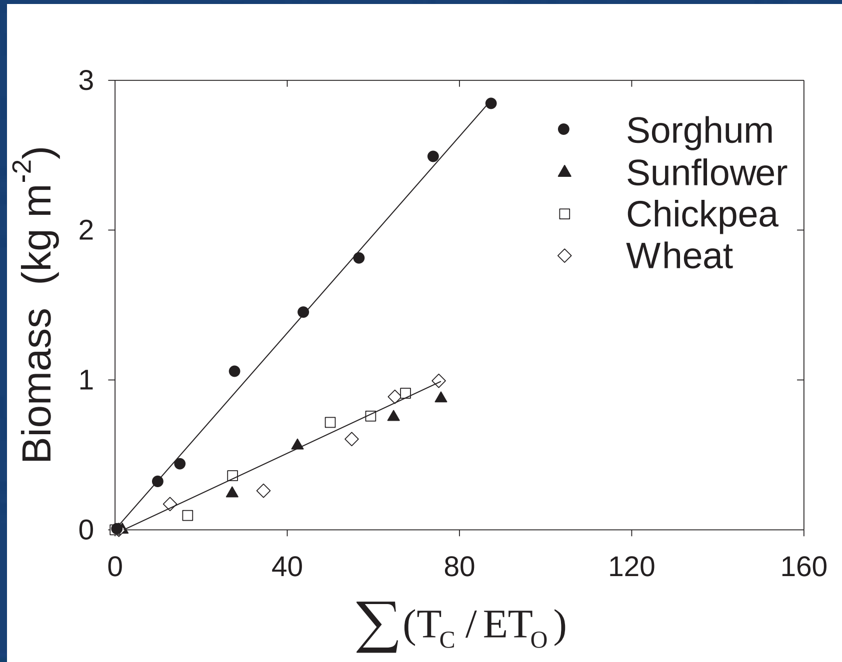
$$WP = \frac{\text{Biomass}}{\sum T_C}$$

(g m^{-2} mm^{-1})

$$WP^{*} = \left[\frac{\text{Biomass}}{\sum\left(\frac{T_C}{ET_O}\right)}\right]_{CO_2\,(2000)}$$

(g m^{-2})





General features

- AquaCrop is explicit and mostly intuitive, and maintains an optimum balance between simplicity, accuracy and robustness
- AquaCrop differs from other models for being water-driven, and for its relatively small number of parameters
- AquaCrop is aimed at practical end-users, as those in farmers and irrigation associations, extension services, governmental agencies and NGOs, for devising water management and saving strategies
- AquaCrop is also aimed at planners and economists who need estimates of production for given amounts of water
- AquaCrop is suitable for perspective studies (e.g., different irrigation strategies, climate change scenarios)

How does AquaCrop perform?

Example of application to maize

Plant parameters, basic, wide applicability

We consider these as conservative (constant) parameters

Parameter	For maize
Canopy	
• Initial canopy cover per seedling (cm^2)	6.5
• Canopy growth coefficient (% of existing canopy)	16
• Maximum canopy cover (plant density dependent)	--
• Canopy decline coefficient (% per day)	14
Root system	
• Average deepening rate (optimal soil conditions, cm/day)	2.4
Transpiration	
• Crop coefficient for transpiration (full canopy)	1.03
• Decline in green canopy activity with age (% per day)	0.3
Production	
• Normalized WP (optimal conditions, year 2000, g m^2)	33.0
• Reference HI (%)	48

Plant stress parameters, basic, wide applicability

Also considered as conservative (constant) parameters

	For maize
K_s function for leaf expansion (canopy growth)	
• p upper for leaf expansion	0.18
• p lower	0.76
• Curve shape	+3
K_s function for stomata (canopy transpiration)	
• p upper	0.76
• Curve shape	+6
K_s function for acceleration of canopy senescence	
• p upper	0.78
• Curve shape	+3
Stress effects on HI	
• Positive effects of stress inhibition of leaf growth	
• Negative effects of stress inhibition of stomata	
Stress effects on WP*	0

Parameters specific to each location & season

- Daily weather (ET_o, rainfall, and temperature)
- Soil water characteristics of depth layers
- Initial soil water content of depth layers
- Rooting depth as affected by restrictive soil layers
- Irrigation schedule (time and amount)
- % of soil surface wetted by irrigation
- Plant density
- Crop phenology (cultivar specific), including flowering, senescence start, and physiological maturity time

