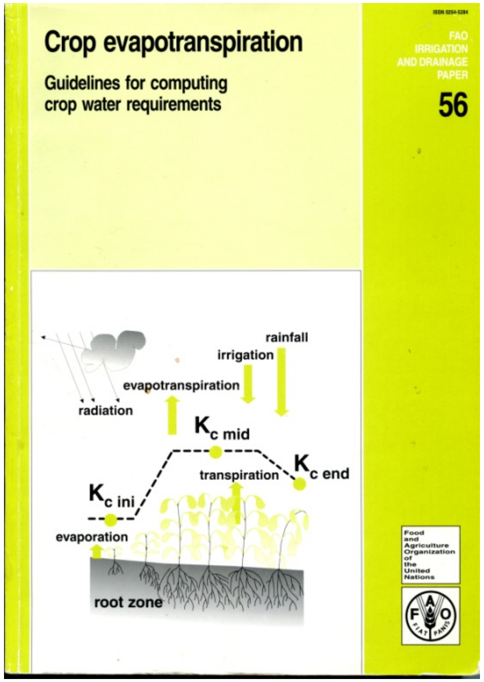
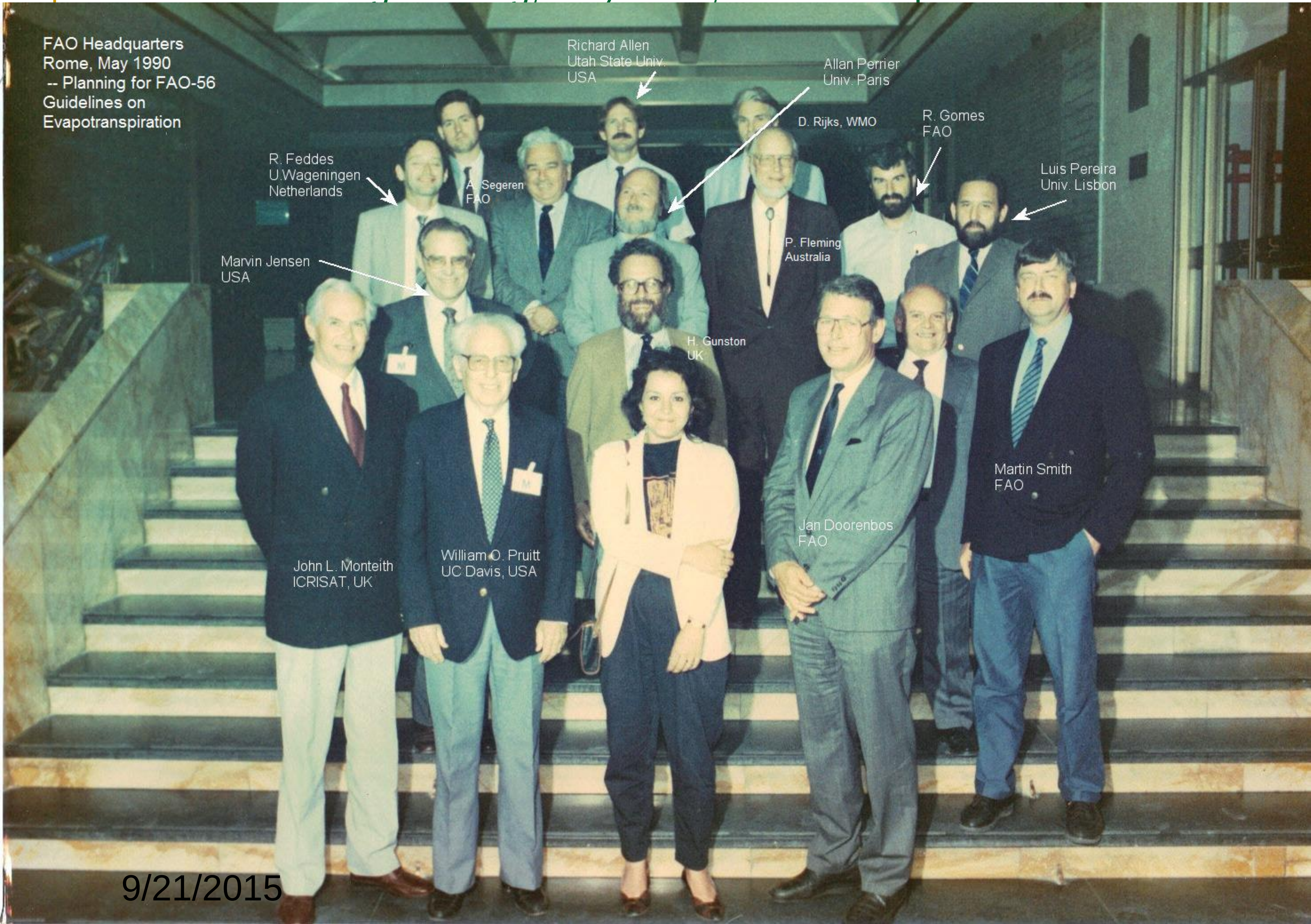
FAO 56 past and future, with focus on the dual crop coefficient approach



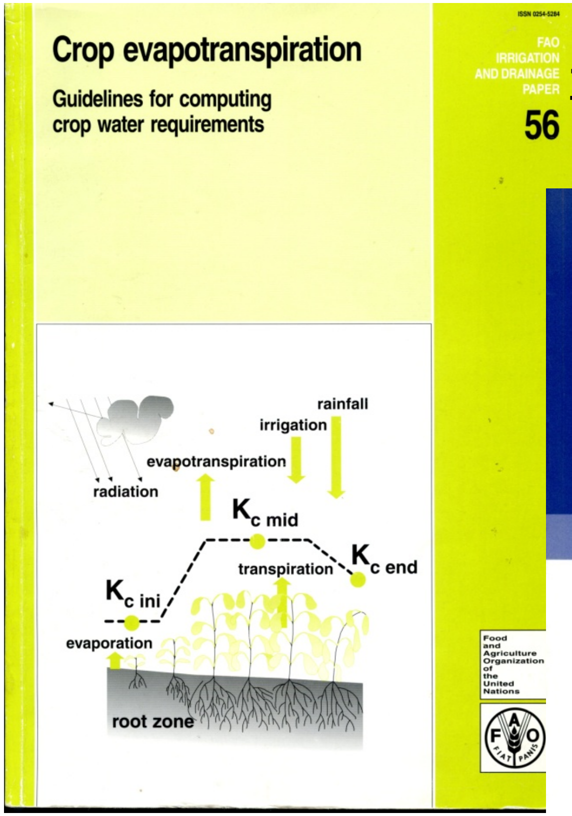
Luis Santos Pereira and Paula Paredes

LEAF, Landscape, Environment, Agriculture and Food
Institute of Agronomy, University of Lisbon

FAO-56 Planning Meeting, May 1990, FAO Headquarters



1998



作 物 腾 发 量

作物需水量计算指南

编著者:

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Martin Smith
Water Resources, Development and Management Service
FAO

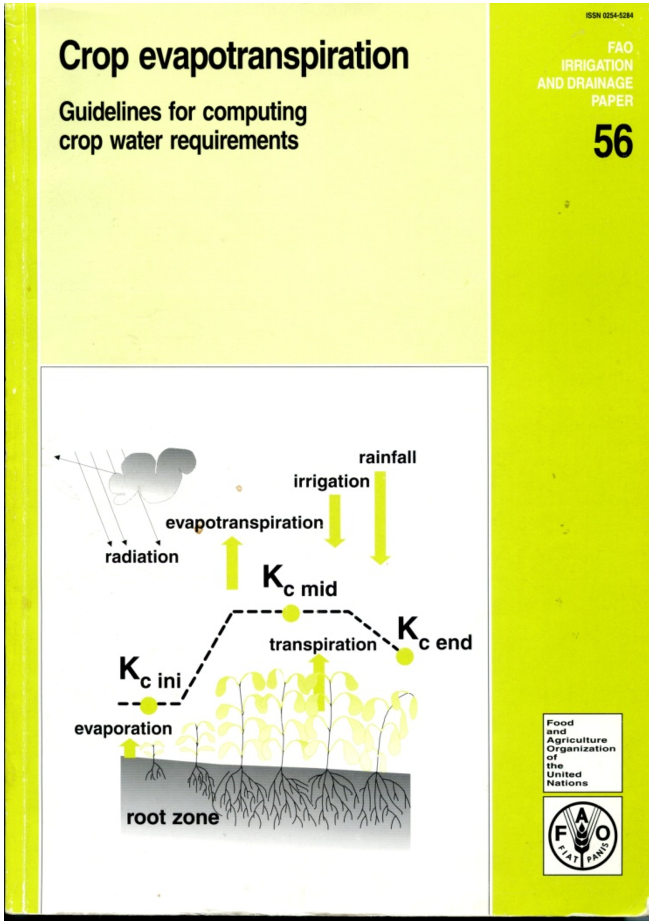
2006

14165 citations

2001

Discussion points:

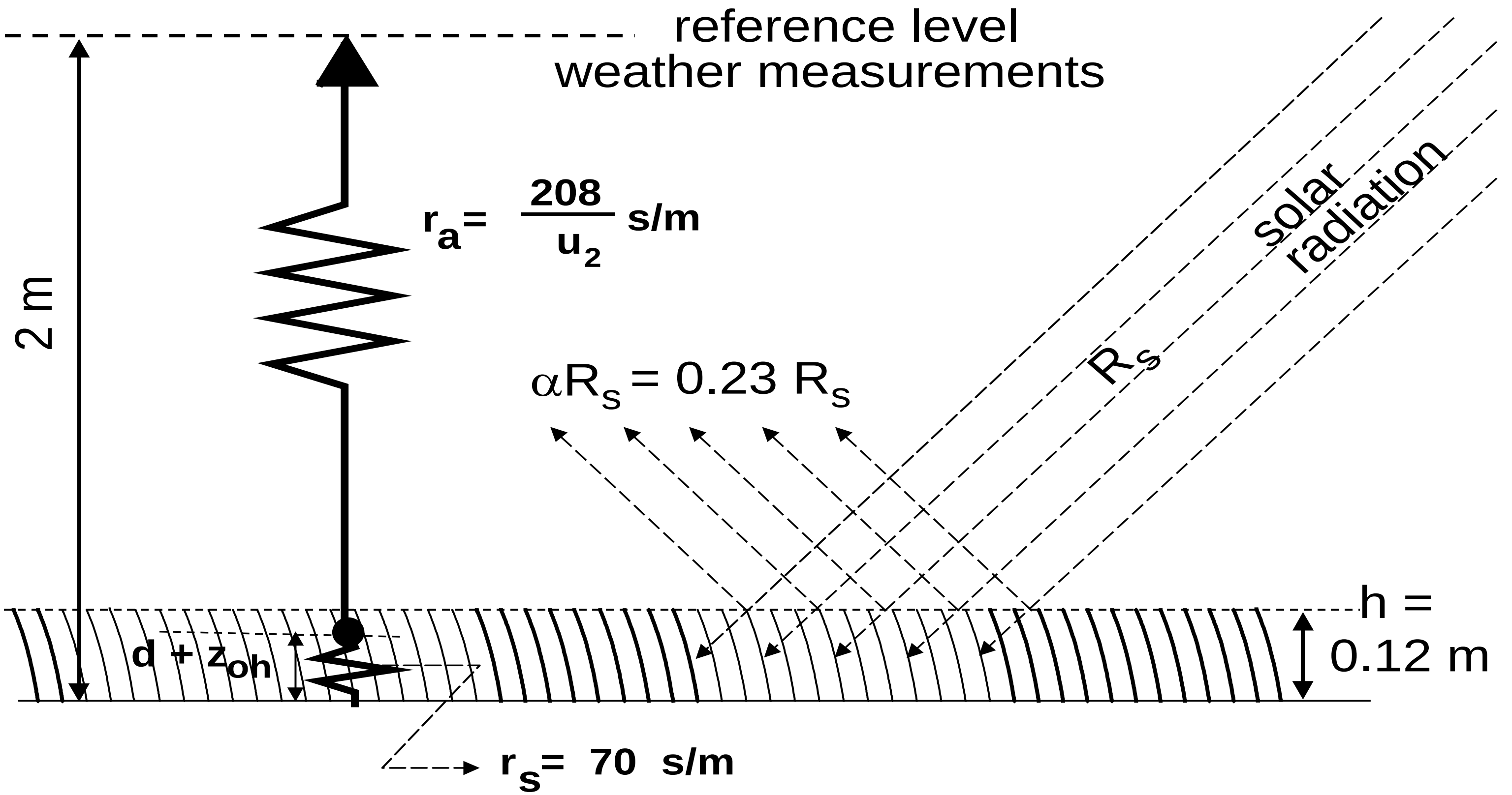
- FAO-PM ETo equation
- Computing ETo with missing variables
- Crop Coefficient
- Dual Crop Coefficient approach
- Crop ET under non-standard conditions



Main collaborations

Y. Liu, Z. Wei, B. Zhang, N.N. Zhao, G.H. Huang, X. Xu, Y. Wu, Q. Miao, X. Ren
J. Martins, M. Petry, R. Carlesso, L. Gimenez, J. Cancela, M. Fandiño, B. Karic,
M. Todorovic, T. Raziei, Z. Popova, I. Alves, T. Paço, I. Pôças, P. Paredes, R. Rosa

Reference ET: FAO-PM equation for grass reference ET



$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{900}{T + 273}\,U_2\,(e_a - e_d)}{\Delta + \gamma\,(1 + 0.34\,U_2)}$$

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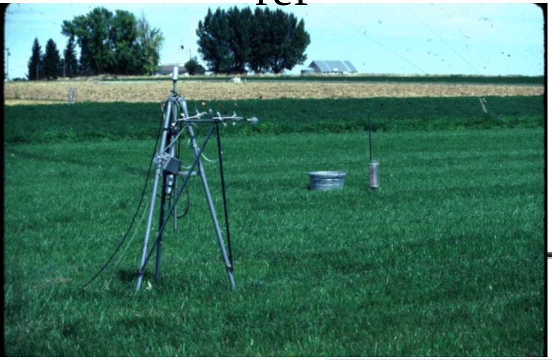
Reference ET: A Living Evaporation Index

$$\mathrm{ET}_{\mathrm{ref}} = \frac{0.408\,\Delta\,(R_n - G) + \gamma \dfrac{C_n}{T+273} u_2\,(e_{\mathrm{s}} - e_{\mathrm{a}})}{\Delta + \gamma\,(1 + C_{\mathrm{d}}\,u_2)}$$



Grass

Alfalfa

	Calculation time step	C_n	C_d
FAO-PM (ET_o)	24-h	900	0.34
	Hourly-proposed	37	0.24/0.96
ASCE-PM (ET_r)	24-h	1600	0.38
	Hourly	66	0.25/1.7

Allen et al., AGWAT. 2006

ETo computed from Tmax and Tmin only

1. Hargreaves-Samani, HS

$$ET_{\circ} = 0.0135 k_{Rs} \frac{R_a}{\lambda} \sqrt{(T_{\max} - T_{\min})} (T_{mean} + 17.8)$$

1. FAO-PM with temperature only, PMT

$$R_s = k_{Rs} \sqrt{(T_{\max} - T_{\min})} R_a$$

$$e_a = e^0(T_{\min}) = 0.611 \exp\left(\frac{17.27\, T_{\min}}{T_{\min} + 237.3} \right)$$

Todorovic et al., J. Hydrol. 2013

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Estimating T_{dew} for FAO-PMT

1. Estimating T_{dew} from T_{min} under aridity

Climate zones	Annual P/ET_o	T_{dew} (°C)
Hyper-arid	<0.08	$T_{dew}=T_{min} - 4$
Arid	0.08-0.20	$T_{dew}=T_{min} - 2$
Semi-arid	0.20-0.50	$T_{dew}=T_{min} - 1$
Dry sub-humid	0.50-0.65	$T_{dew}=T_{min} - 1$

2. Estimating T_{dew} from T_{max} and T_{min} under humid conditions:

$$T_{\mathrm{dew}} = \left(\frac{T_{\mathrm{max}} + T_{\mathrm{min}}}{2}\right) - a_d$$

with a_d = 2 °C when 0.8 <P/ET_o < 1.0

a_d = 1 °C when P/ET_o > 1.0.

Ren et al., 2015, WARM

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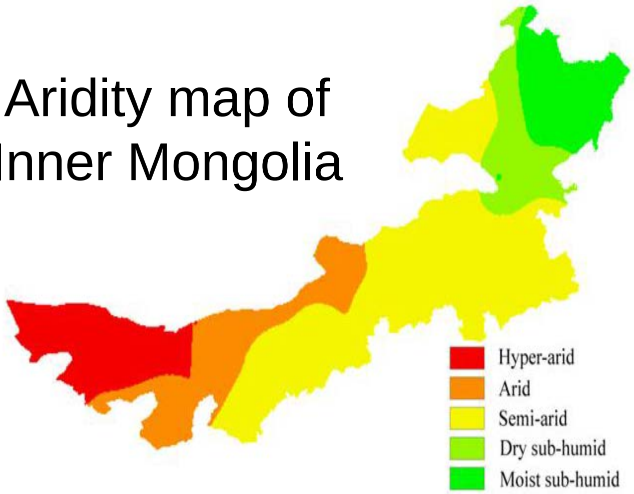
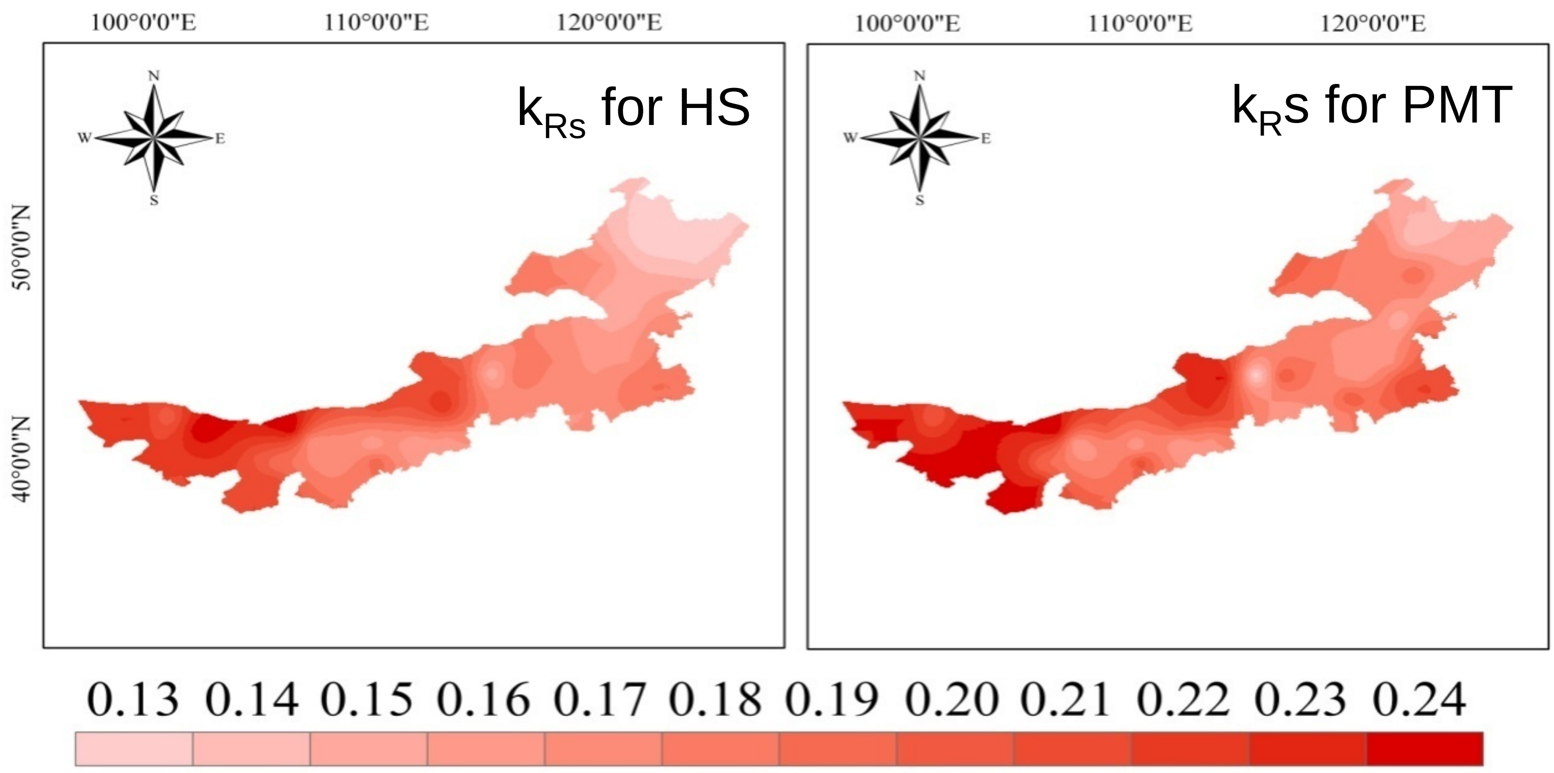
k_{Rs} for HS and PMT relate with aridity

$$ET_o = 0.0135\, k_{Rs} \frac{R_a}{\lambda} \sqrt{(T_{\max} - T_{\min})}\,(T_{mean} + 17.8)$$

$$R_s = k_{Rs} \sqrt{(T_{\max} - T_{\min})}\, R_a$$

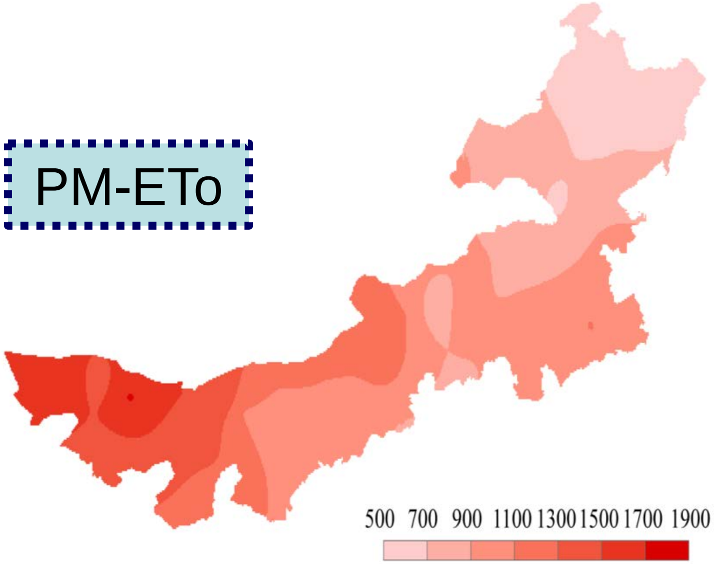
Aridity map of Inner Mongolia



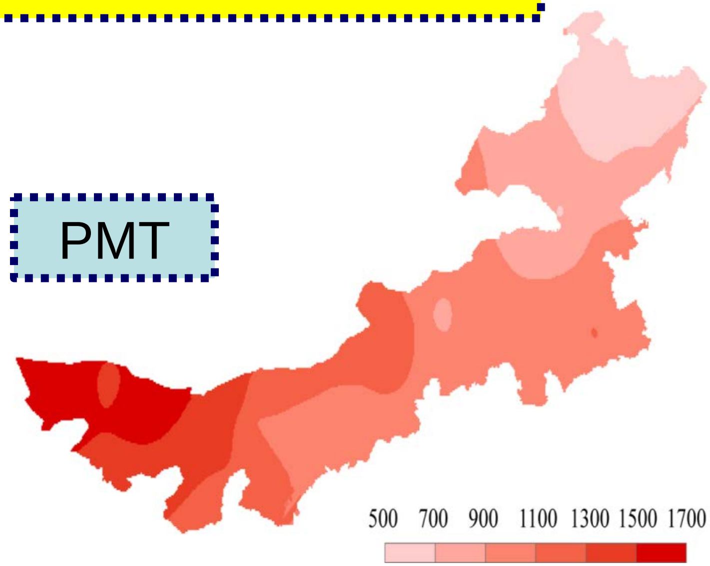


Inner Mongolia: Results for PMT and HS are quite similar.

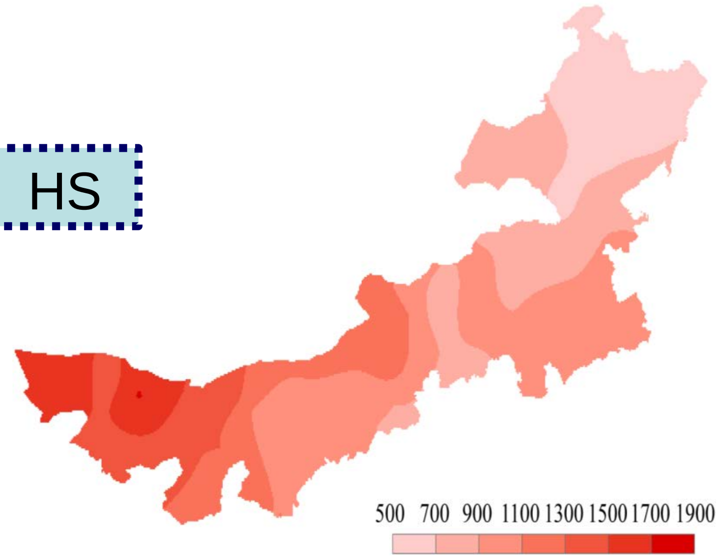
PM-ETo



PMT



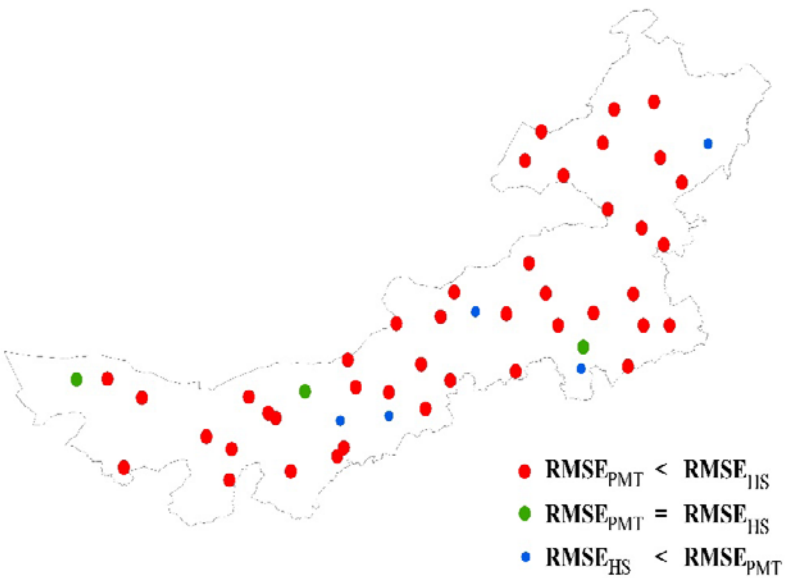
HS

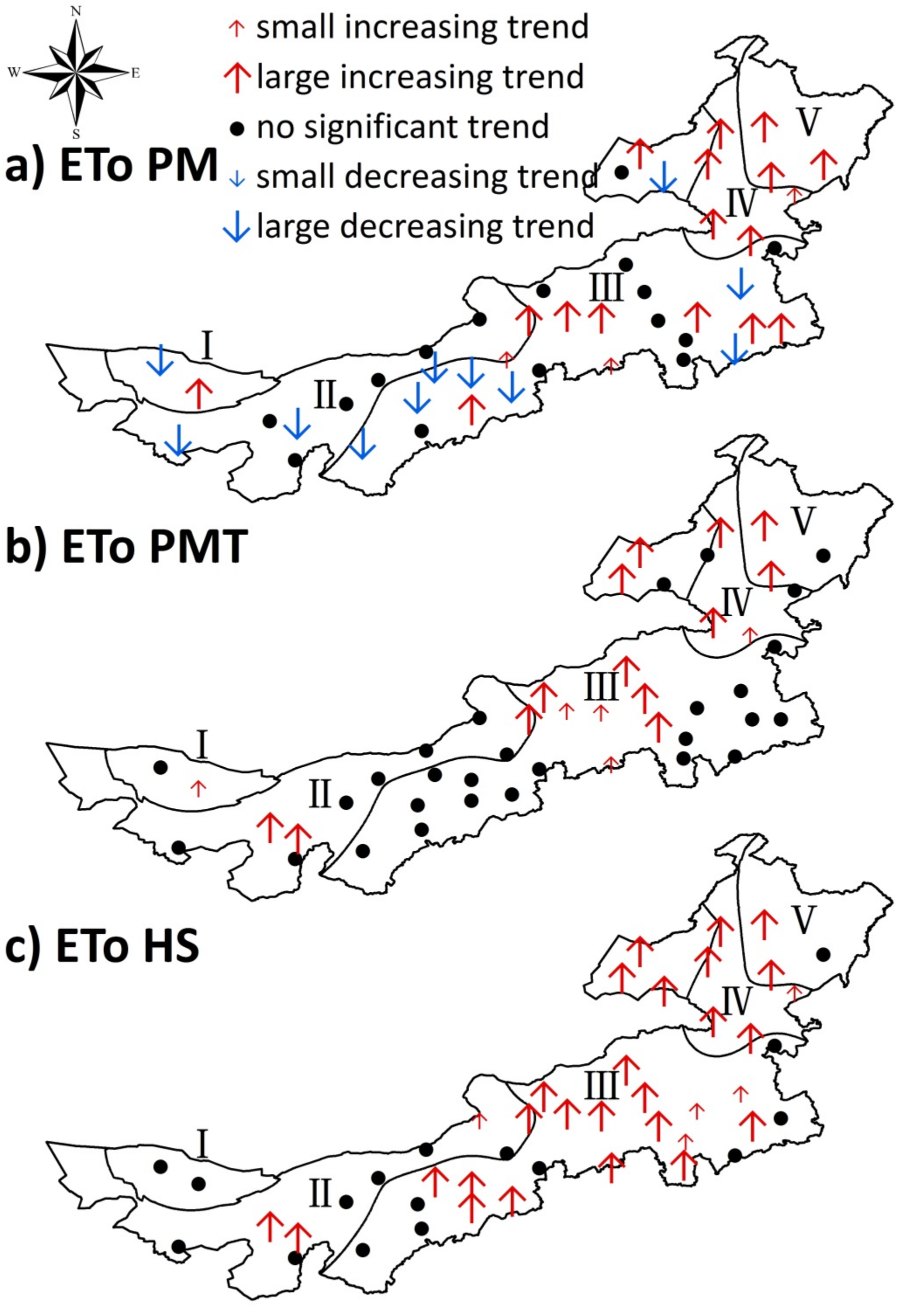


Ren et al., 2015

Climatic zones	Stations	PMT performance indicators			HS performance indicators		
		b	RMSE (mm d^{-1})	EF	b	RMSE (mm d^{-1})	EF
Hyper-arid	JiKede	**0.99**	1.21	0.86	0.97	1.21	0.86
	Ejin	0.98	**1.00**	0.86	0.98	1.03	0.86
	Guaizi Lake	0.97	**1.62**	**0.76**	**0.98**	1.64	0.75
Arid	Jartai	**0.99**	**0.90**	0.86	0.96	0.92	0.86
	Bayan knoll	**1.00**	**0.99**	**0.85**	0.97	1.00	0.84
	Alxa R.	0.98	**1.13**	**0.80**	0.98	1.15	0.79
	Hailisu	0.97	**0.93**	**0.88**	**0.99**	0.99	0.87
	Erenhot	0.98	**0.83**	**0.89**	**1.01**	0.87	0.88
	Hanggin	**1.00**	**0.76**	**0.86**	1.01	0.79	0.85
	Linhe	0.98	**0.64**	0.90	0.98	0.65	0.90
	Mandula	0.98	**0.92**	**0.86**	**0.99**	0.96	0.85
	Sonid L.	**0.98**	**0.85**	**0.89**	0.97	0.86	0.88
	Zhurihe	0.99	**1.01**	**0.85**	0.99	1.06	0.83
	Alxa L.	0.98	**0.90**	**0.84**	**1.00**	0.93	0.83
	Urat r	**1.00**	0.74	0.89	0.97	0.74	0.89
Semi-arid	Damao	0.98	**0.77**	**0.86**	**0.99**	0.81	0.85
	Naranbulag	**1.00**	**0.64**	**0.92**	0.99	0.66	0.91
	Otog	0.98	**0.75**	0.86	0.98	0.76	0.86
	XilinHot	1.00	**0.73**	0.89	1.00	0.74	0.89
	Xin Barag R.	**0.98**	**0.65**	0.91	0.97	0.66	0.91
	Dong Ujimqin	0.97	**0.68**	**0.90**	**1.00**	0.70	0.89
	Kailu	**0.99**	**0.88**	**0.82**	0.98	0.91	0.81
	Abag	**1.00**	0.51	0.92	0.98	**0.45**	**0.93**
	Baotou	**0.98**	0.66	0.88	0.96	**0.65**	**0.89**
	EjinHoro.	0.98	**0.83**	**0.83**	**1.01**	0.86	0.82
	Ongniud	**1.00**	0.90	0.79	0.96	0.90	0.79
	Xin Barag L.	0.98	**0.57**	0.92	**1.00**	0.60	0.92
	Manzhouli	**1.00**	**0.68**	0.89	0.98	0.69	0.89
	Tongliao	**1.00**	**0.88**	**0.81**	0.99	0.90	0.80
	Dongsheng	0.97	**0.66**	**0.89**	**0.98**	0.68	0.88
	Chifeng	**1.00**	0.80	0.83	0.96	**0.79**	0.83
	Jarud	0.98	**0.77**	**0.83**	0.98	0.80	0.82
	Xi Ujimqin	1.00	**0.74**	**0.86**	1.00	0.76	0.85
	Jining	**1.00**	**0.71**	0.84	0.97	0.72	0.84
	Bairin L.	0.98	**0.90**	**0.78**	**0.99**	0.92	0.77
	BaoGuotu	**1.00**	**0.90**	**0.77**	0.99	0.91	0.76
	Linxi	**0.98**	**0.83**	**0.80**	0.96	0.85	0.79
	Hohhot	**1.00**	0.64	0.88	0.96	**0.63**	**0.89**
	Siziwangqi	**1.00**	**0.68**	0.88	0.98	0.70	0.88
	Duolun	**0.99**	**0.73**	**0.83**	0.98	0.76	0.82
	Huade	**1.00**	**0.71**	**0.87**	0.98	0.73	0.86
	Ulanhot	**1.00**	**0.77**	**0.85**	0.99	0.79	0.84
	Hailar	1.01	**0.57**	0.91	**1.00**	0.58	0.91
Dry sub-humid	Sauron	**1.00**	**0.68**	**0.86**	0.97	0.72	0.84
	EjiGuna	0.97	**0.53**	**0.91**	**0.99**	0.55	0.90
	Zhalantun	**0.98**	**0.65**	**0.87**	0.95	0.67	0.86
Moist sub-humid	Arxan	**0.99**	**0.53**	**0.89**	0.98	0.55	0.88
	Bugt	**0.99**	**0.58**	**0.87**	0.96	0.61	0.86
	Tulihe	**1.00**	**0.44**	0.91	0.98	0.46	0.91
	Xiaoer Gou	0.99	0.54	0.89	1.01	**0.53**	0.89

PMT reveals superior to HS





Trend of annual ETo relative to the period 1981 to 2012 in 45 weather stations of Inner Mongolia

PMT reveals superior to HS because, contrarily to HS, their trends do not contradict those of ETo-PM

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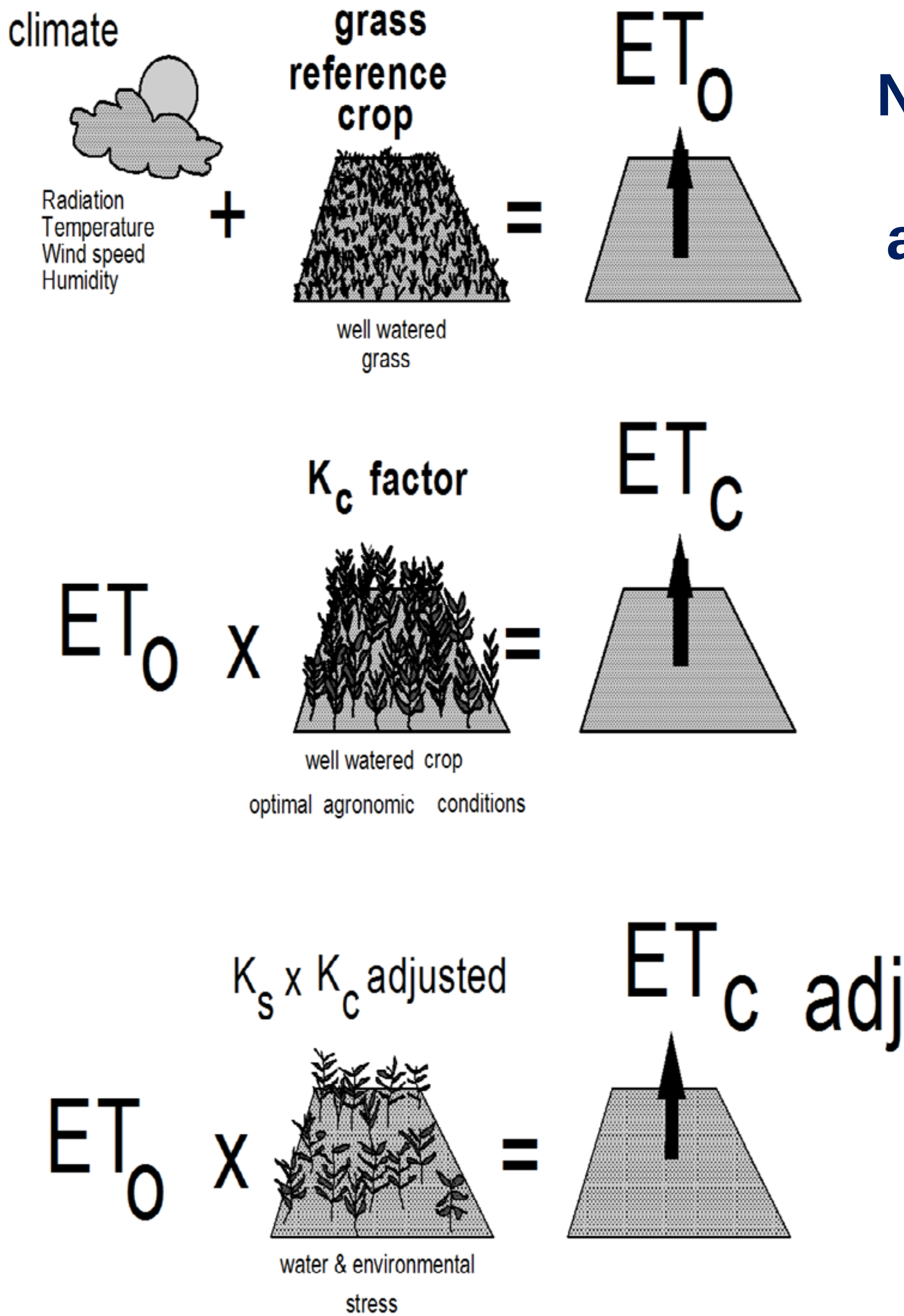
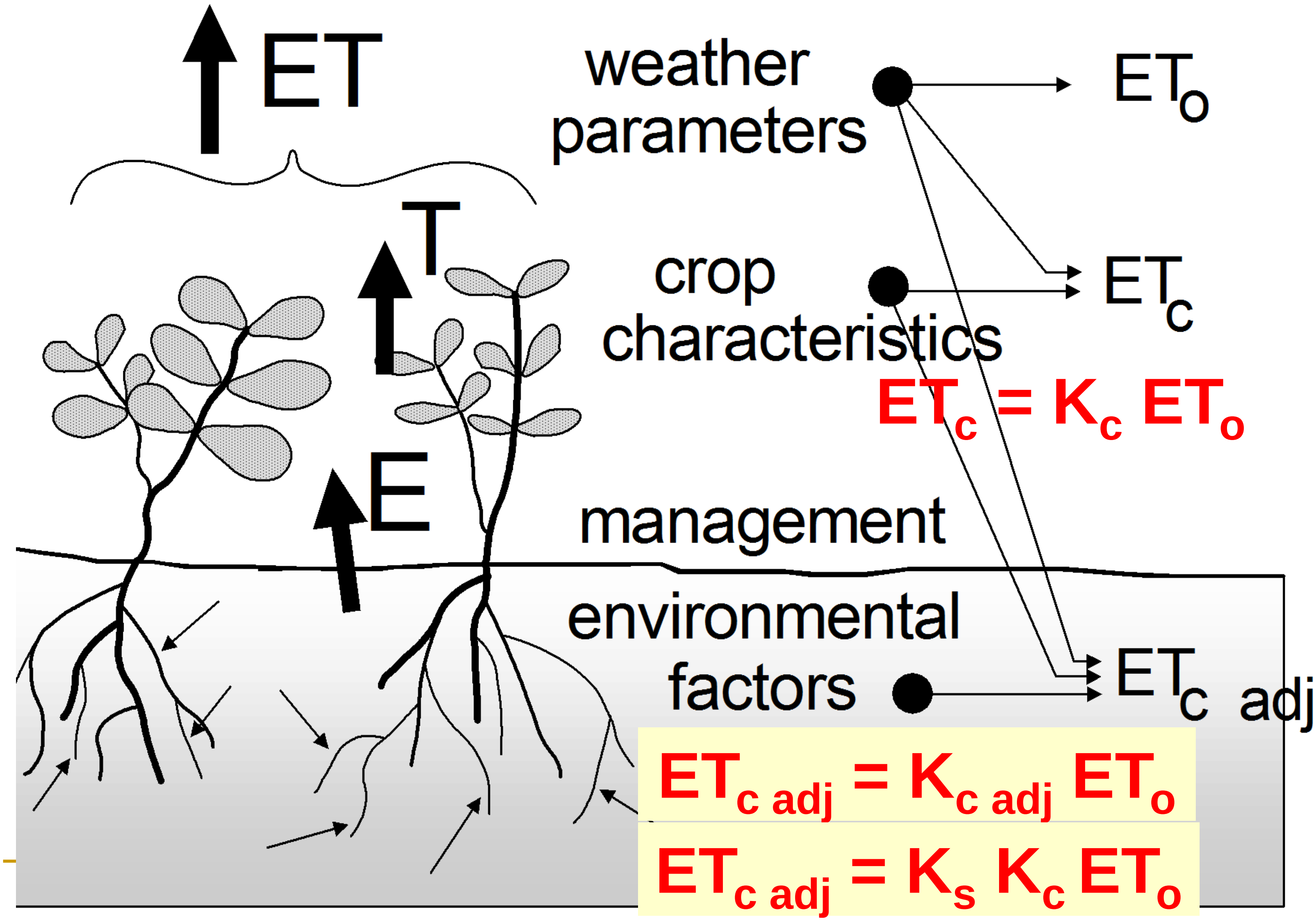
Need to distinguish between potential and actual crop ET