1974 Experiment

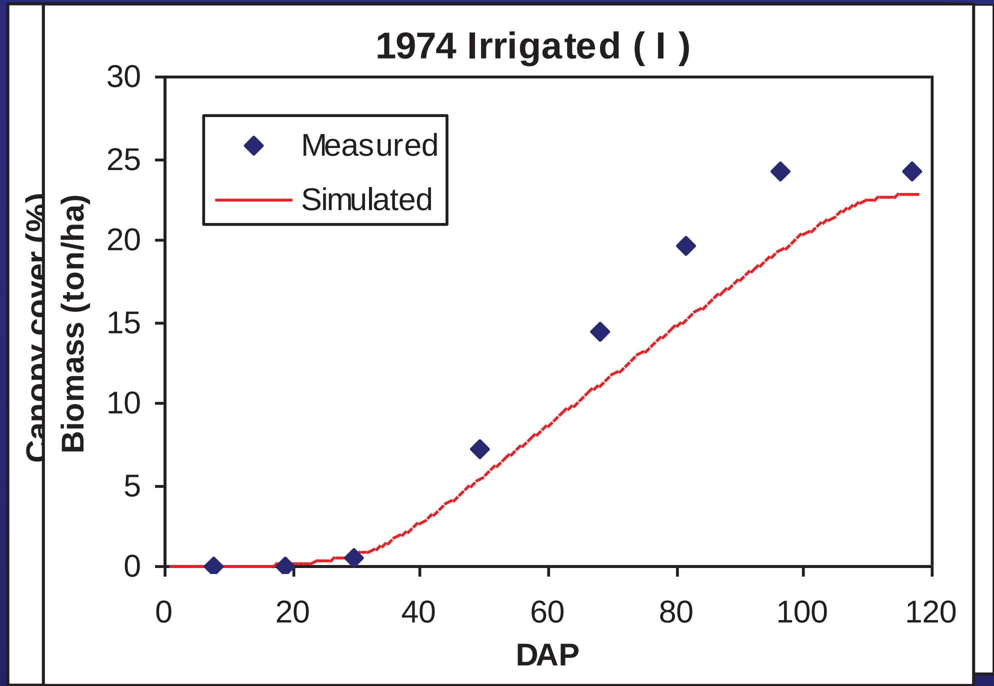
Treatments:

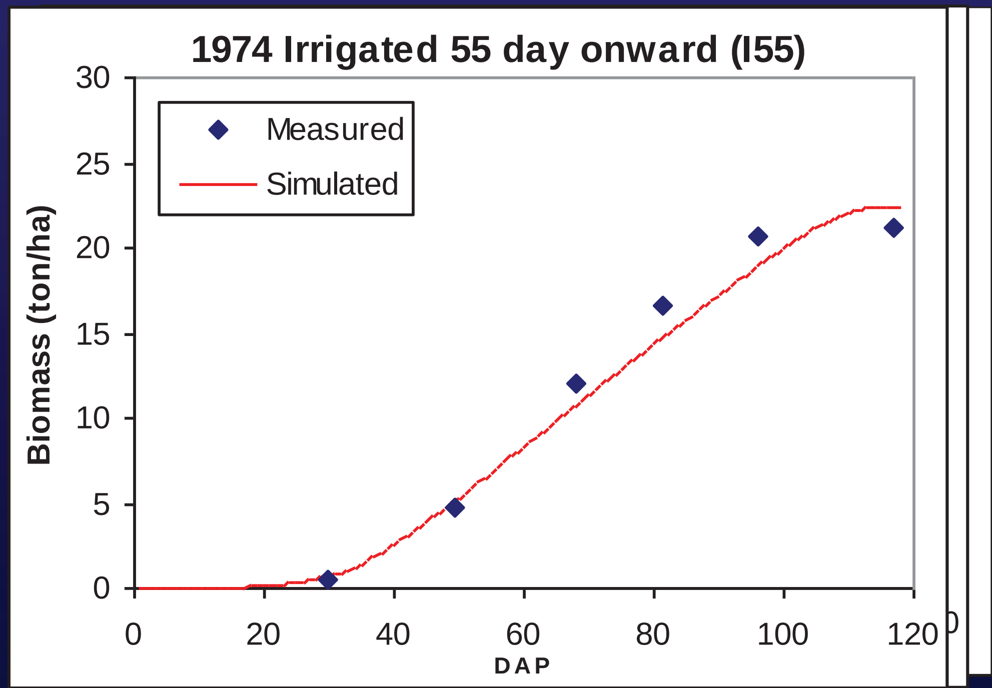
Irrigated (I)
Rainfed (NI)
Irrig. day 55 onward (I55)

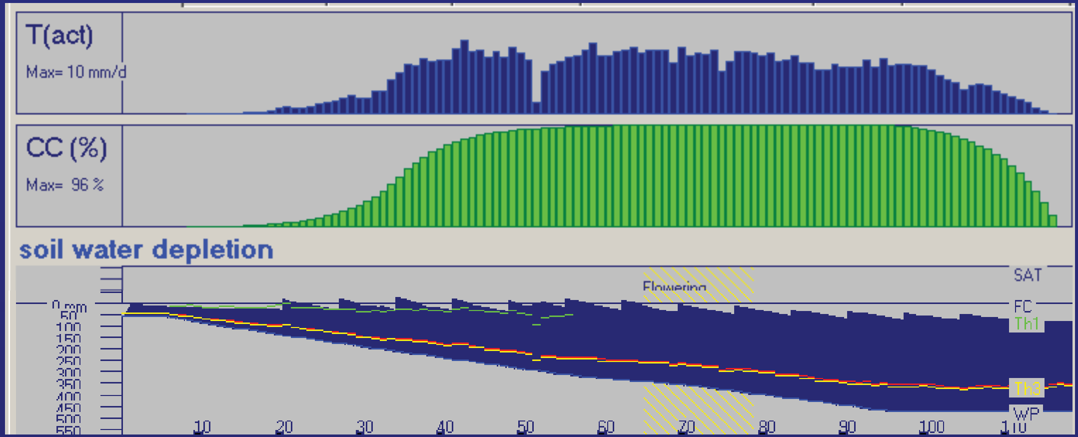
- Early senescence of NI fairly well simulated
- Biomass time course and difference fairly well simulated
- Effects of early stress and late irrigation fairly well simulated

	Biomass		Yield	
I	24.3	22.7	11.4	10.8
NI	16.8	16.8	5.2	6.2
I55	21.2	22.4	10.3	10.6

White—measured
Blue—simulated

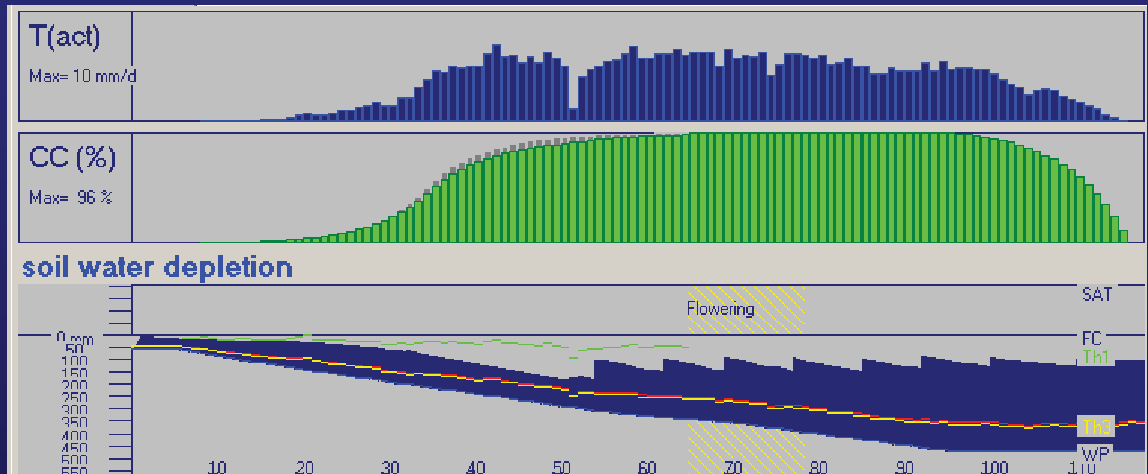




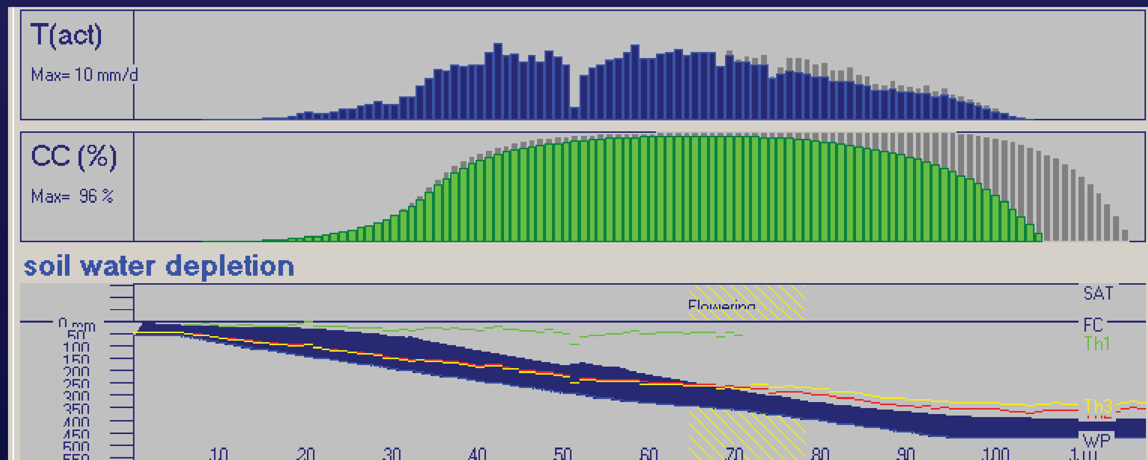


I
Treatment

I 55
Treatment



NI
Treatment



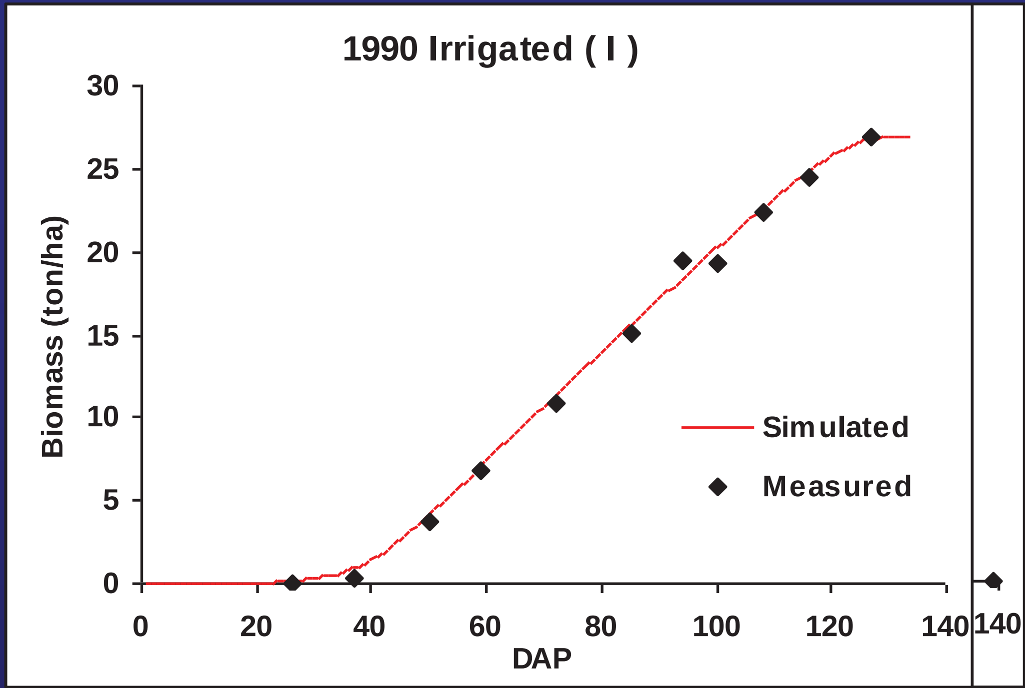
1990 Experiment

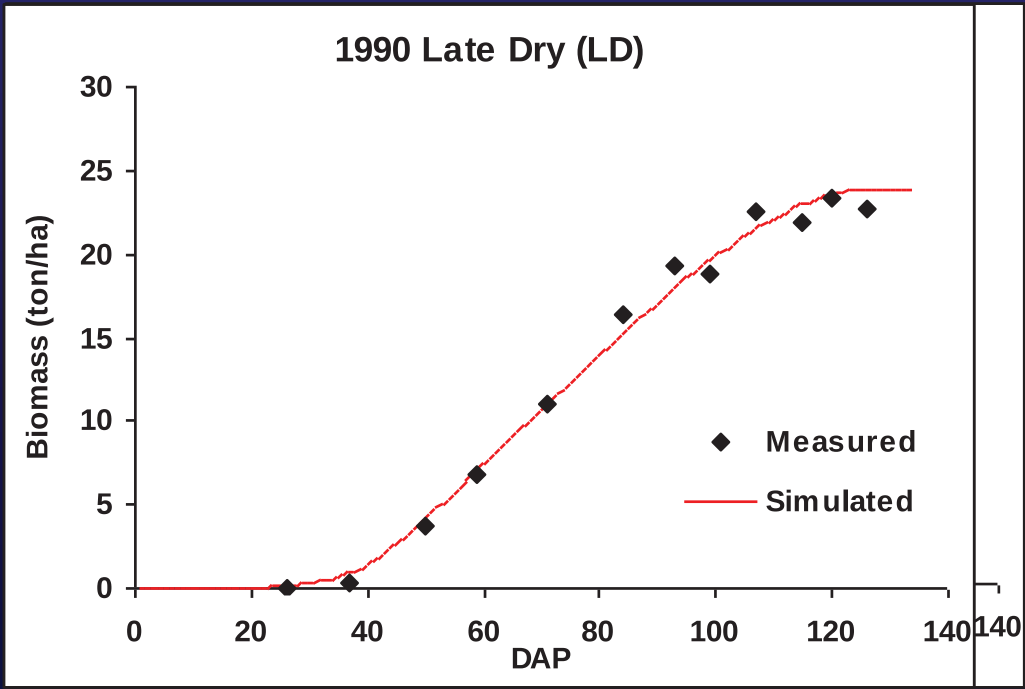
Treatments:
Irrigated (I)
Late dry (LD, dry day 56 on)

- Canopy decline of LD under-simulated slightly
- Reduced late biomass accumulation of LD well simulated