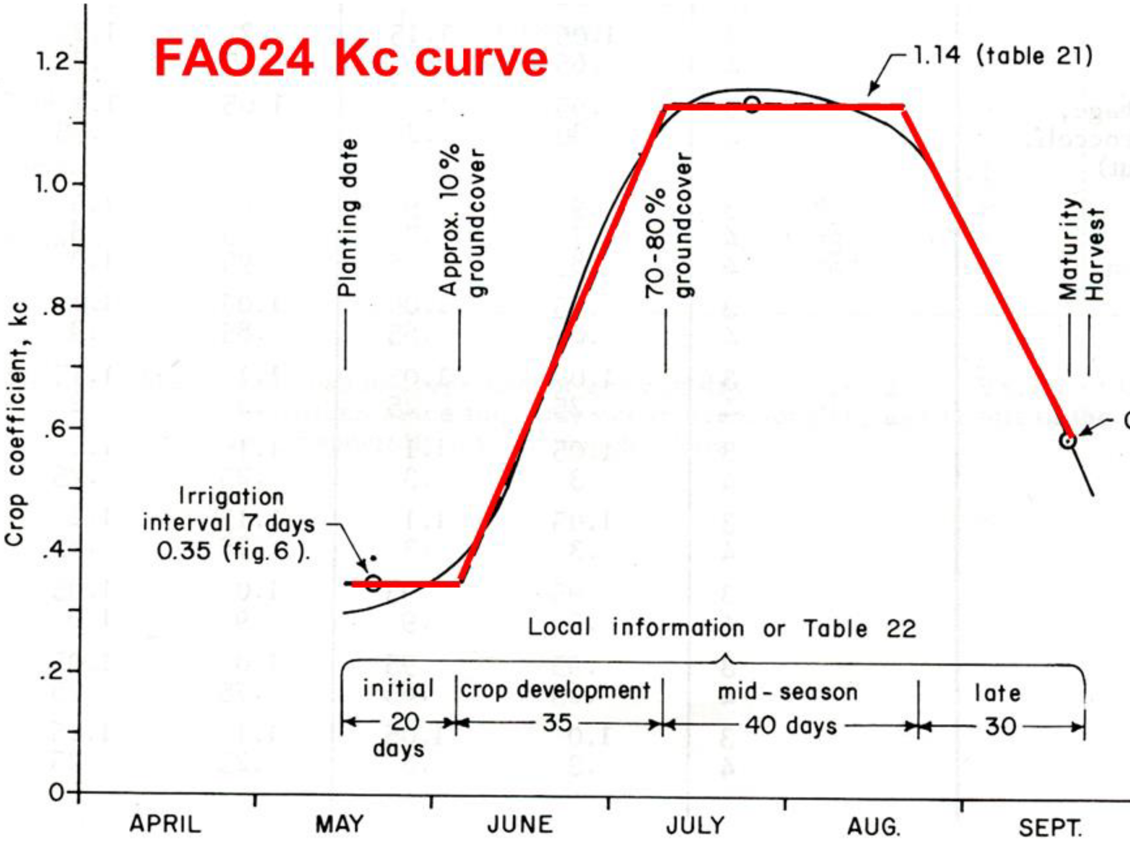
Need to distinguish between potential and actual Kc



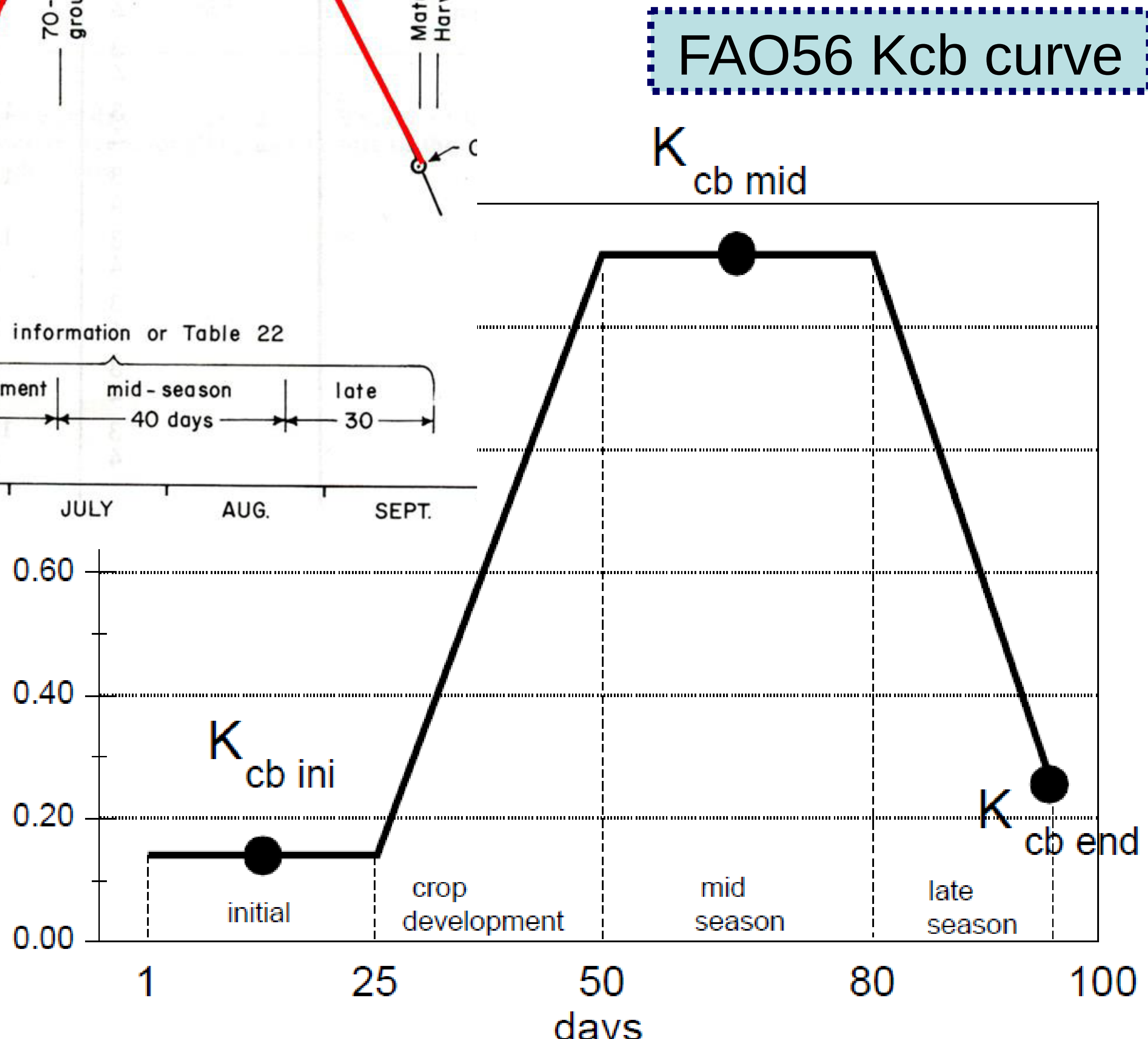
$$ET_c = K_c\ ET_o$$

$$ET_{c\ adj} = K_{c\ adj}\ ET_o$$

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

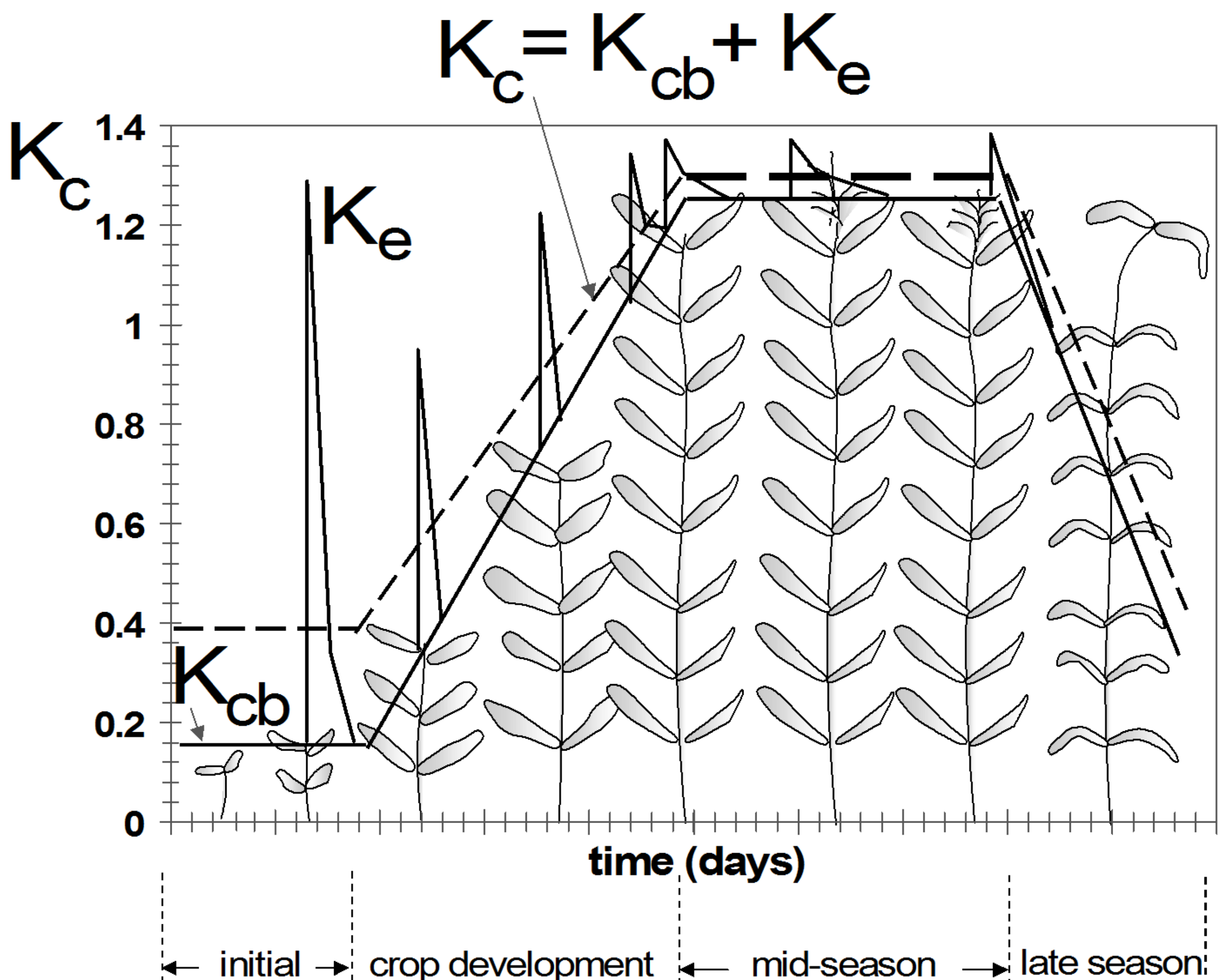


FAO24 Kc curve
1.14 (table 21)
1.2
1.0
.8
.6
.4
.2
0
Crop coefficient, kc
Planting date
Approx. 10% groundcover
70-80% groundcover
Maturity
Harvest
Irrigation interval 7 days 0.35 (fig.6).
Local information or Table 22
initial
20 days
crop development
35
mid-season
40 days
late
30
APRIL
MAY
JUNE
JULY
AUG.
SEPT.



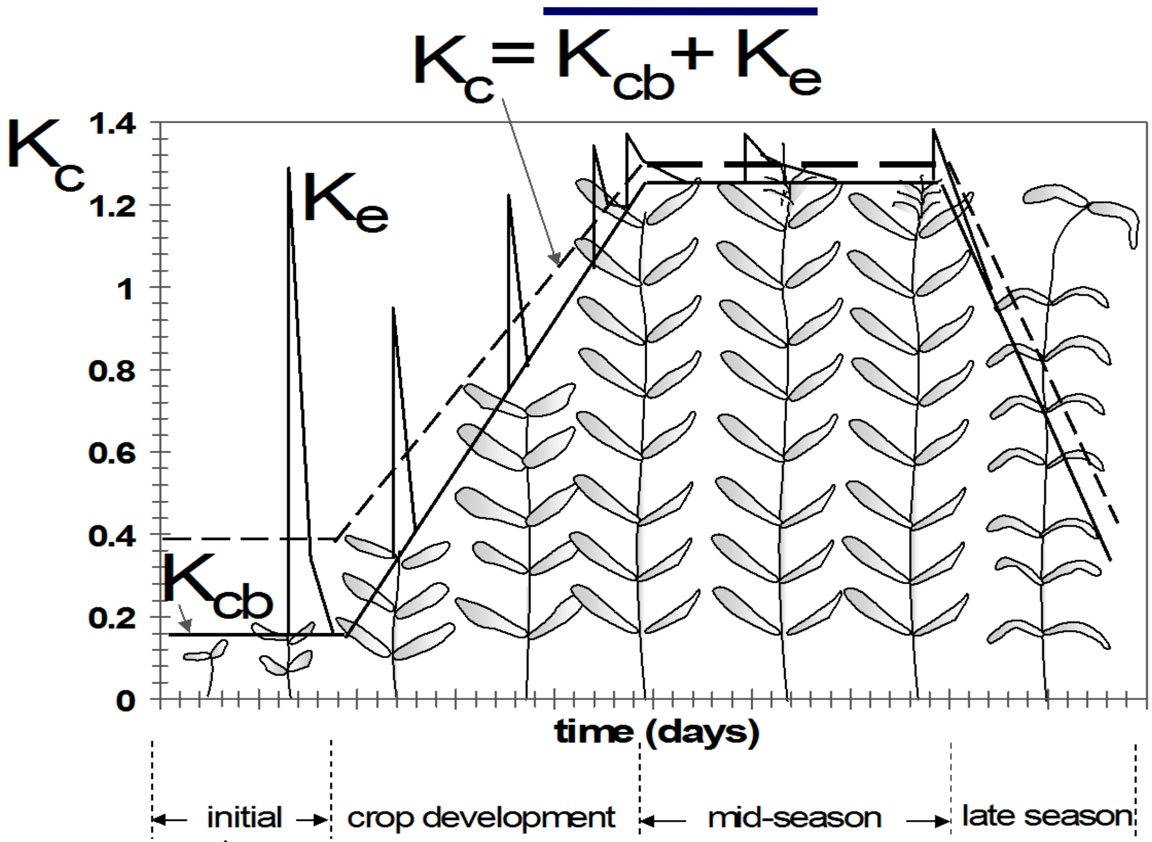
FAO56 Kcb curve
K cb mid
K cb ini
K cb end
0.60
0.40
0.20
0.00
initial
crop development
mid season
late season
1
25
50
80
100
days

Crop coefficient curves showing the basal K_{cb}, soil evaporation K_e and the corresponding single $K_c = K_{cb} + K_e$ curve



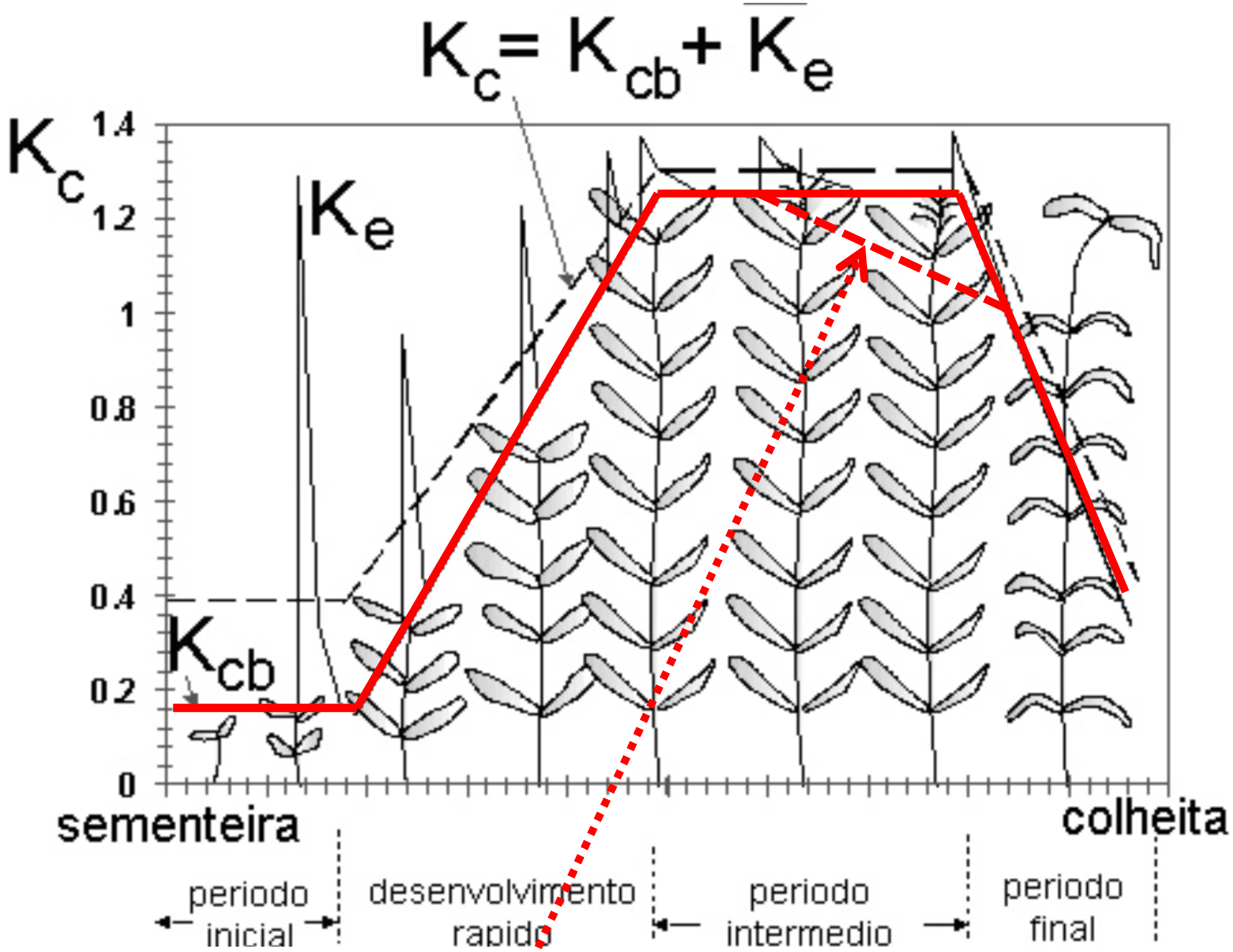
Need for using observed, actual dates for crop stages