	Biomass		Yield	
I	26.9	26.9	12.0	12.4
LD	22.7	23.9	10.1	10.7

White—measured
Blue—simulated





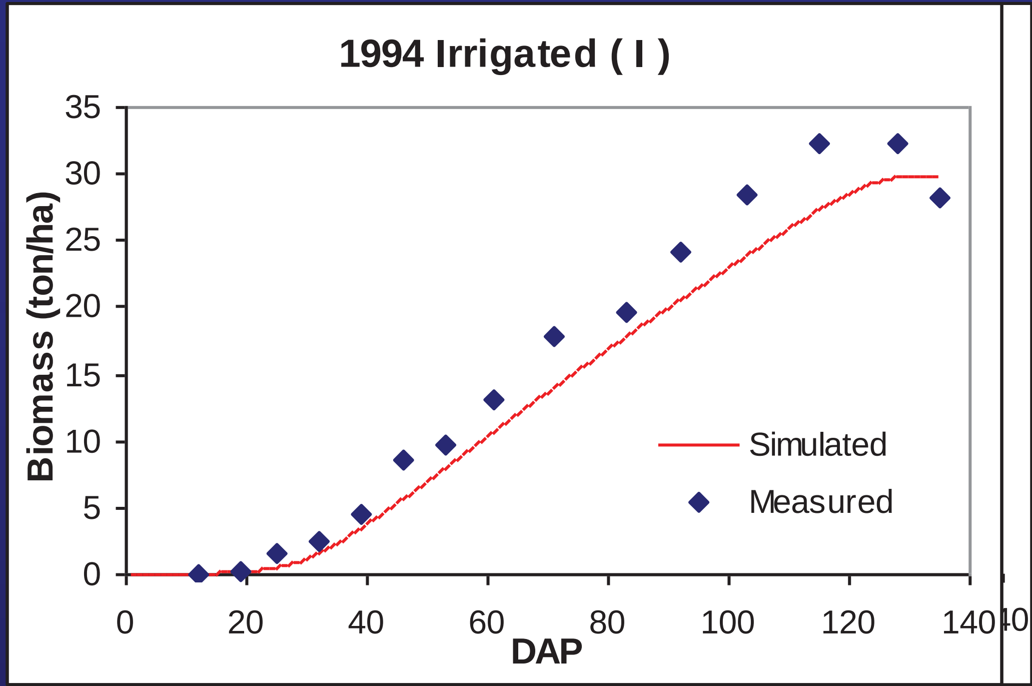
1994 Experiment

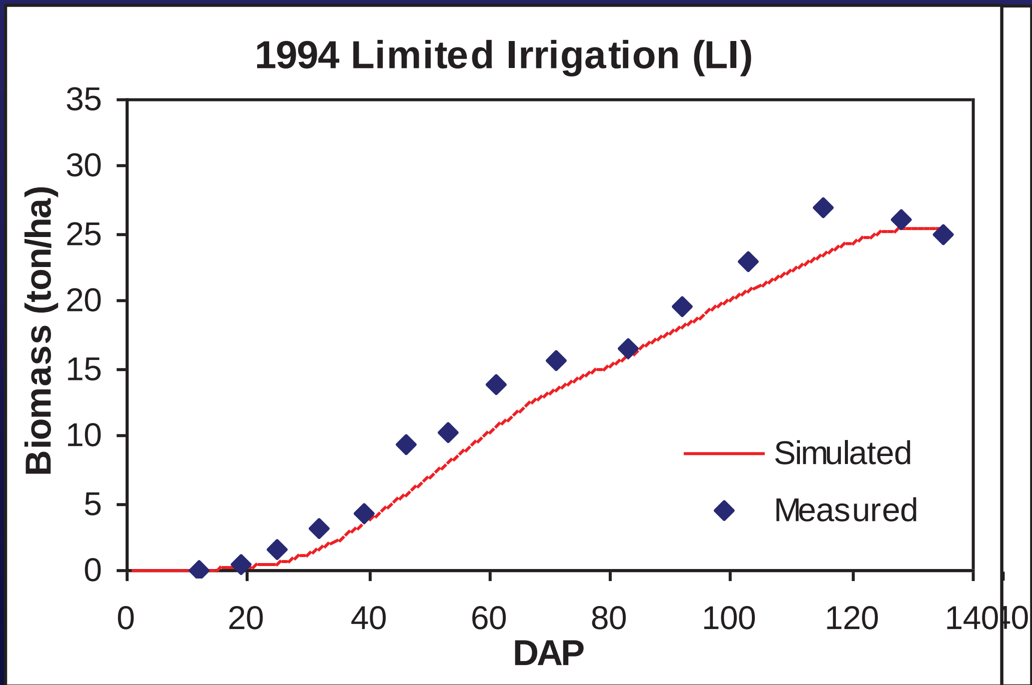
Treatments:

Irrigated (I)

Limited irrig. (LI)

- Effects of irrigation in delaying senescence well simulated
- Recovery in biomass growth upon irrigation simulated





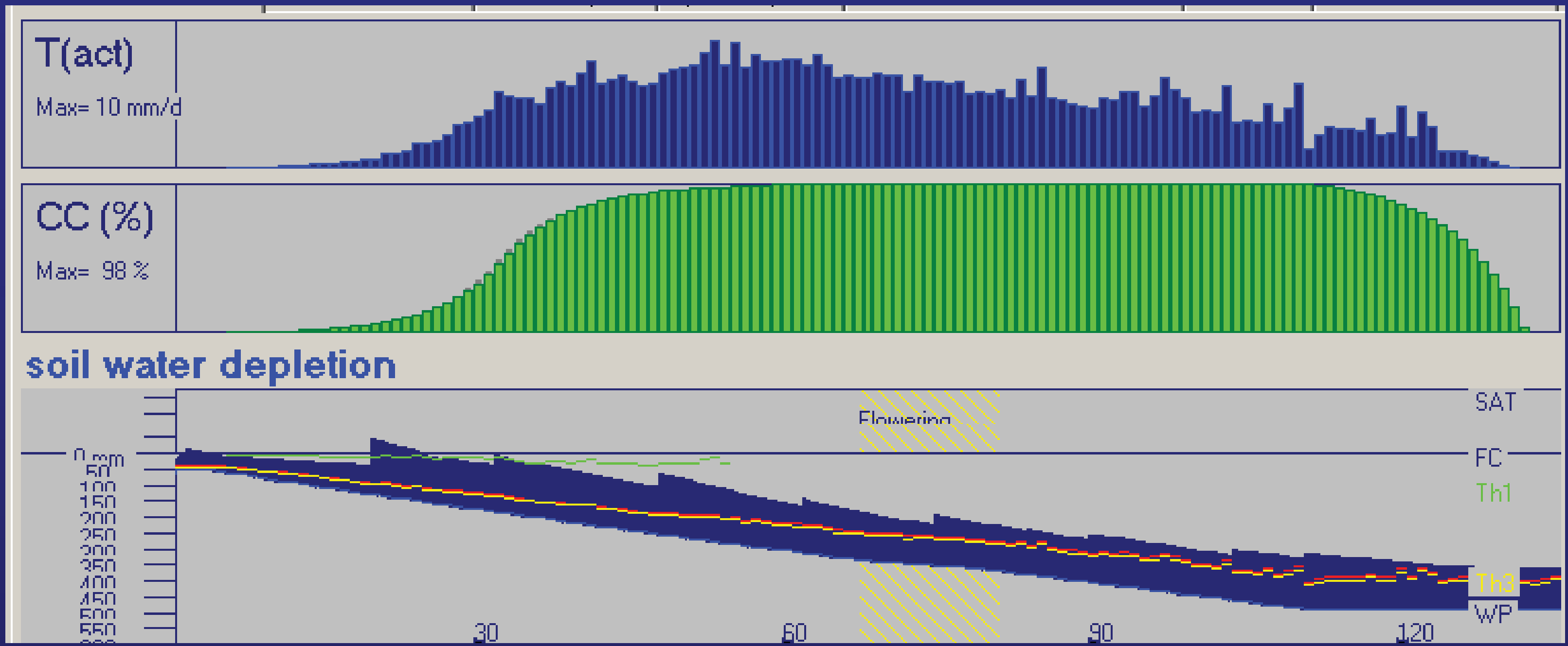
	Biomass		Yield	
I	27.6	29.8	12.7	14.1
LI	22.2	25.4	10.2	12.1