FAO56 Dual Kc approach



Kc= Kcb + Ke

$K_{cb\ ini}$ includes the residual diffusive evaporation component

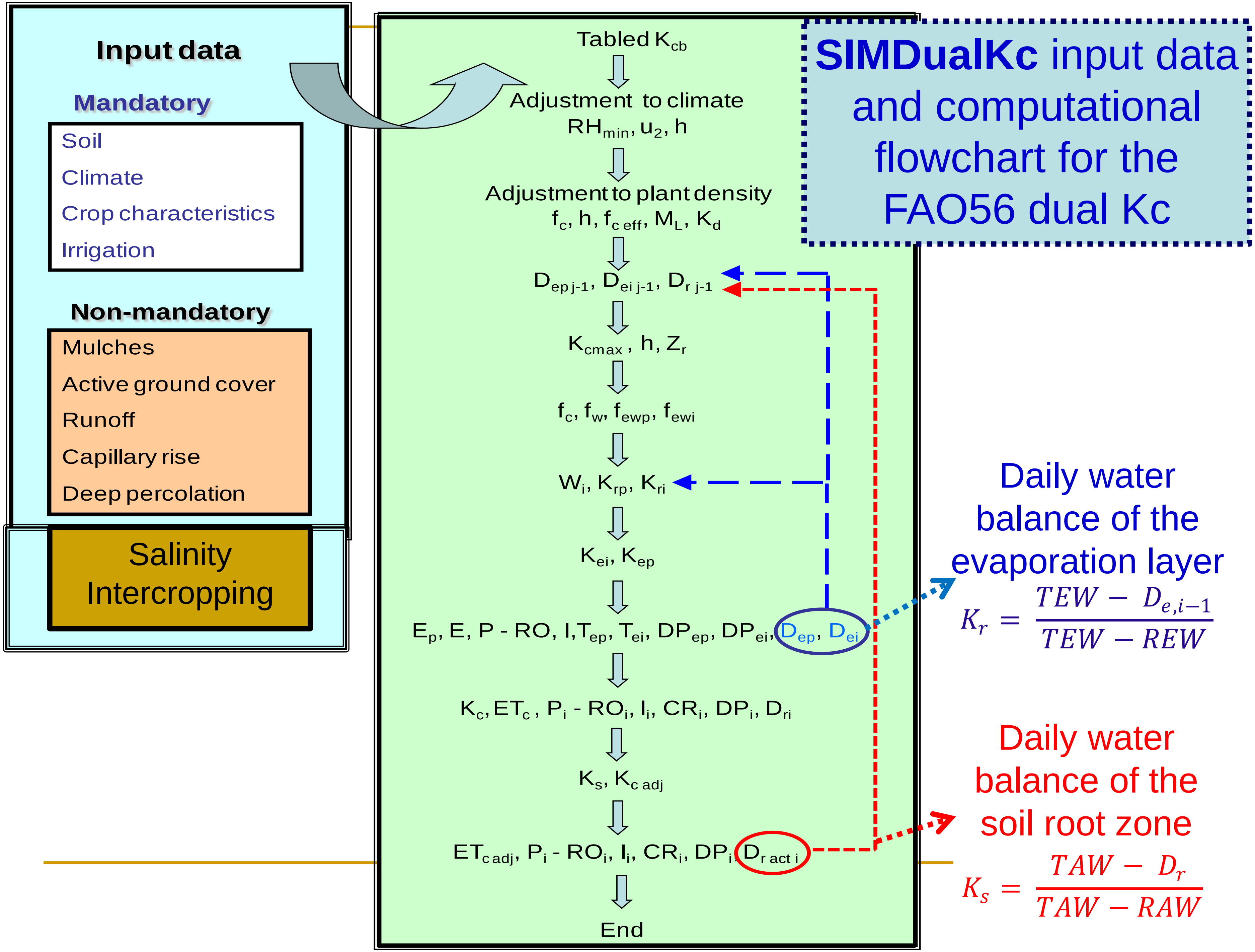


The FAO56 dual Kc method is aplied with **SIMDualKc** water balance simulation model

$$ET_{c\ act} = (K_s K_{cb} + K_e)\ ET_o$$

$$K_s = \frac{TAW - D_r}{TAW - RAW}$$

$$ET_{c\ act} = (K_{cb\ act} + K_e)\ ET_o$$



SIMDualKc input data and computational flowchart for the FAO56 dual Kc
Input data
Mandatory
Soil
Climate
Crop characteristics
Irrigation
Non-mandatory
Mulches
Active ground cover
Runoff
Capillary rise
Deep percolation
Salinity
Intercropping
Tabled K_{cb}
Adjustment to climate
RH_{min}, u_2, h
Adjustment to plant density
f_c, h, $f_{c\ eff}$, M_L, K_d
$D_{ep\ j-1}$, $D_{ei\ j-1}$, $D_{r\ j-1}$
$K_{c\ max}$, h, Z_r
f_c, f_w, f_{ewp}, f_{ewi}
W_i, K_{rp}, K_{ri}
K_{ei}, K_{ep}
E_p, E, P - RO, I, T_{ep}, T_{ei}, DP_{ep}, DP_{ei}, D_{ep}, D_{ei}
K_c, ET_c, P_i - RO_i, I_i, CR_i, DP_i, D_{ri}
K_s, $K_{c\ adj}$
$ET_{c\ adj}$, P_i - RO_i, I_i, CR_i, DP_i, $D_{r\ act\ i}$
End
Daily water balance of the evaporation layer
$K_r = \frac{TEW - D_{e,i-1}}{TEW - REW}$
Daily water balance of the soil root zone
$K_s = \frac{TAW - D_r}{TAW - RAW}$

FAO-56 Dual Crop Coefficient Method for Estimating Evaporation from Soil and Application Extensions

Richard G. Allen, M.ASCE[1]; Luis S. Pereira, M.ASCE[2]; Martin Smith[3]; Dirk Raes[4]; and James L. Wright, M.ASCE[5]

DOI: 10.1061/(ASCE)0733-9437(2005)131:1(2)

An application extension aimed at increased accuracy of Ke computation for incomplete cover crops irrigated with drip systems:

Soil evaporation coefficient

$$K_e = K_r(K_{c\ max} - K_{cb}) \leq f_{ew}K_{c\ max}$$

Extension

$$K_e = K_{ei} + K_{ep}$$

Soil evaporation coefficient relative to the **soil fraction wetted by both irrigation and by precipitation**

$$K_{ei} = K_{ri}W(K_{c\ max} - K_{cb}) \leq f_{ewi}K_{c\ max}$$

Soil evaporation coefficient relative to the fraction of soil that is exposed and wetted by precipitation only

$$K_{ep} = K_{rp}(1 - W)(K_{c\ max} - K_{cb}) \leq f_{ewp}K_{c\ max}$$

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The 2009 approach considers the influence of crop density and height on ET_c through a **density coefficient** (K_d), that depends of the **fraction of ground cover** (f_c) **and crop height** h.

$$K_{cb} = K_{c\min} + K_d \left(K_{cbfull} - K_{c\min} \right)$$

K_{cmin} = minimum K_{cb} for bare soil (~0.10-0.15)

$K_{cb\ full}$ = K_{cb} for full ground covered by vegetation

$$K_d = \min\left(1,\ f_{c\,eff}^{\left(\frac{1}{1+h}\right)},\ M_L\ f_{c\,eff} \right)$$

K_d = density coefficient (0-1)

M_L = multiplier on $f_{c\ eff}$ (~1.5-2)
(to set upper flux limit per fraction of cover)

$f_{c\ eff}$ = effective fraction of ground covered (shaded) by vegetation (0-1)

h = height, m

Allen and Pereira, Irri Sci, 2009

Assuming bare soil between vegetation:

$$K_{cb} = K_{c\,min} + K_d\left(K_{cb\,full} - K_{c\,min}\right)$$

K_{cmin} = minimum K_{cb} for bare soil (~0.10-0.15)

K_d = density coefficient (0-1)

$K_{cb\,full}$ = K_{cb} for full ground covered by vegetation

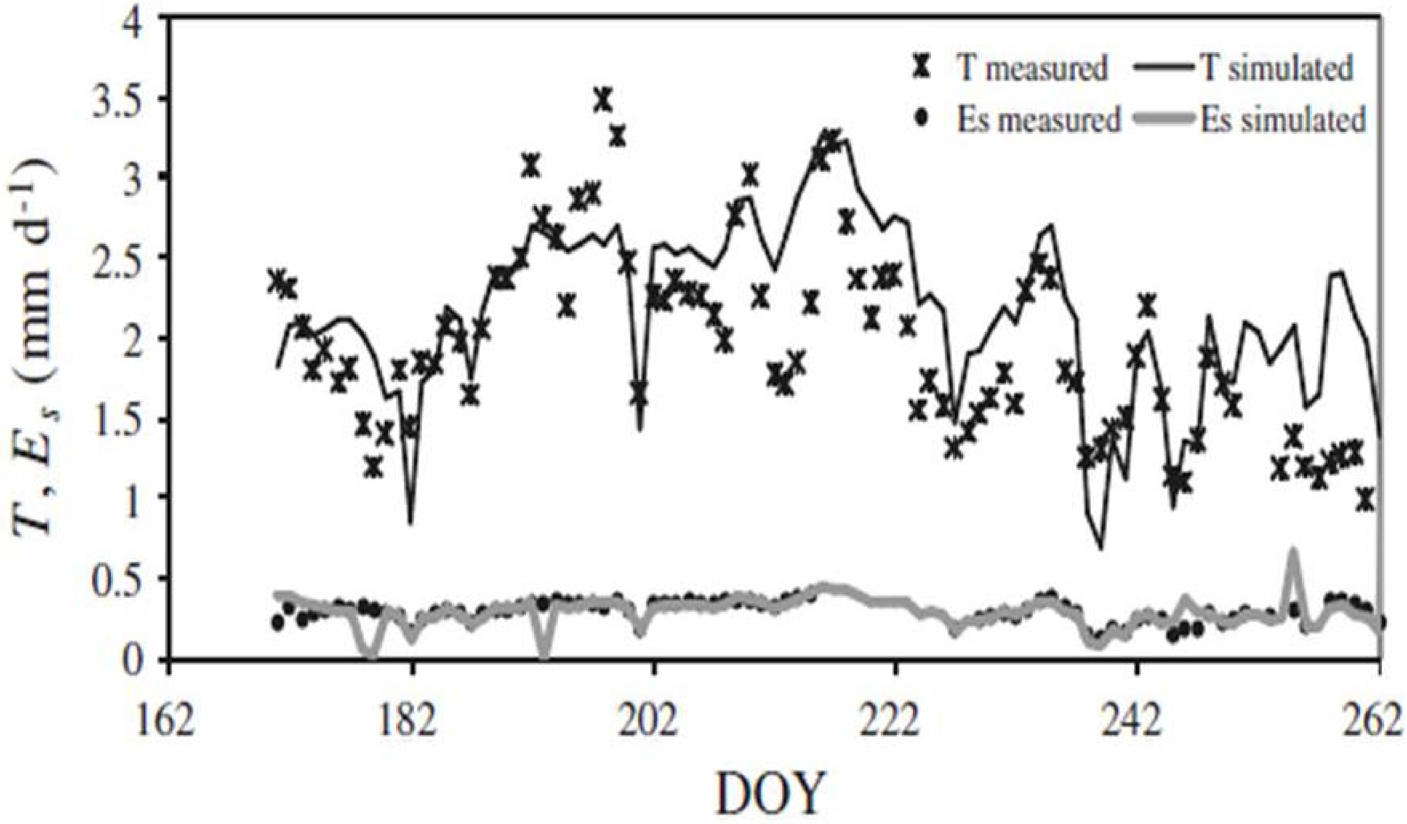
Trees and vines with active ground cover:

$$K_{cb} = K_{cb\,cover} + K_d\left(\max\left[K_{cb\,full} - K_{cb\,cover}, \frac{K_{cb\,full} - K_{cb\,Cover}}{2}\right]\right)$$

$K_{cb\,cover}$ = Kcb of the ground cover in the absence of tree foliage.

APPLICATIONS OF THE FAO56 DUAL CROP COEFFICIENT

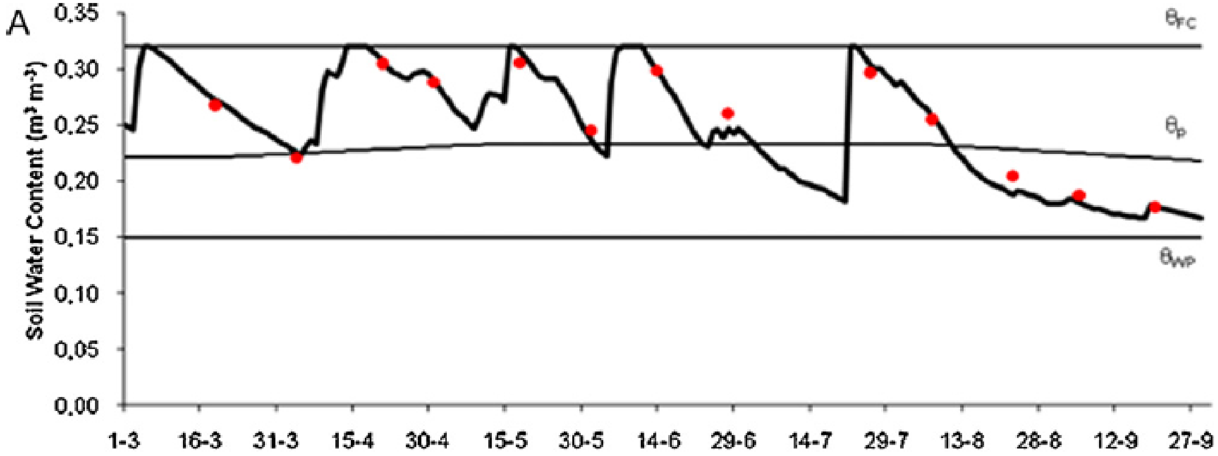
The FAO56 dual crop coefficient approach using a density factor applied to a peach orchard: SIMDualKc model vs. eddy covariance, sap flow and microlysimeter observations