White—measured

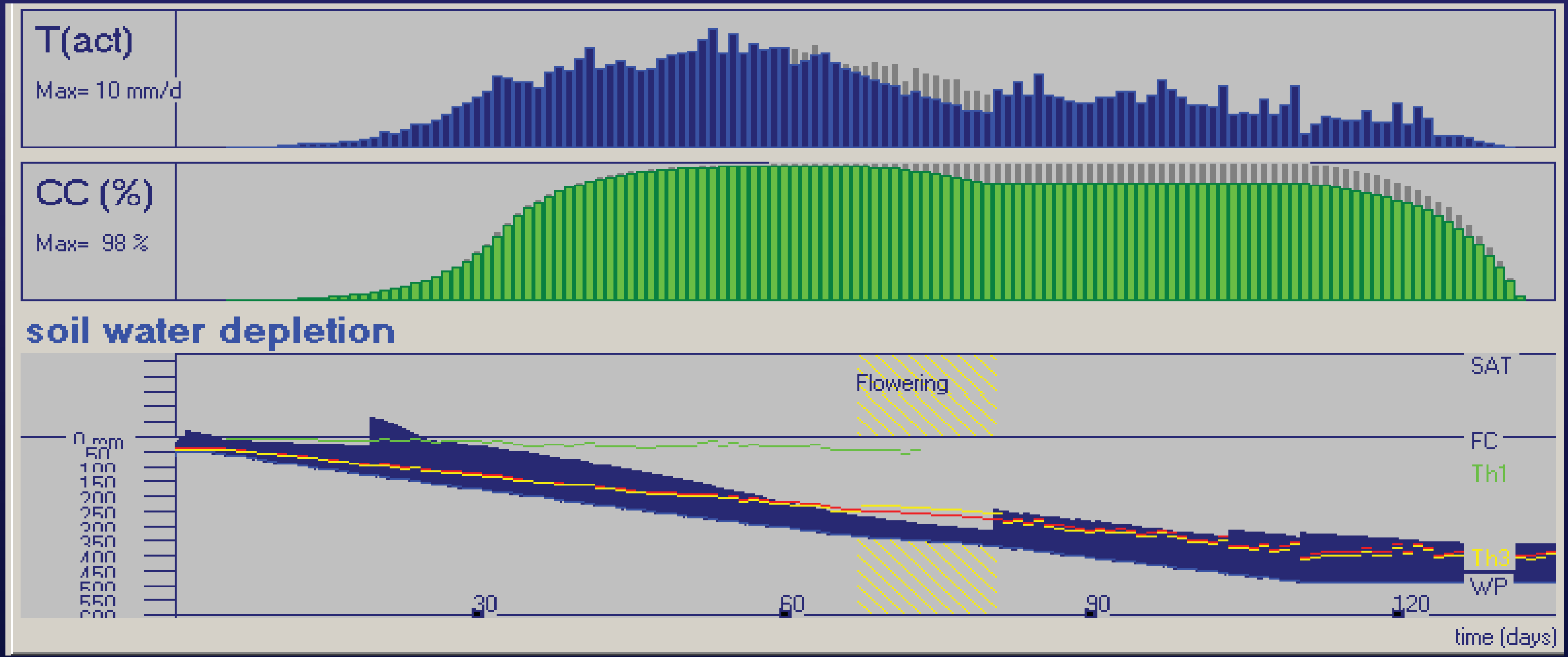
Blue—simulated

1994

irrigated

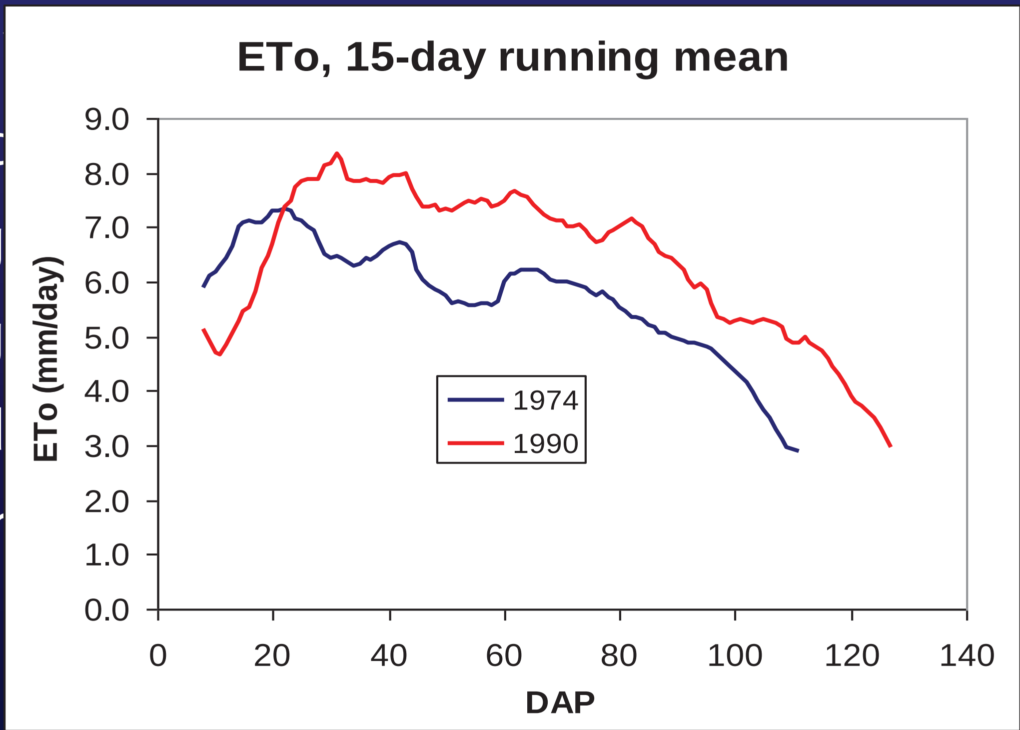


Limited irrigation



Range of 6 different years in Davis simulated
(same basic parameters)

- Three different cultivars
- Planting dates: May 14 to June 16
- Time to maturity: 118 to 138 days
- Substantial range of evaporative conditions
- Variety of
  - Rainfed
  - No irrig
  - No irrig
  - Limited
  - Fully irr



Testing for other locations:

Heng L. et al, 2009. Agron J.

- Bushland Texas—high wind and very high ET_o
  soil water holding capacity = 15%

- Gainsville Florida—sandy soil and humid, low ET_o
  soil water holding capacity = 5 to 10%

- Zaragoza Spain—sandy loam and 3 irrigation regimes
  soil water holding capacity = 17 to 20%

All using same conservative parameters as Davis

Coefficients of efficiency for the simulations was 0.9 or higher for the large majorities of the test cases

So far AquaCrop has been parameterized for only a number of crops:

Available now:

- Maize
- Cotton
- Wheat (mild winter)
- Paddy rice

- Soybean
- Sunflower
- Sugar beet
- Quinoa
- Potato

Highest

Reliability

Lowest

Working on:

- Sorghum
- Tomato
- Sugar cane
- Barley

Next to do:

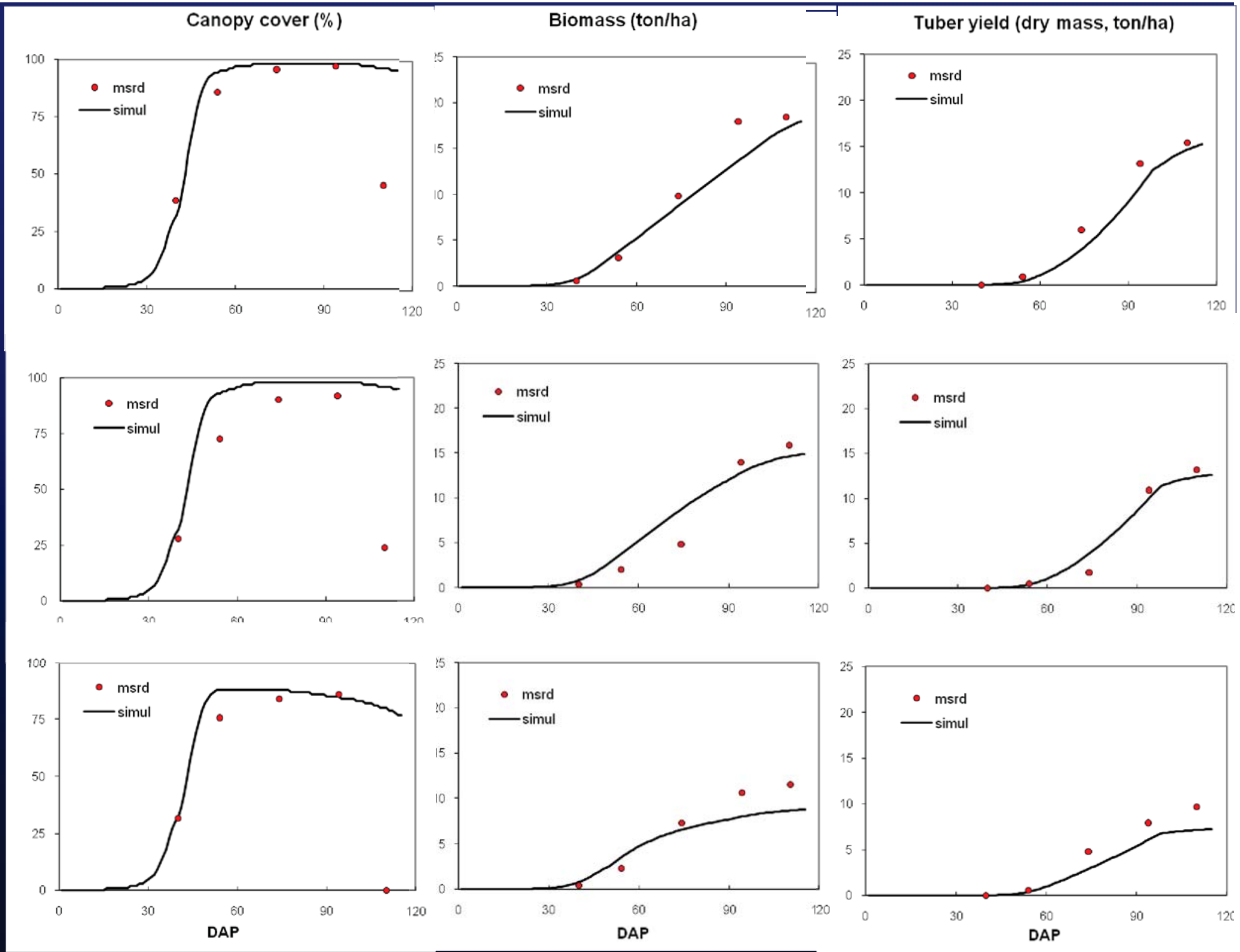
- Wheat (cold winter)
- Alfalfa

Potato Davis 80

Full irrig.

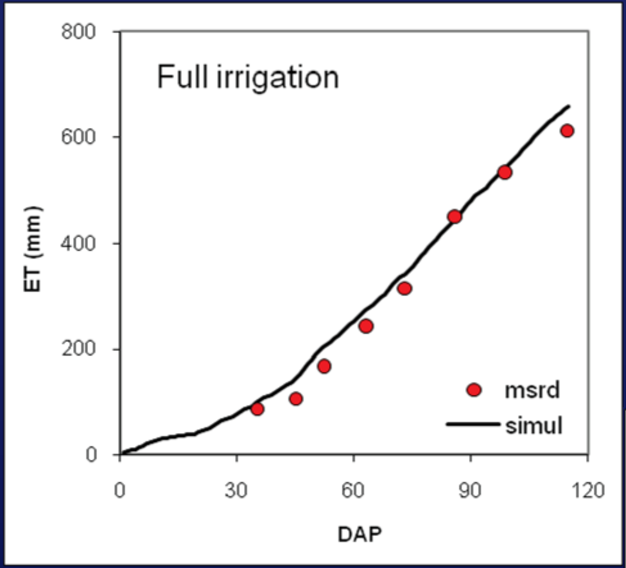
65% irrig.

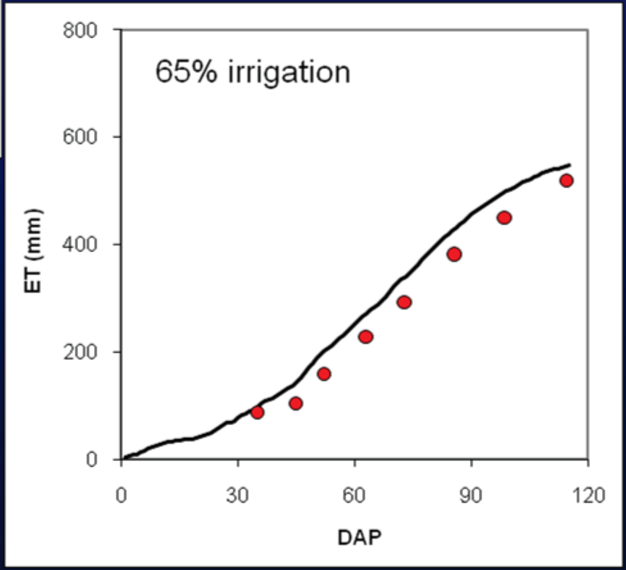
24% irrig.

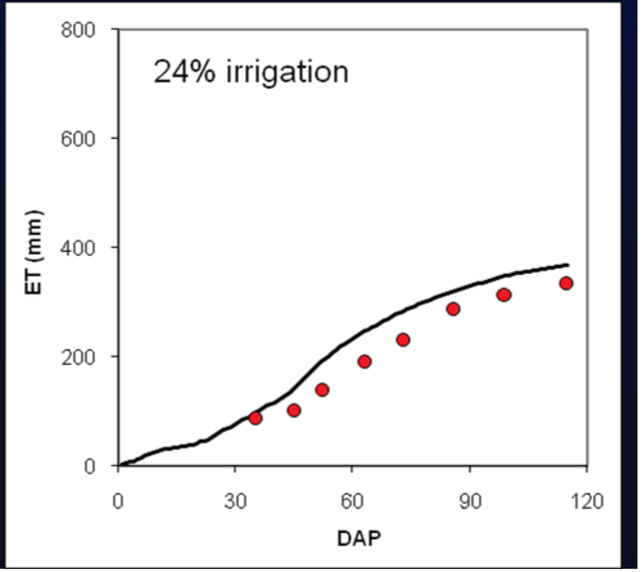


- Need to make canopy growth coefficient (CGC) more sensitive to water stress
- Need to make transpiration less sensitive
- Need to make the HI vs. DAP function a curve instead of straight line

What about potato water use, simulated?







- Water balance is simulated OK in this case
- Hard to find data where ET, CC or LAI, and biomas are sampled over the season, along with detailed weather data

Data desired for parameterization and testing

- Daily weather (rainfall, radiation, temperature, humidity, and wind)
- Soil water characteristics of depth layers
- Initial soil water content of depth layers
- Irrigation schedule (time and amount)
- Soil water content at different times
- Plant density
- Canopy cover (CC from LAI) progression with time
- Rooting depth at different times
- Transpiration (or ET) as function of time
- Biomass at different times and final harvest
- Yield

Most experiments not provide all desired data

Have to test various aspects separately

Now demonstration of model use

AQUACROP
crop production simulator

www.fao.org/nr/water