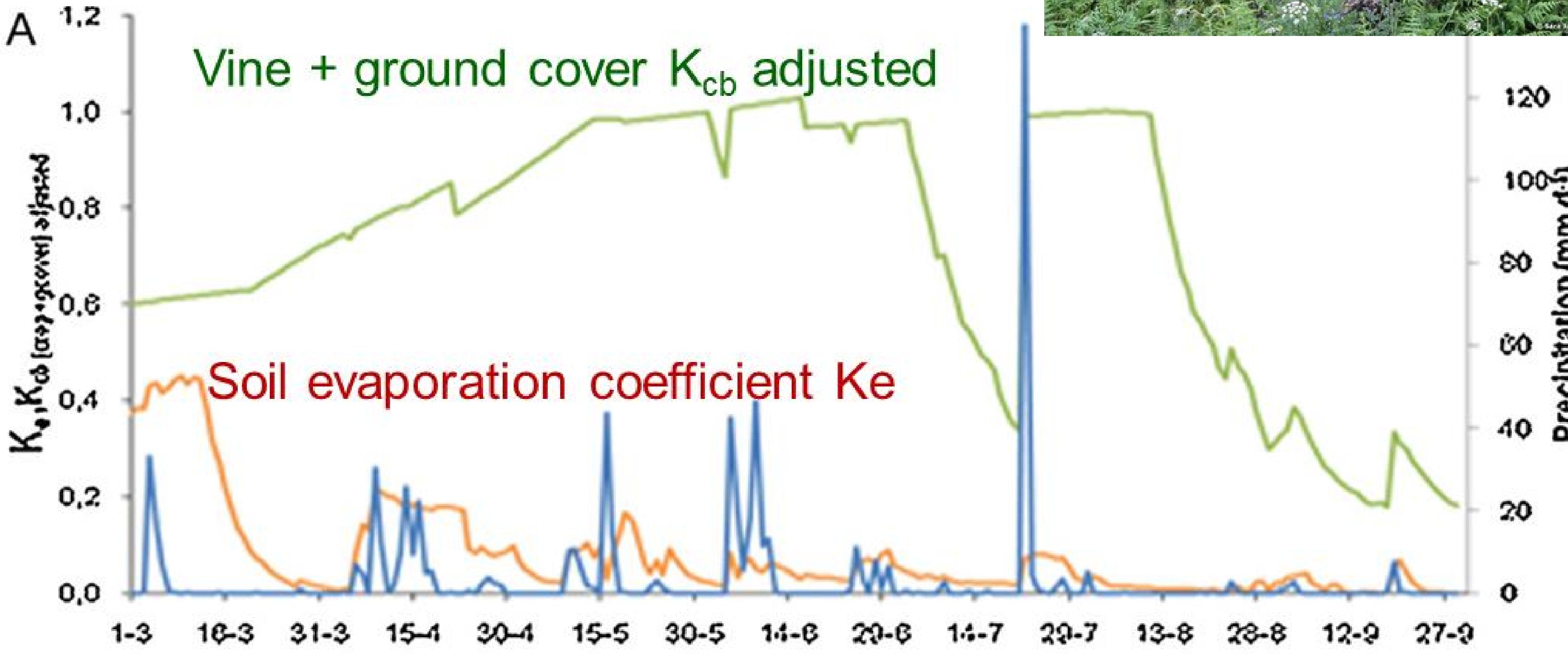
T Paço et al., Irri Sci, 2012

The FAO56 dual-Kc approach in Albariño vineyards with active ground cover

Simulated vs. observed soil water content

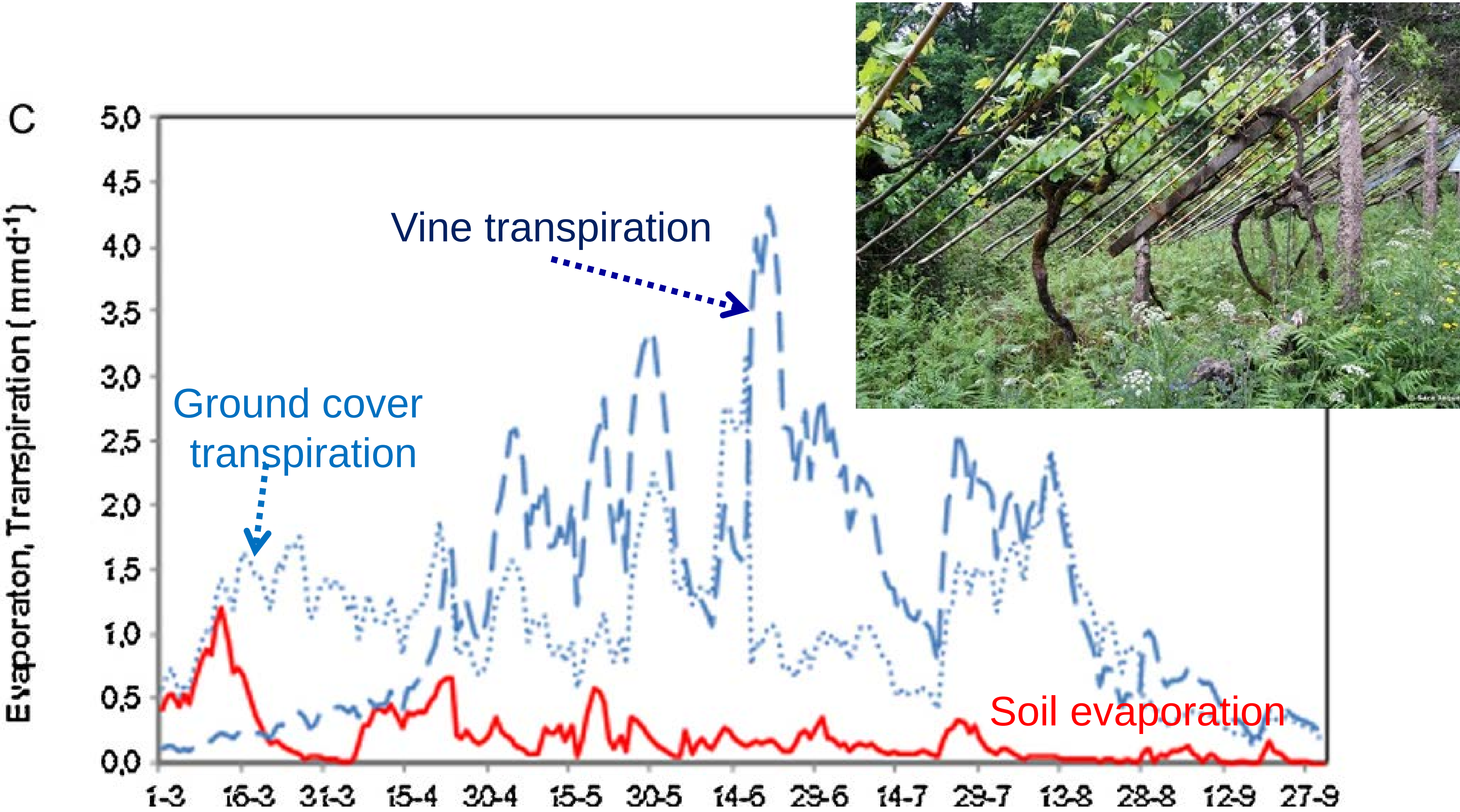


Kcb and Ke curves



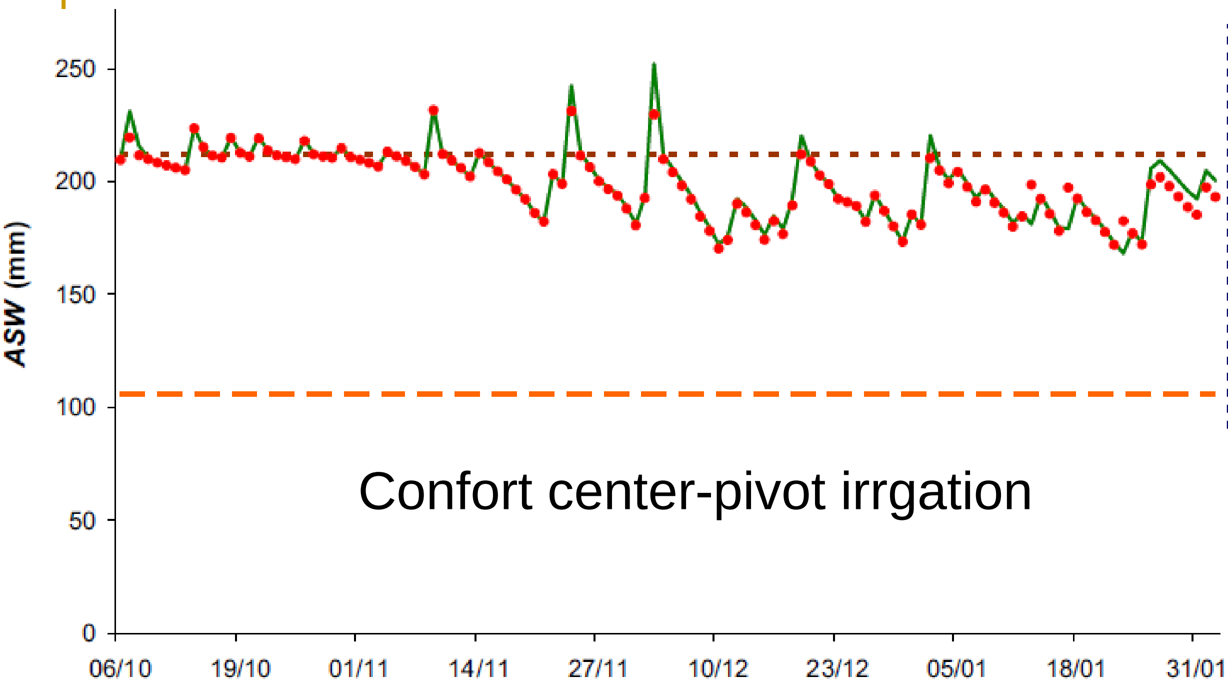
Fandiño et al., 2012, AGWAT

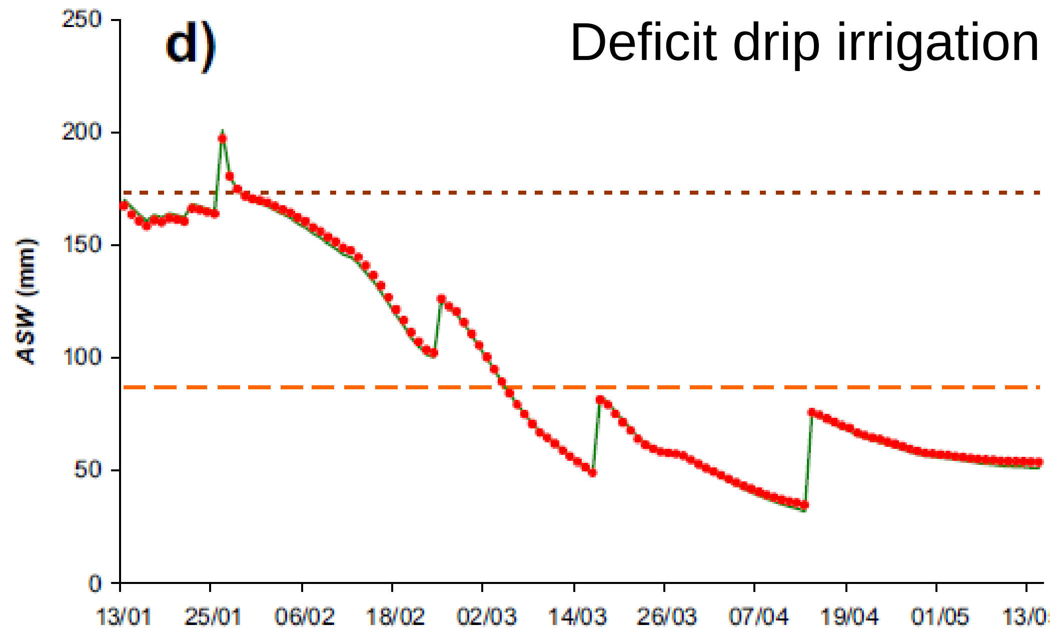
Partition of ET into crop transpiration, ground cover transpiration and soil evaporation



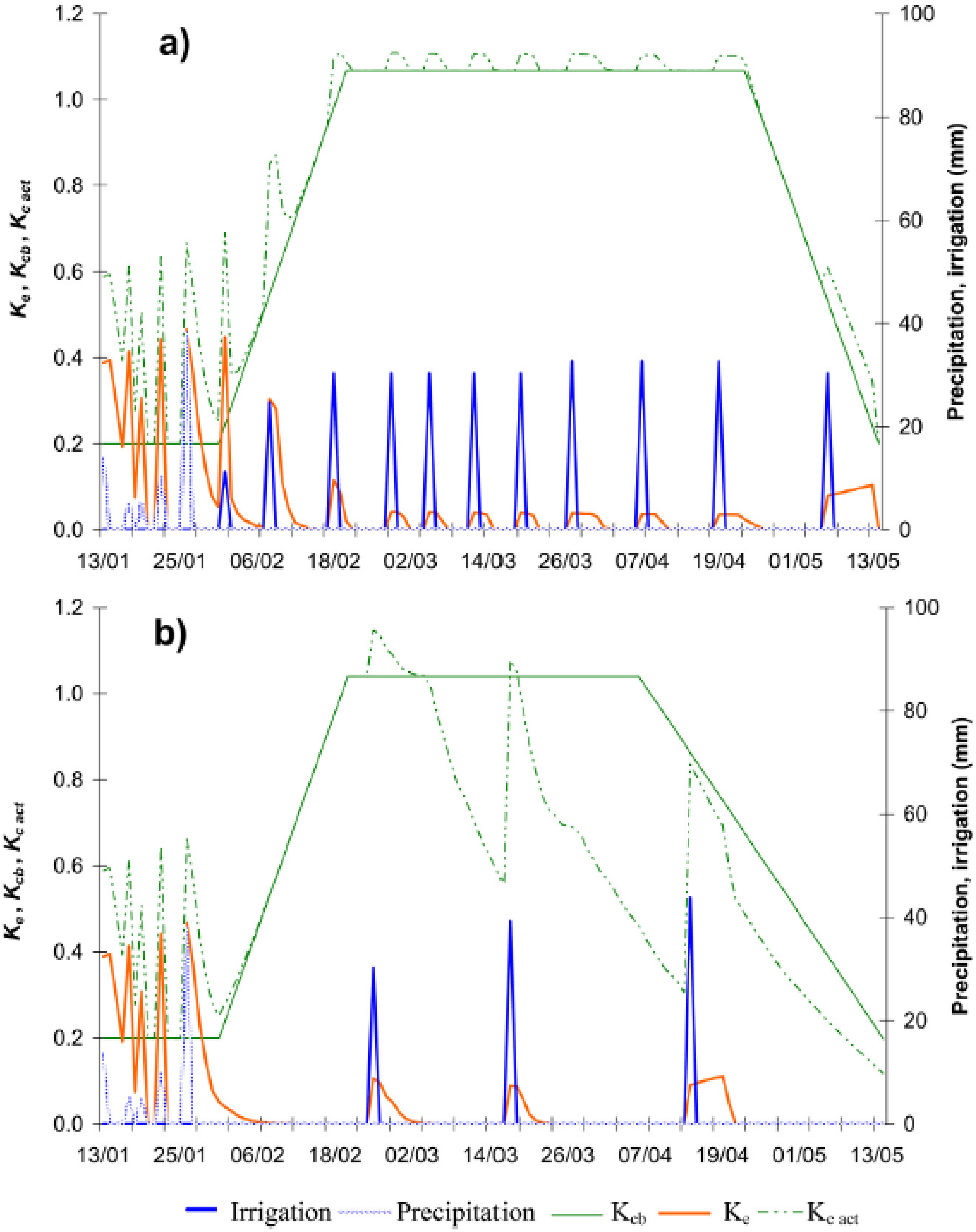
Fandiño et al., 2012, AGWAT

Dual crop coefficients for maize in Brazil with sprinkler and drip irrigation and **mulched soil**





Martins et al., 2013, Biosystems Eng



Maize without stress

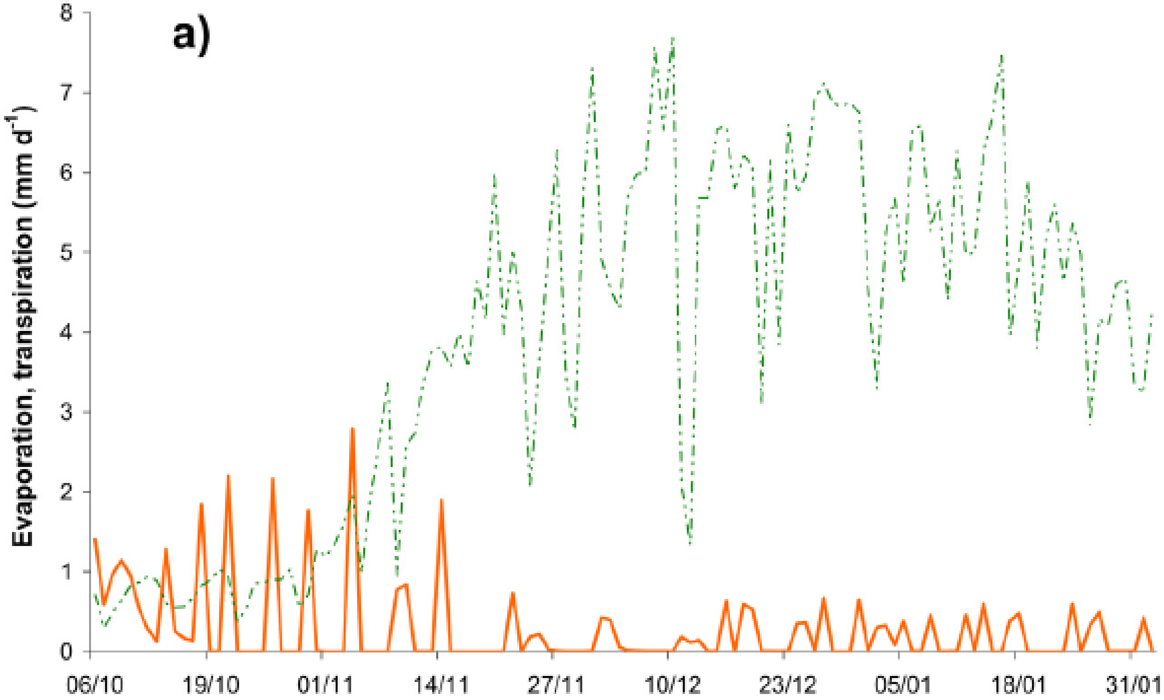
$K_c = K_{cb} + K_e$

Maize with deficit irrigation

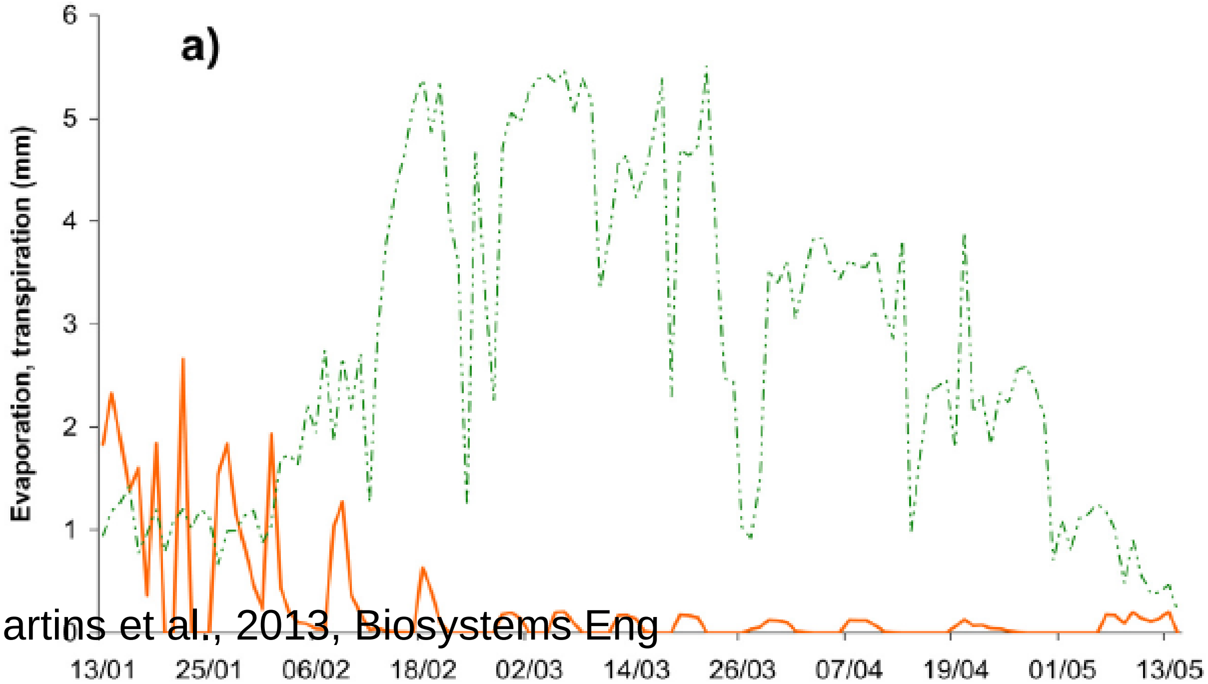
$K_{c\,adj} = K_s\,K_{cb} + K_e$

Martins et al., 2013, Biosystems Eng

Partitioning maize ET into transpiration and soil evaporation



Sprinkler irrigation, no stress, mulched soil

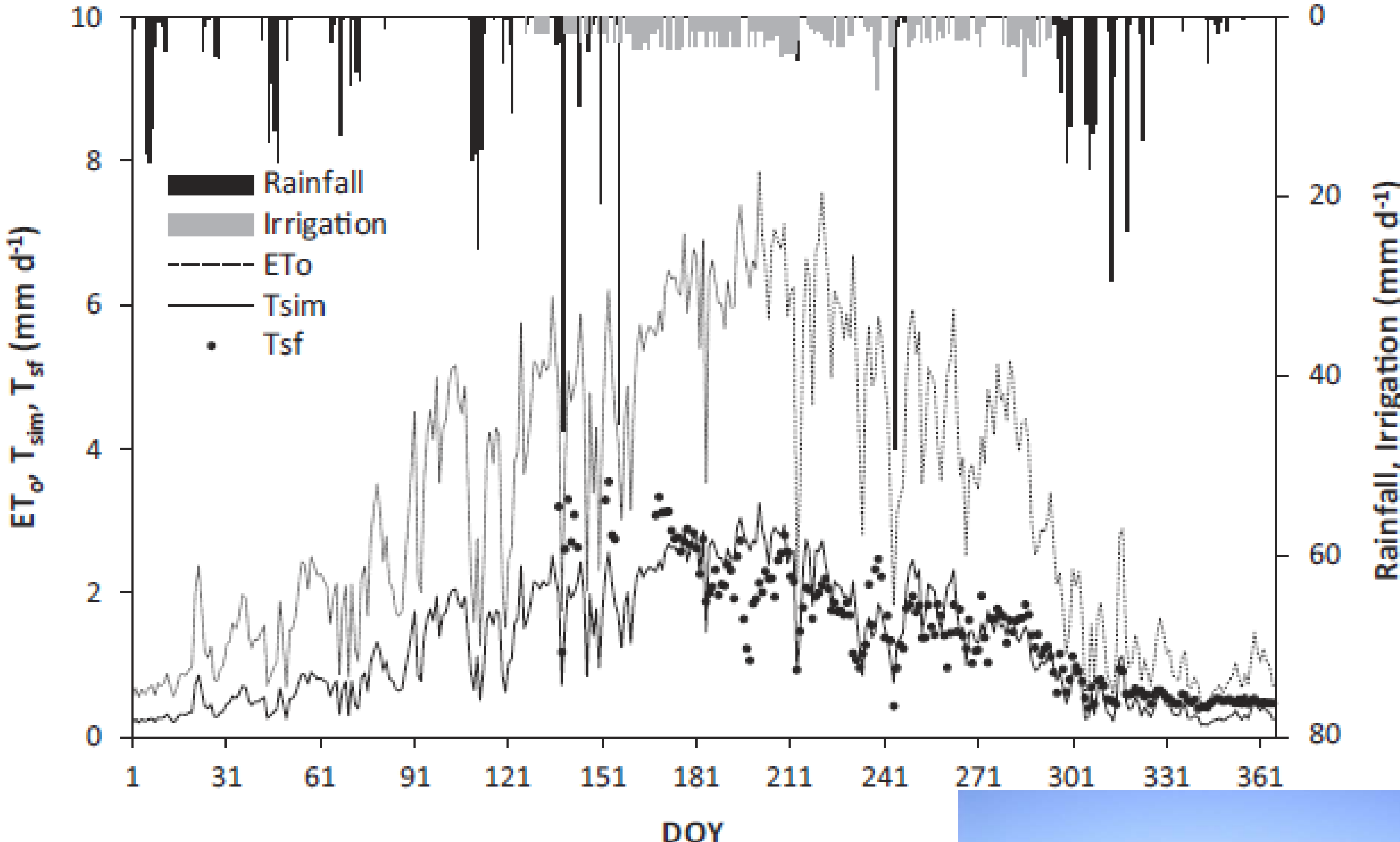


Martins et al., 2013, Biosystems Eng

Drip irrigation, with stress, mulch

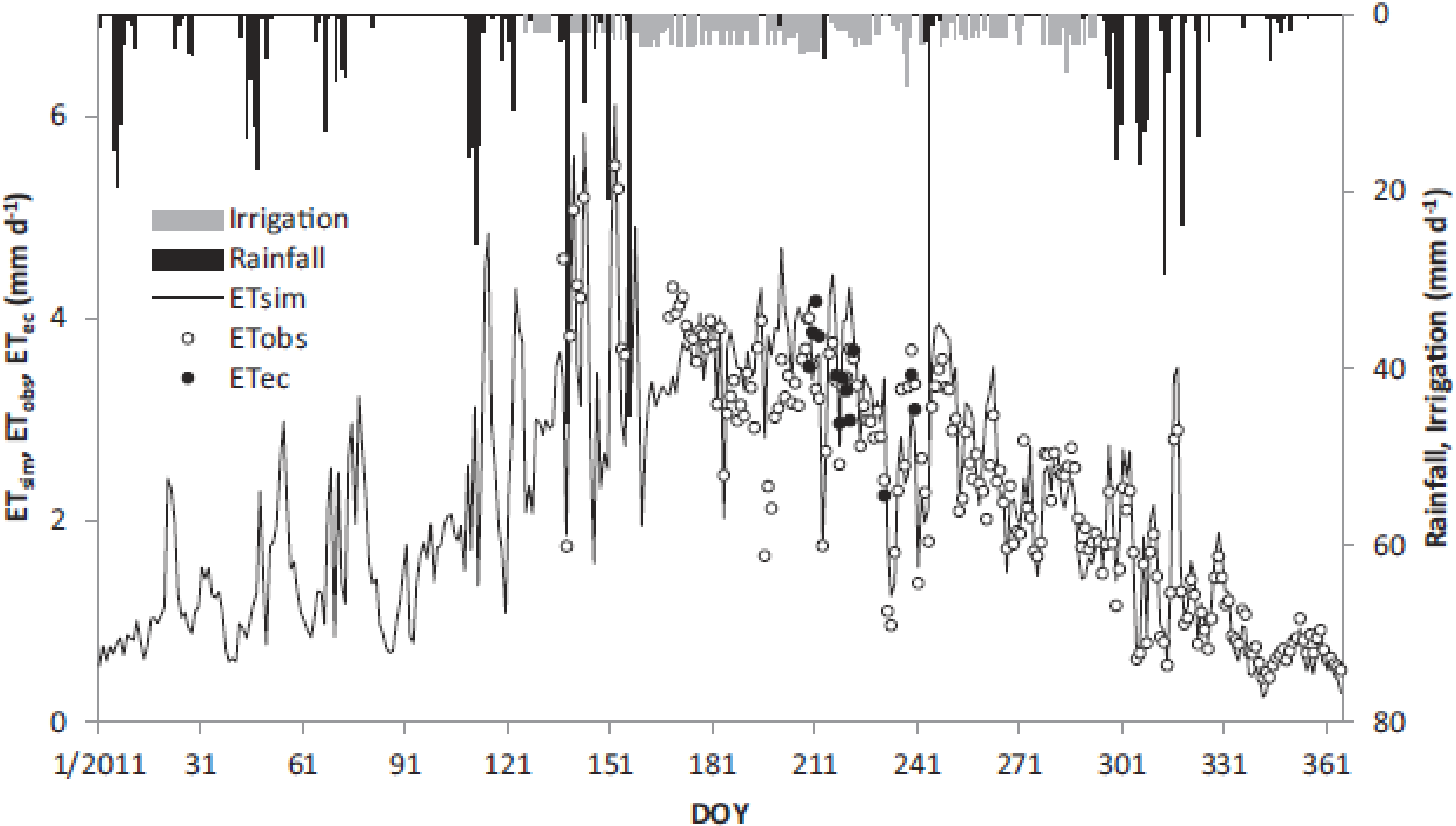
Martins et al., 2013, Biosystems Eng

FAO56 dual Kc applied to a super-intensive olive orchard



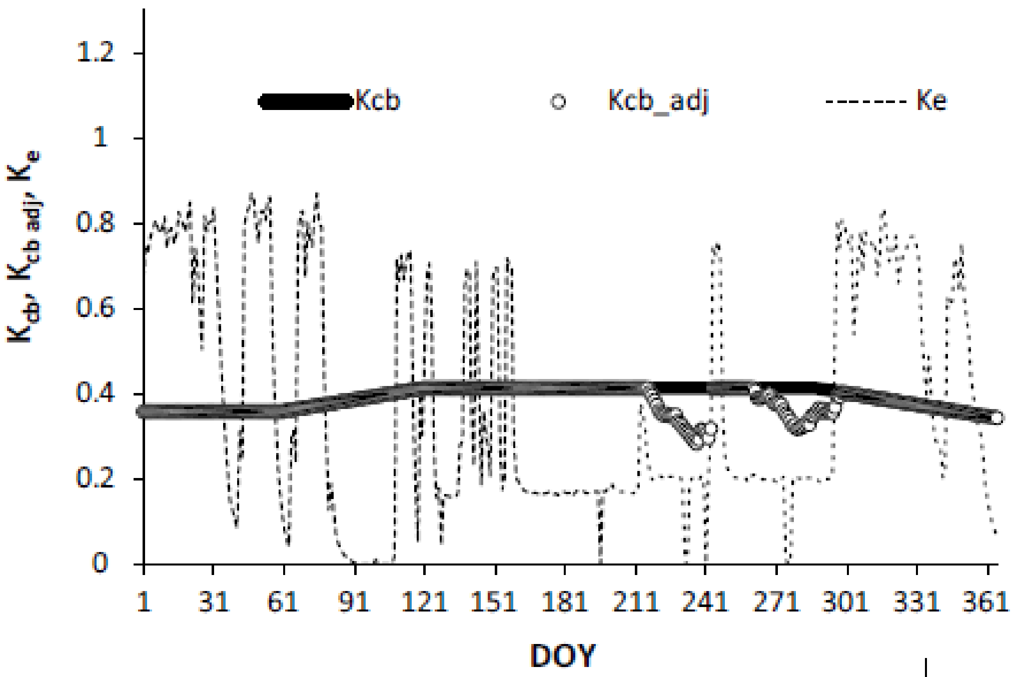
- Tsim: Plant transpiration modeled with SIMDualKc
- Tsf: sap-flow calibrated transpiration
- ETo
- Rainfall and irrigation

T Paço et al., J. Hydrology, 2014



Comparing evapotranspiration simulated with SIMDualKc (ETsim) with ETobs (observed data), ET obtained with the eddy covariance technique (ETec), reference evapotranspiration (ETo), rainfall and irrigation, 2011

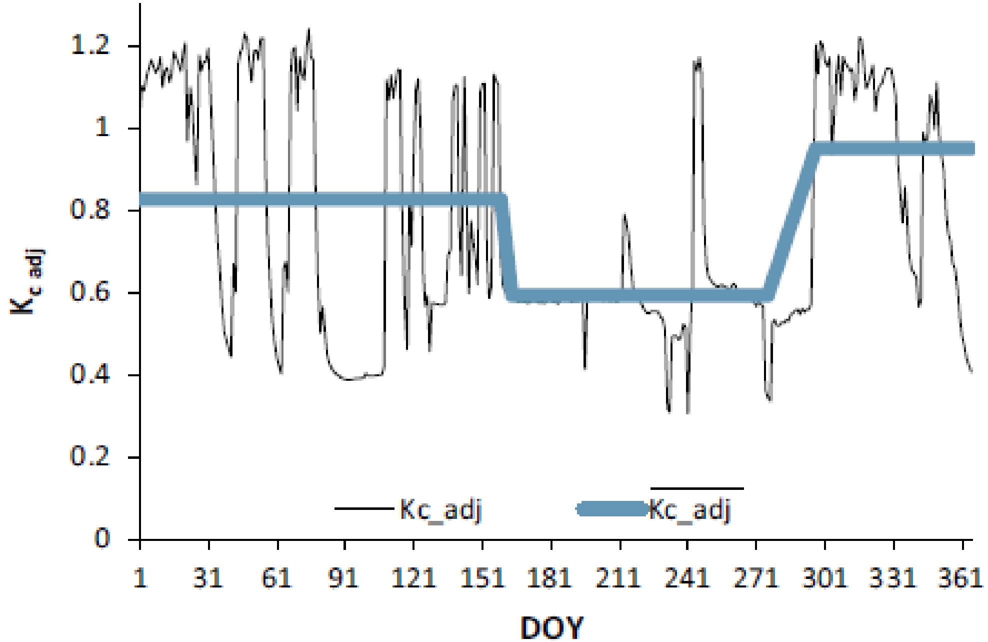
T Paço et al., J. Hydrology, 2014



Daily dual crop coefficients derived from SIMDualKc:

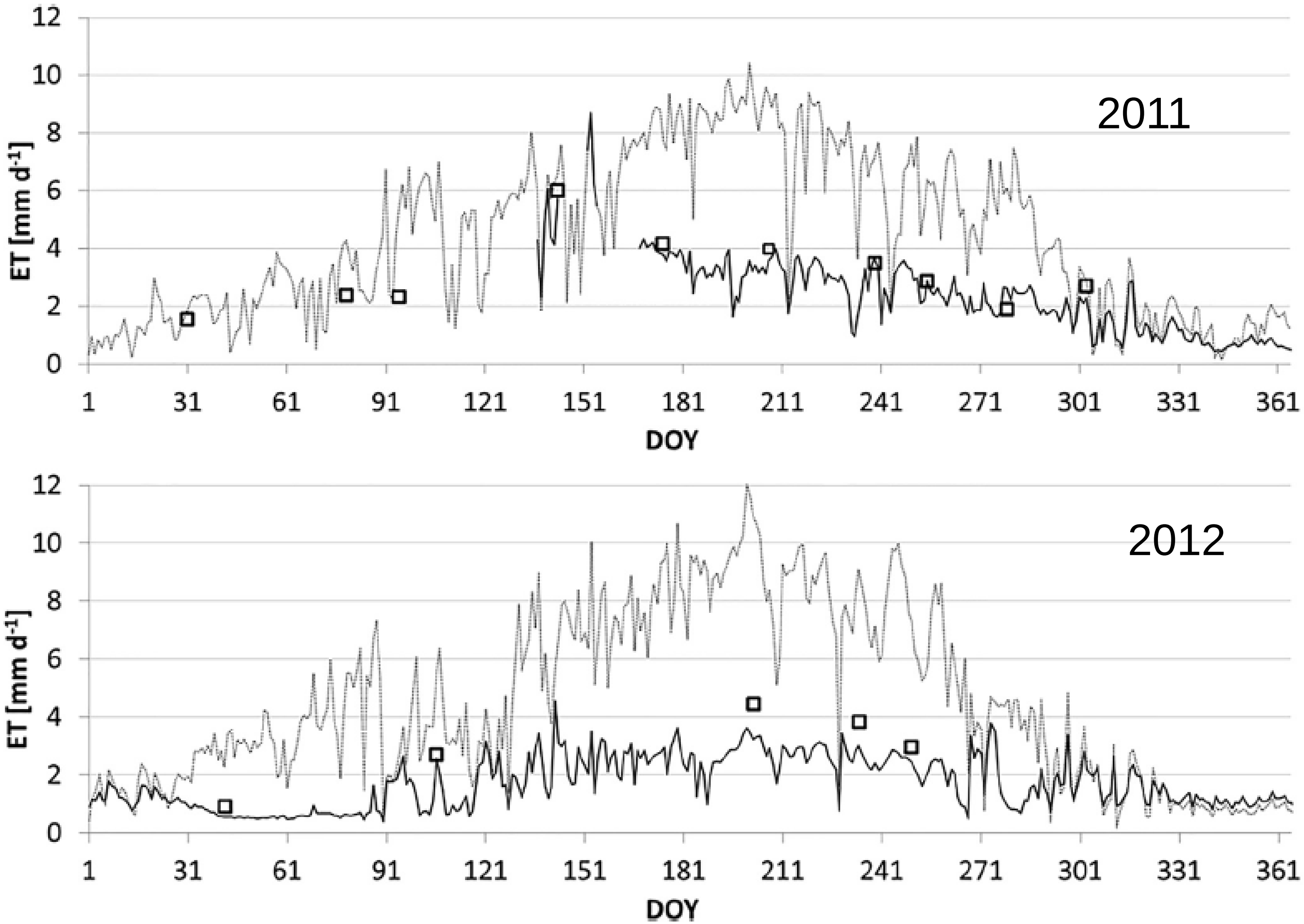
- basal crop coefficient adjusted for climate conditions and canopy density (Kcb),
- adjusted basal crop coefficient (Kcb adj) for water stress conditions,
- soil evaporation coefficient (Ke)

- Daily crop coefficient adjusted for water stress (Kc adj = Kcb adj + Ke)
- mean Kc adj for the different growth stages



T Paço et al., J. Hydrology, 2014

Olives evapotranspiration derived from ground data (--- ET_{obs}), and from METRIC algorithm (□, ET_{METRIC}) and alfalfa reference ET (— ET_r)

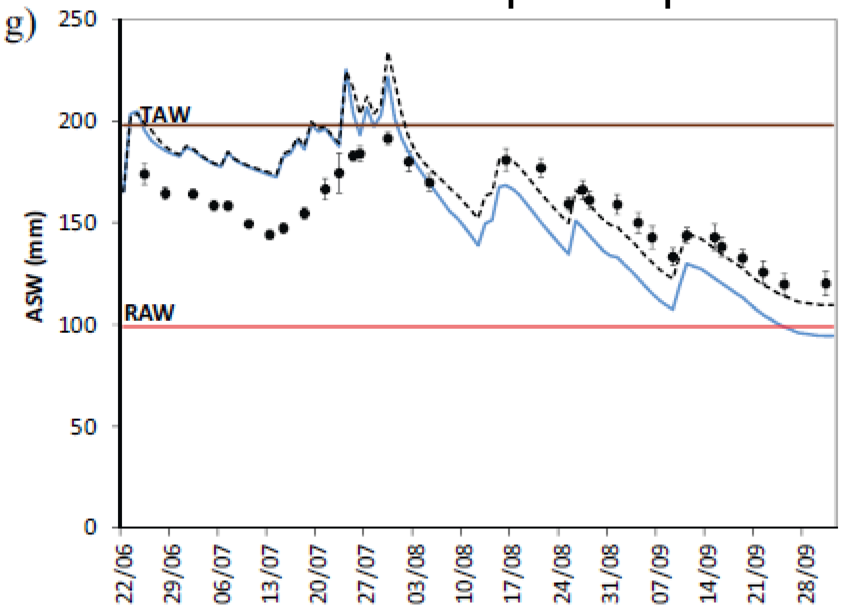


Pôças et al., 2014, Biosystems Eng.

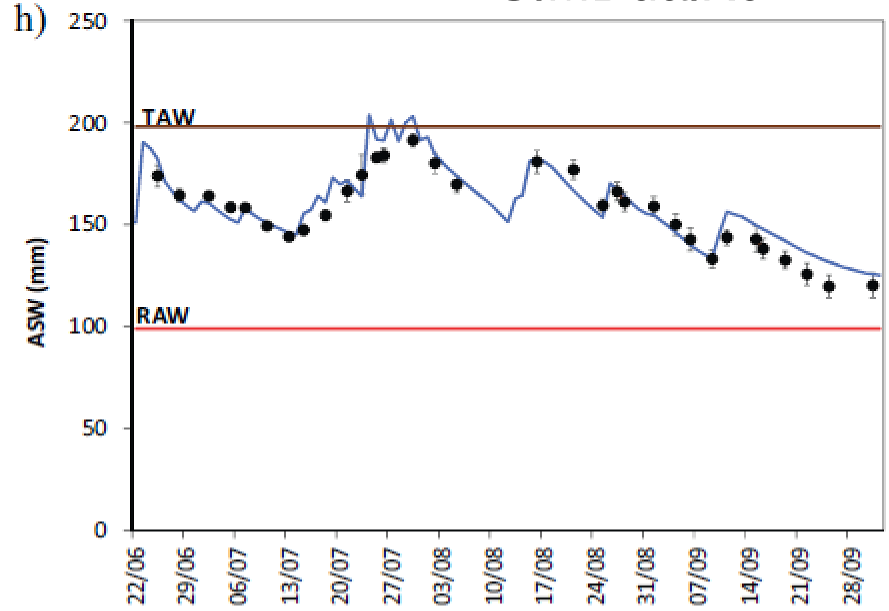
LEAF

FAO56 dual Kc and other dual Kc approach applied to a soybean crop in China

AquaCrop

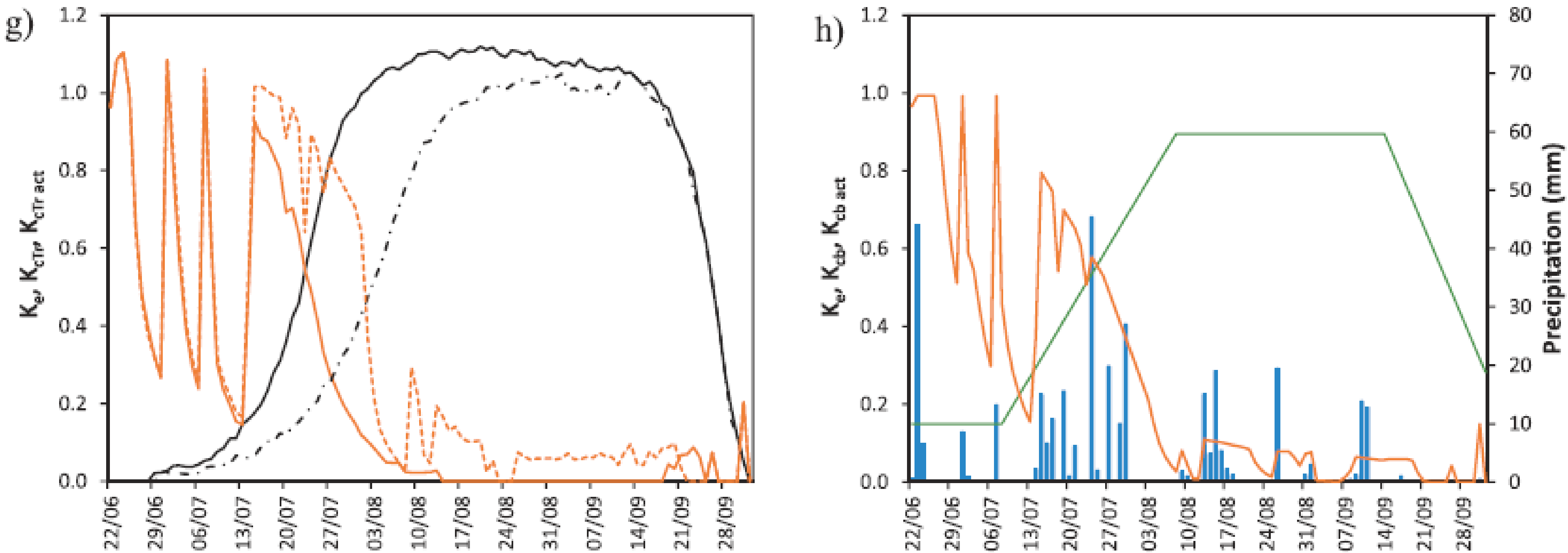


SIMDualKc



Observed (•) and simulated (—) daily available soil water (ASW) using data of 2011.
AquaCrop simulation using default parameters (---)

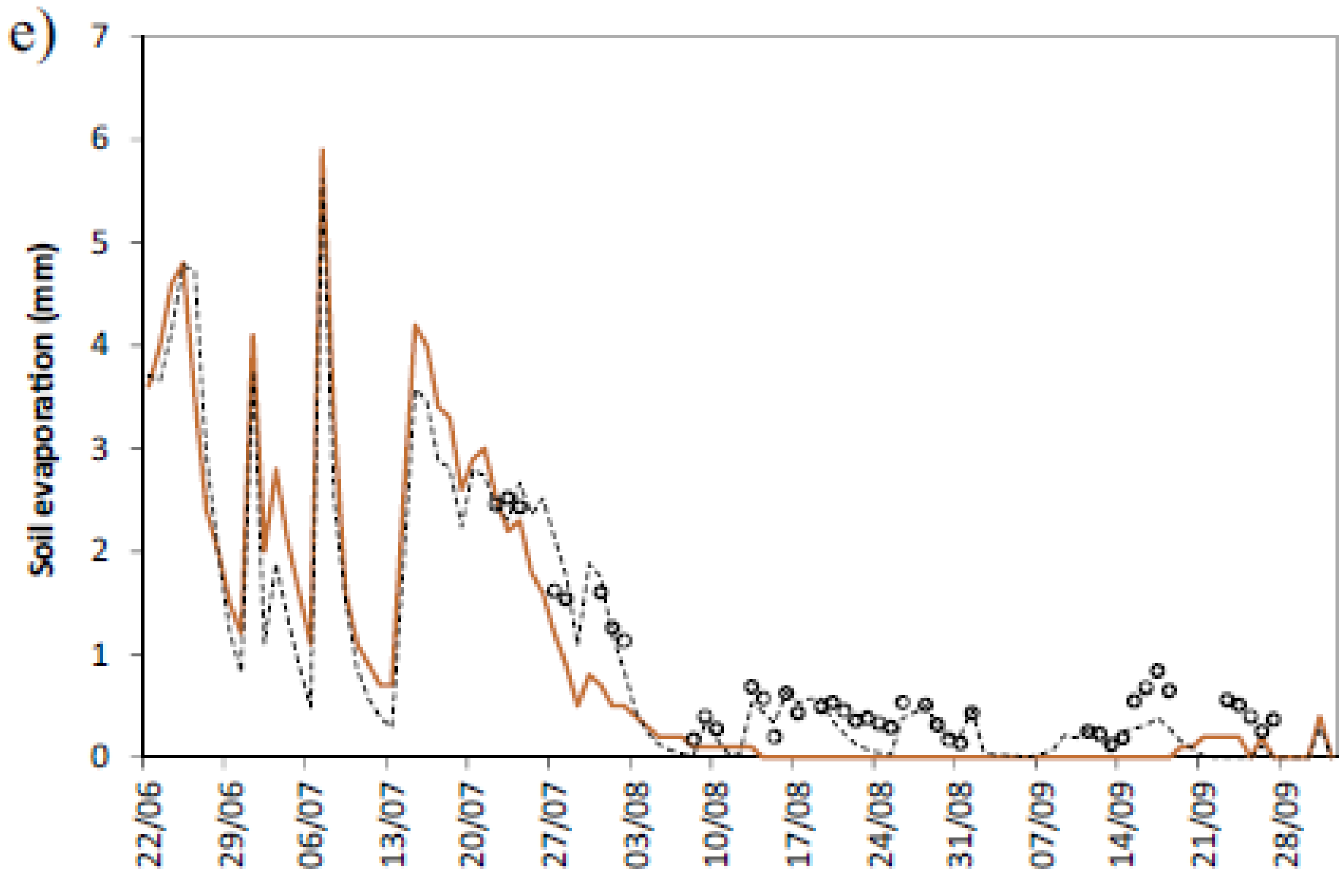
P. Paredes, AGWAT, 2015



K_e when using default ( ) and calibrated parameters ( ); K_{cb} ( ); $K_{cb\ adj}$ ( ); K_{cTr} when using default ( ) and calibrated parameters ( ), $K_{cTr\ adj}$ ( ), precipitation ( ), irrigation ( )

Seasonal variation of the soil evaporation coefficient (Ke) and crop coefficients (Kcb or Kc,Tr) relative to 2011.
rainfall and irrigation are represented only in the pictures on the right.

P. Paredes et al., AGWAT, 2015

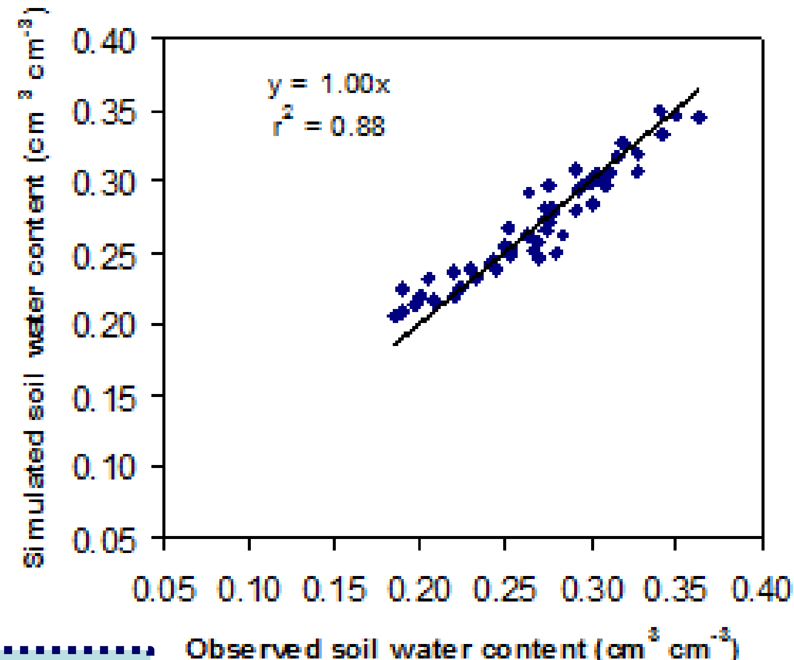


Daily soil evaporation (Es) dynamics when using the AquaCrop after adequate calibration (–) and SIMDualKc (----) compared with microlysimeters observations () for 2011

SIMDualKc data from Wei et al., 2015

P. Paredes, AGWAT, 2015

FAO56 dual Kc approach applied to hops



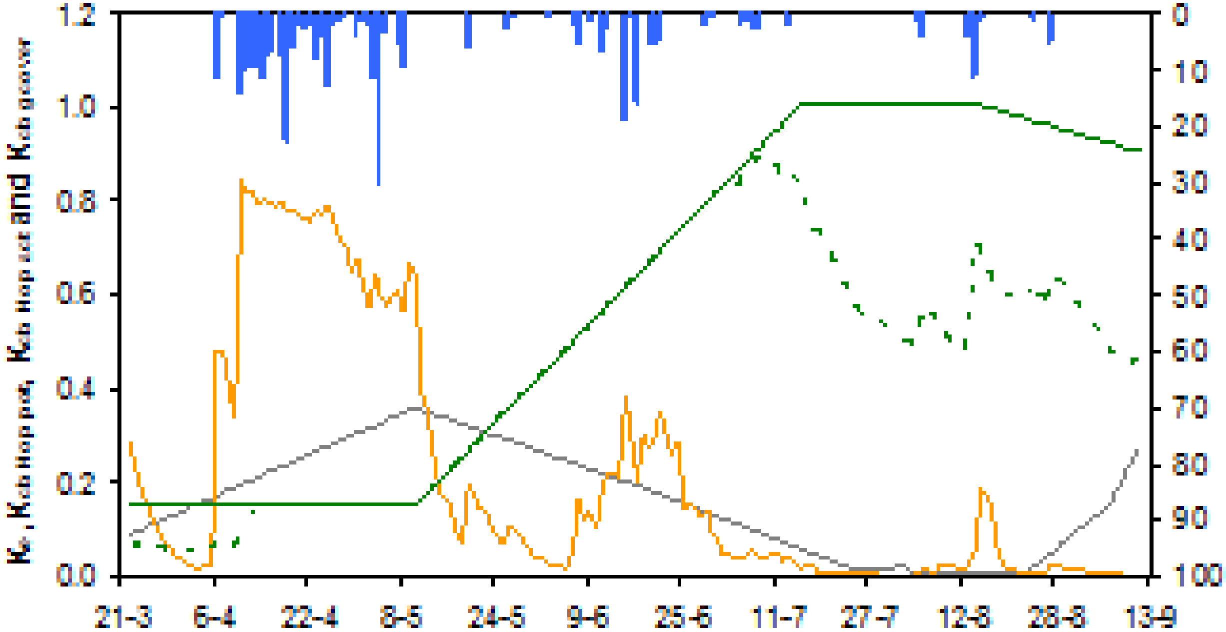
Simulated *vs.* observed soil water content relative to hop fields

Indicators of "goodness-of-fit"

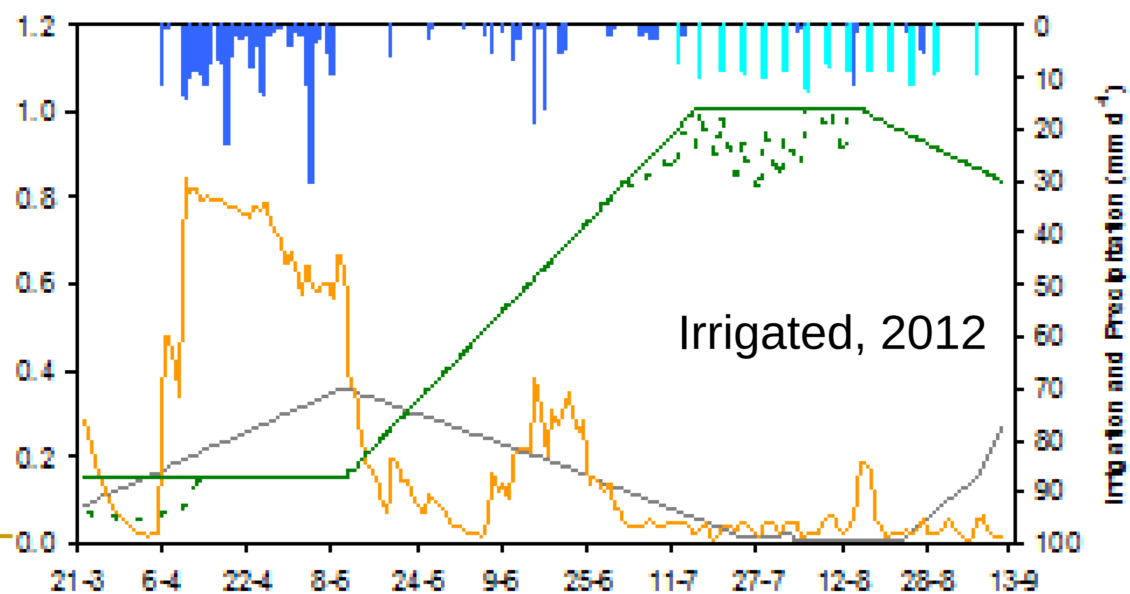
	b	R^2	RMSE (mm)	RSR	AAE (mm)	ARE (%)	PBIAS (%)	EF
2013, plot 1	0.99	0.90	2.4	0.14	1.9	4.0	1.5	0.81
2012, both plots	1.01	0.73	1.9	0.10	1.6	4.4	-1.9	0.84
2013, plot 2	1.03	0.97	2.5	0.12	1.7	5.0	-3.5	0.86
2014, both plots	0.99	0.72	2.0	0.10	1.5	3.1	0.4	0.81

Fandiño et al., Ind. Crops Prod., 2015

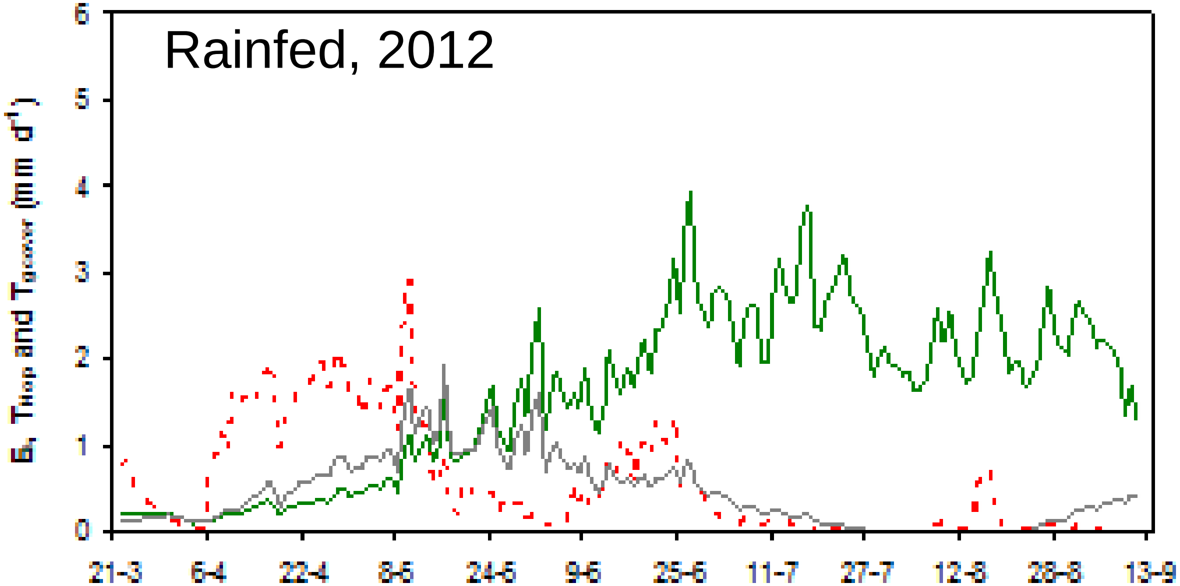
Rainfed, 2012



Kcb Hop pot (—)
Kcb Hop act (- - -)
Kcb gcover (–)
Ke (–)
irrigation (|) and
precipitation (|)



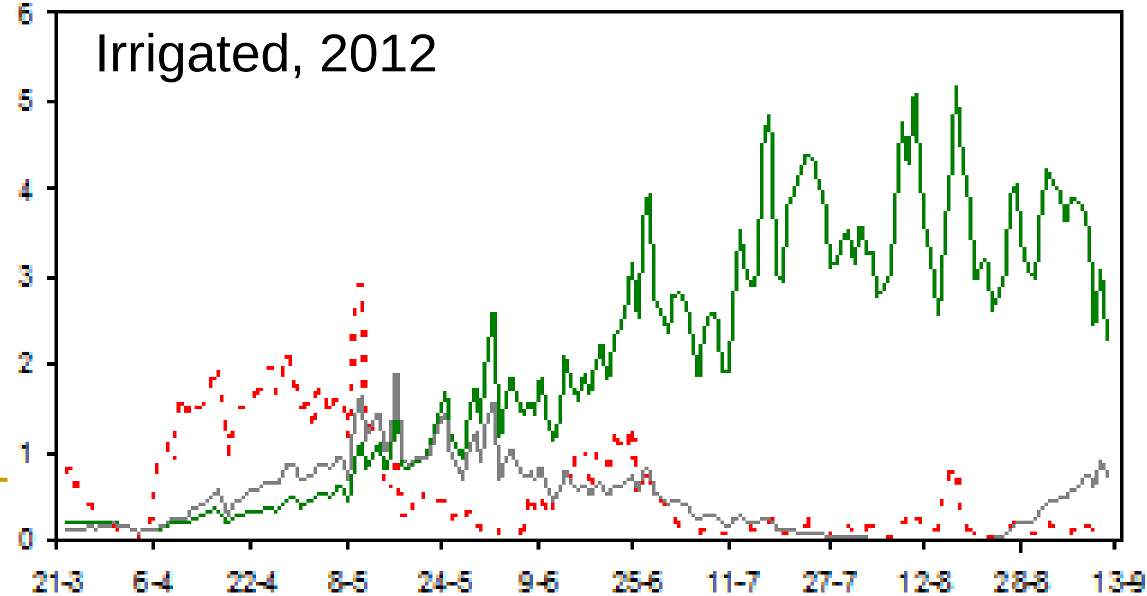
Fandiño et al., Ind. Crops Prod., 2015



Soil evaporation (Es, ---)

Hop transpiration (THop, —)

Ground cover transpiration (Tgcover, —)



Fandiño et al., Ind. Crops Prod., 2015

Extension of FAO56 dual Kc to relay intercropping

$$K_{cb\ inter} = max[K_{cb\ sub} + K_{d\ dom}(K_{cb\ dom} - K_{cb\ sub});\ K_{cb\ dom} + K_{d\ sub}(K_{cb\ sub} - K_{cb\ dom})]$$

$$K_{d\ dom} = f_{r\ dom}^{\left(\frac{1}{1+\max(h\ dom - h\ sub;0)}\right)}$$

$$K_{d\ sub} = f_{r\ sub}^{\left(\frac{1}{1+\max(h\ sub - h\ dom;0)}\right)}$$

$$p_{inter} = p_{dom} \qquad If\ Date_{act} < Date_{plant\ sub}$$

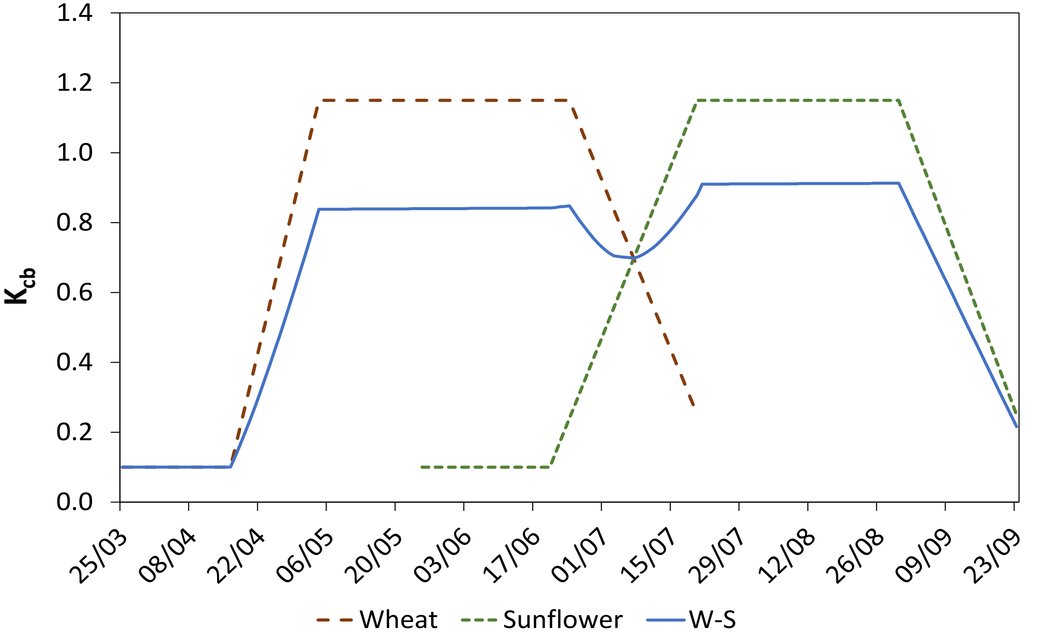
$$p_{inter} = \frac{p_{dom} f_{c\ dom} K_{cb\ dom} + p_{sub} f_{c\ sub} K_{cb\ sub}}{f_{c\ dom} K_{cb\ dom} + f_{c\ sub} K_{cb\ sub}} \qquad If\ Date_{plant\ sub} \leq Date_{act} \leq Date_{plant\ dom}$$

$$p_{inter} = p_{sub} \qquad If\ Date_{act} > Date_{harv\ dom}$$

Comparing the potential K_{cb} curves relative to the single crops with those of the intercrops for:

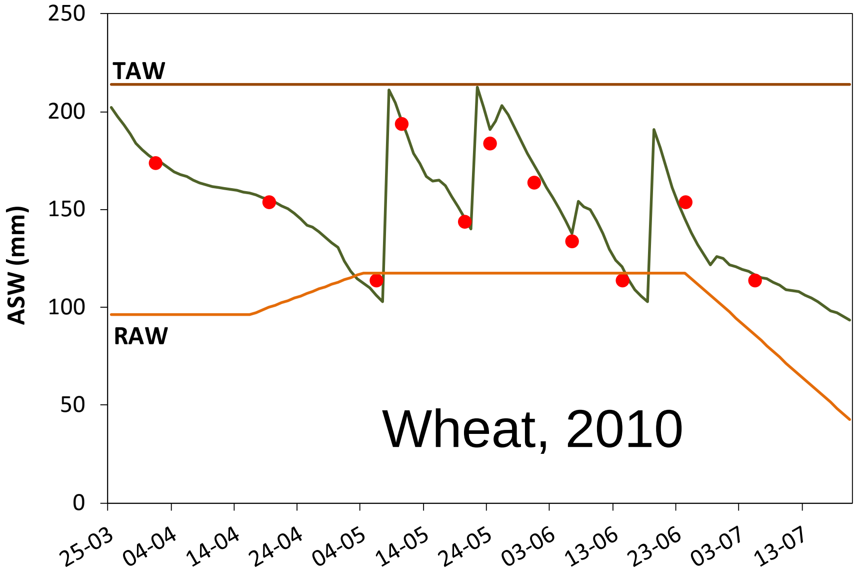
a) the wheat-maize (W-M) intercrop and

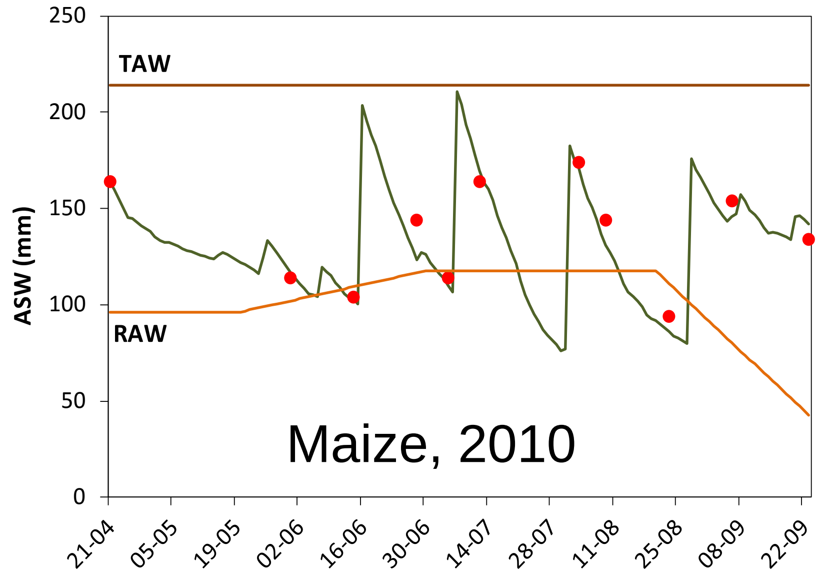
b) the wheat-sunflower (W-S) intercrop for 2010 season

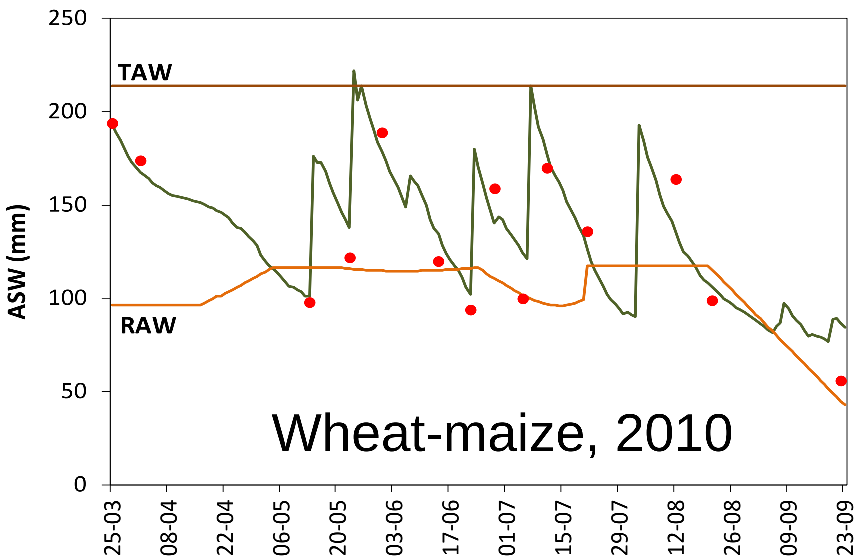


Miao et al., AGWAT submitted

FAO56 dual Kc approach applied to spring wheat-maizerelay intercropping, China

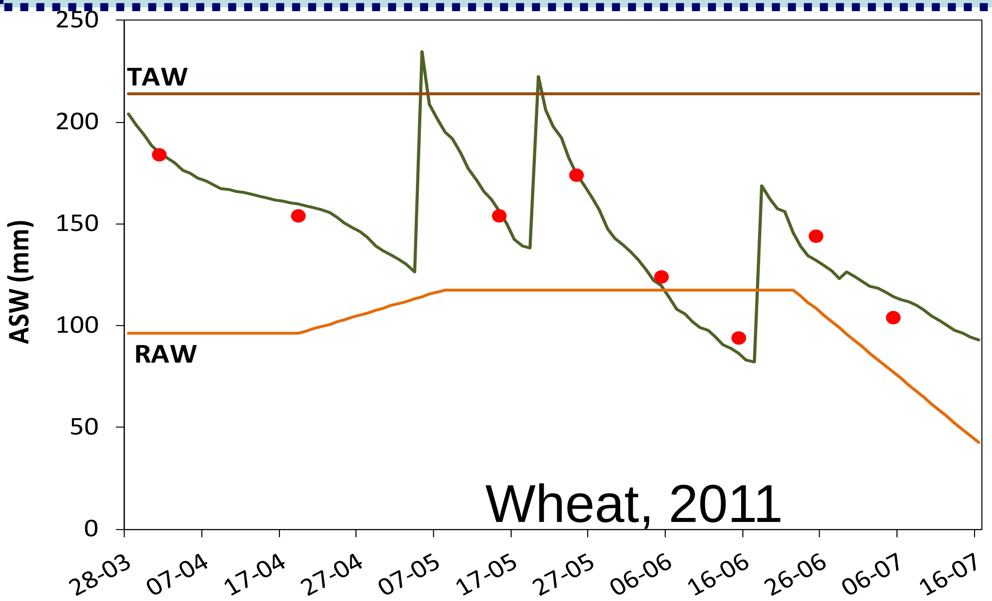


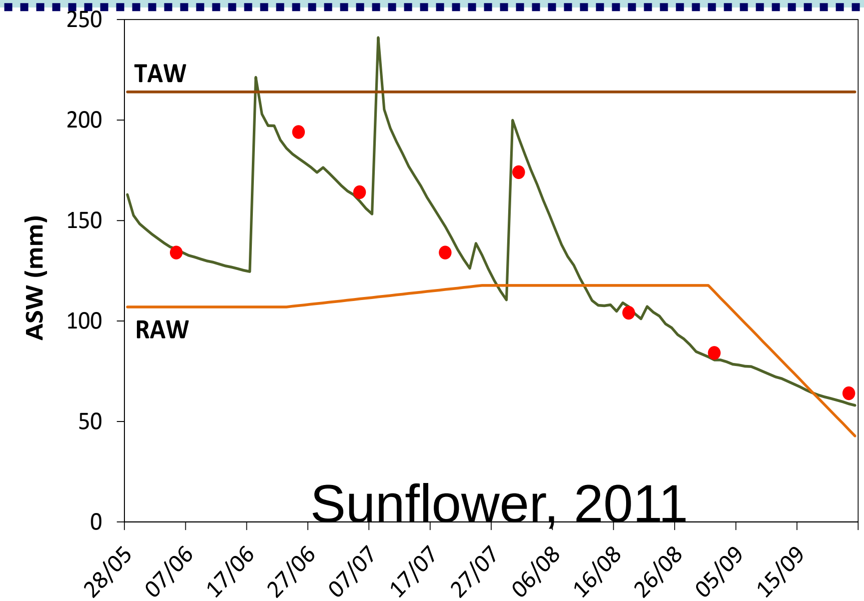


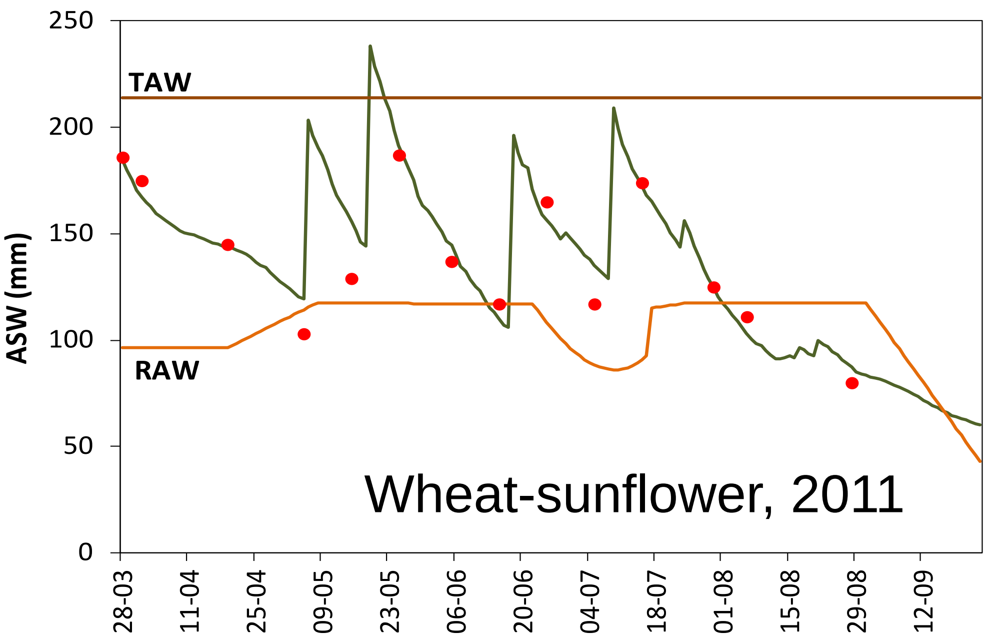


Simulated (–) vs. observed (•) seasonal variation of the available soil water (mm) for wheat, maize and wheat-maize intercrop

FAO56 dual Kc applied to spring wheat-sunflower relay intercropping, China

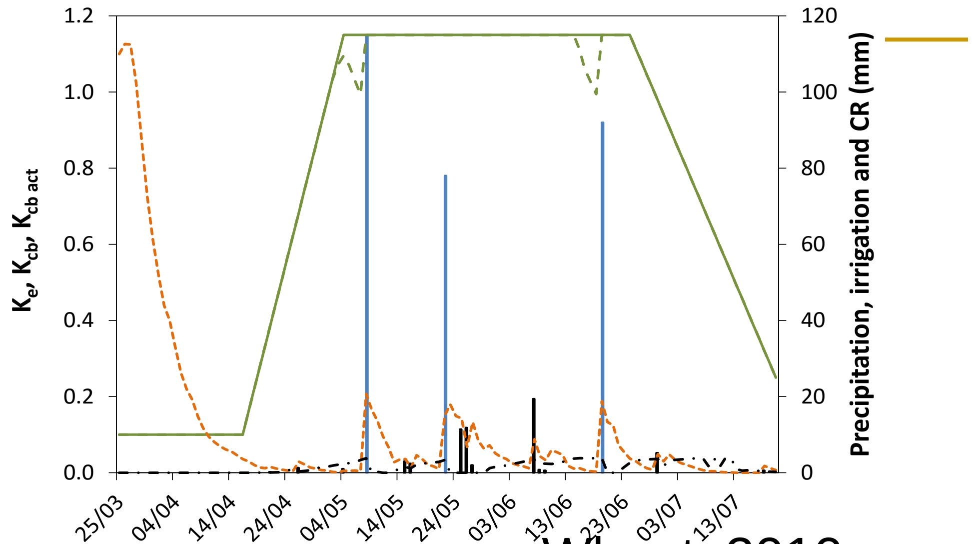




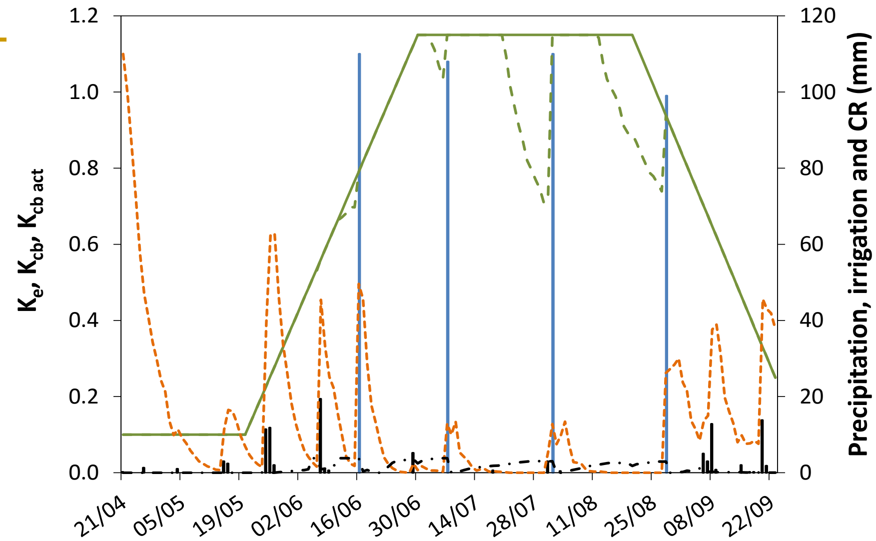


Miao et al., AGWAT submitted

Simulated (–) vs. observed (•) seasonal variation of the available soil water (mm) for wheat, sunflower and wheat-sunflower intercrop

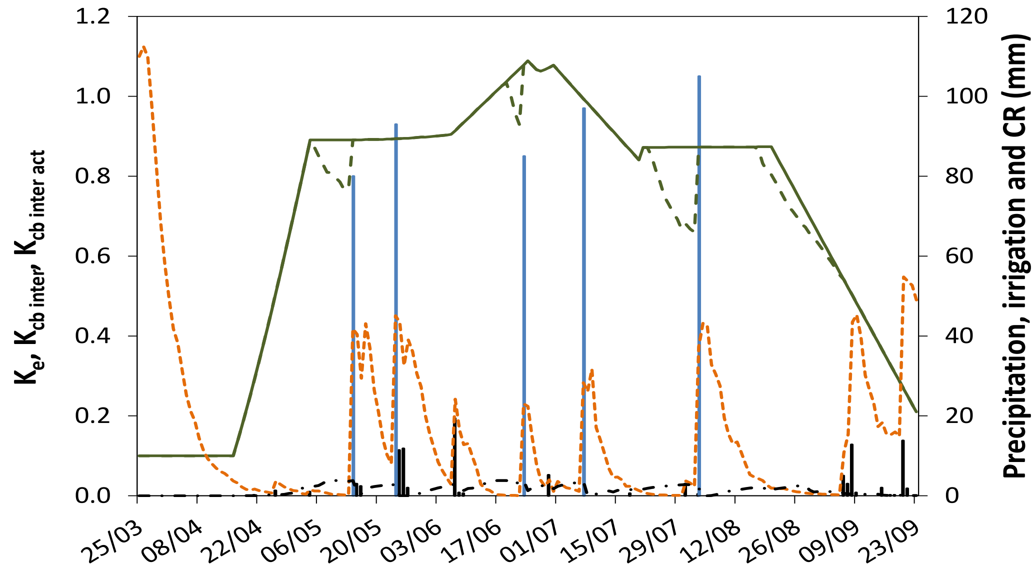


Wheat, 2010



Maize, 2010

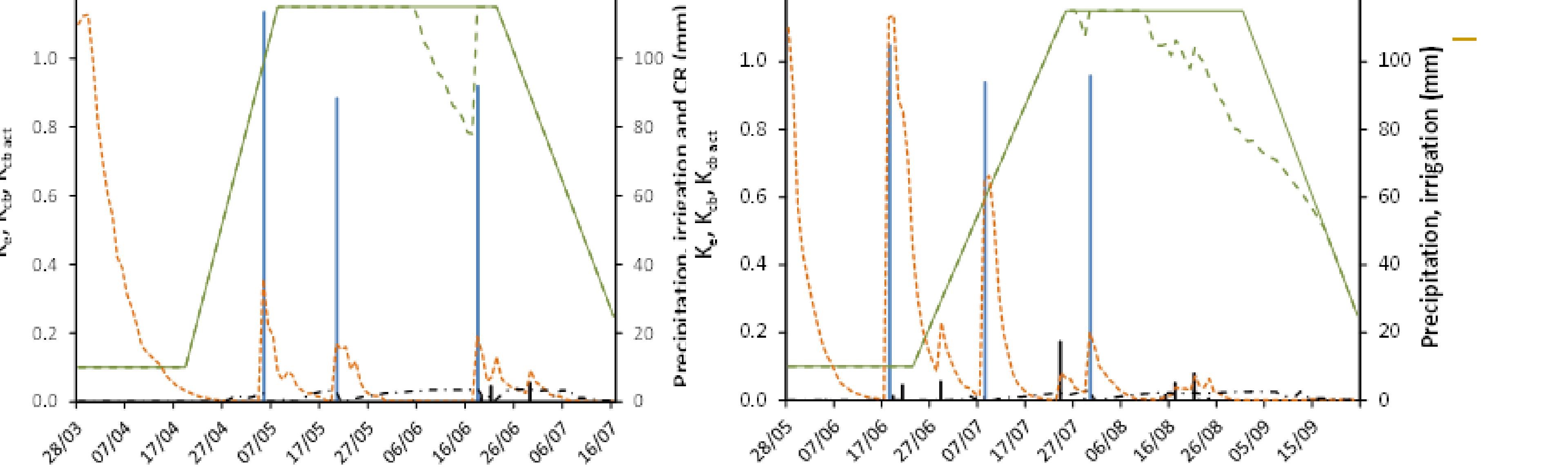
Curves of the basal crop coefficients K_{cb} (___) and $K_{cb\ act}$ (_ _ _), and evaporation coefficient K_e (---) of single cropped wheat and maize, (I) precipitation, (I) irrigation and capillary rise (– - -)



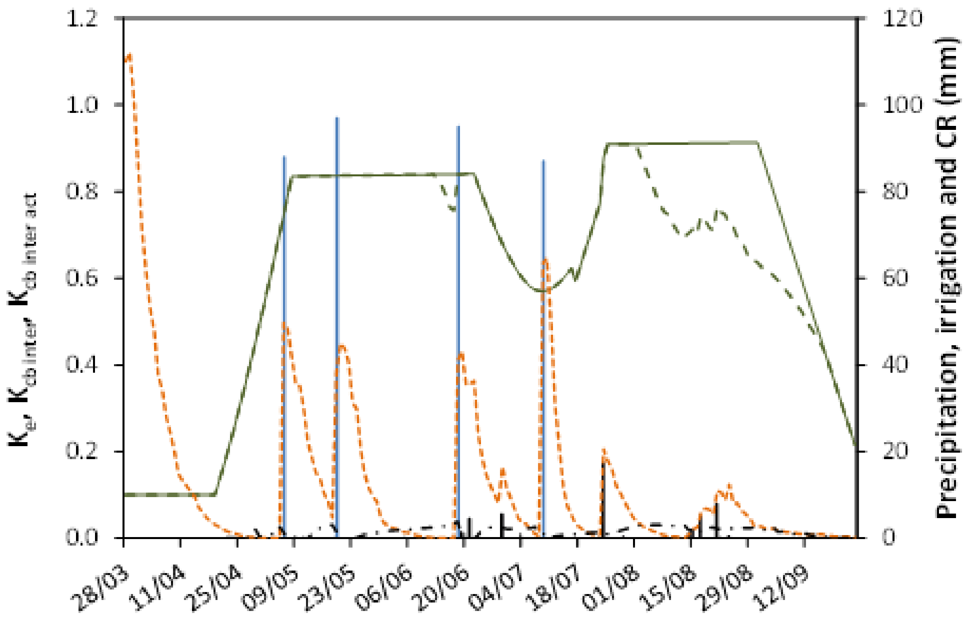
Wheat-maize, 2010

Curves of the crop coefficients for the intercrop:
$K_{cb\ inter}$ (–) and $K_{cb\ inter\ act}$ (---), K_e (---), (I) precipitation, (I)

Miao et al., AGWAT submitted



Curves of the basal crop coefficients K_{cb} (___) and $K_{cb\ act}$ (_ _ _), and evaporation coefficient K_e (---) of single cropped wheat and maize, (I) precipitation, (I) irrigation and capillary rise (_ - -)



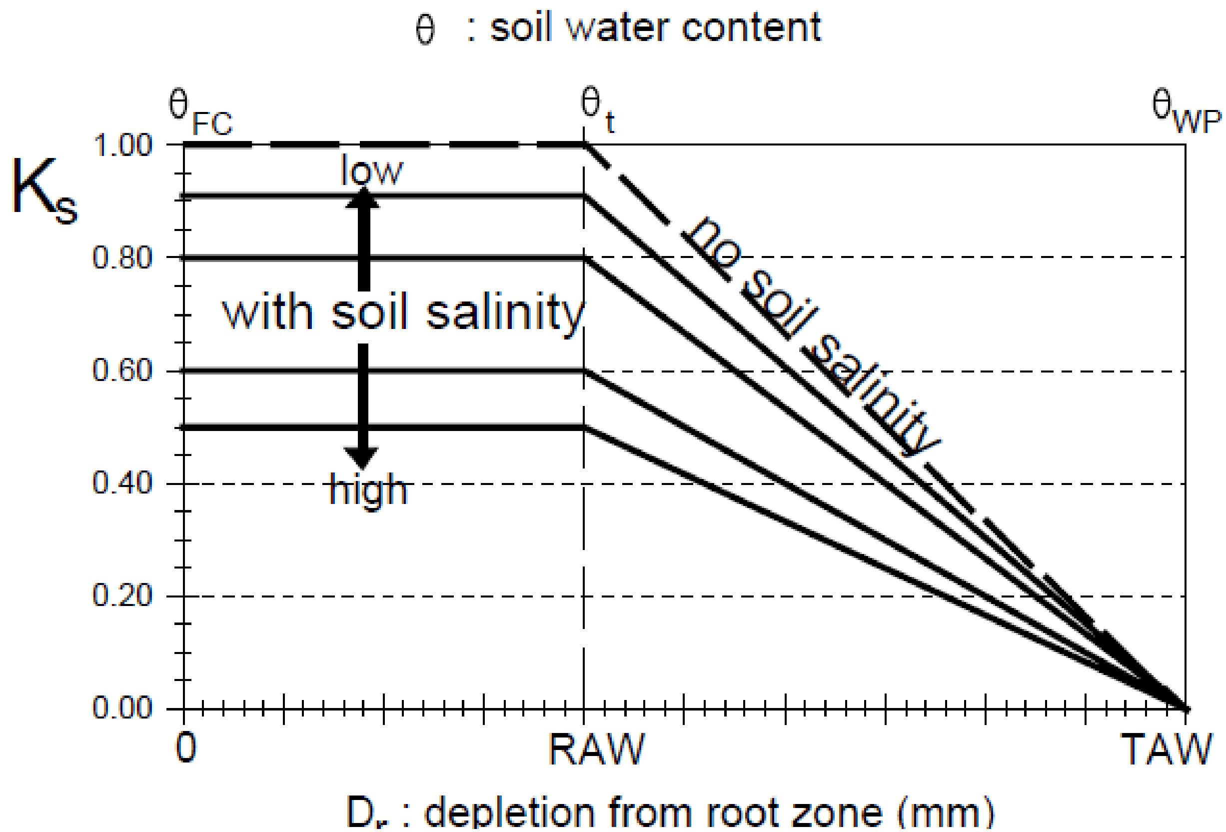
Curves of the crop coefficients for the intercrop:
$K_{cb\ inter}$ (—) and $K_{cb\ jnter\ act}$ (---), K_e (---), (I) precipitation, (I)

Miao et al., AGWAT, submitted

Extension of FAO56 dual Kc for non-standard conditions: Water and salinity stress

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

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



Adjusting soil water content (wilting point) to salinity and crop tolerance

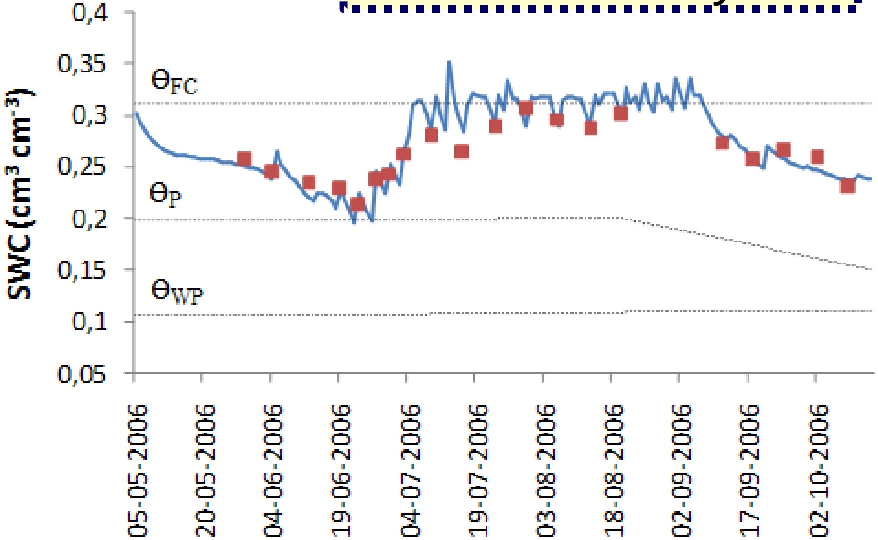
$$\theta_{WP} = \theta_{WP} + \frac{b}{100}\left(\frac{EC_e - EC_{e\ threshold}}{10}\right)(\theta_{FC} - \theta_{WP})$$

Adjusting soil water depletion fraction p to salinity and crop tolerance

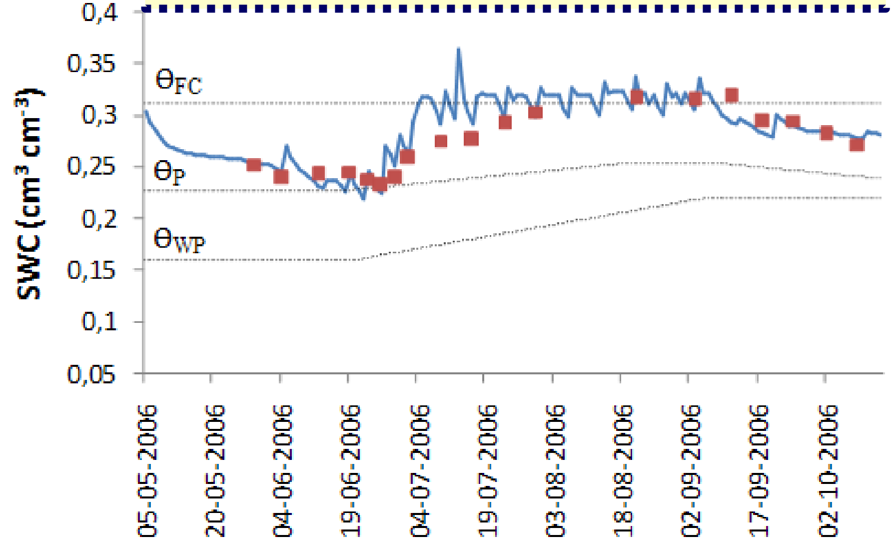
$$p_{salt} = p - b(EC_e - EC_{e\ threshold})p$$

Application to maize with blended water with adjusted θ_{WP} and p (and θ_P)

Low salinity

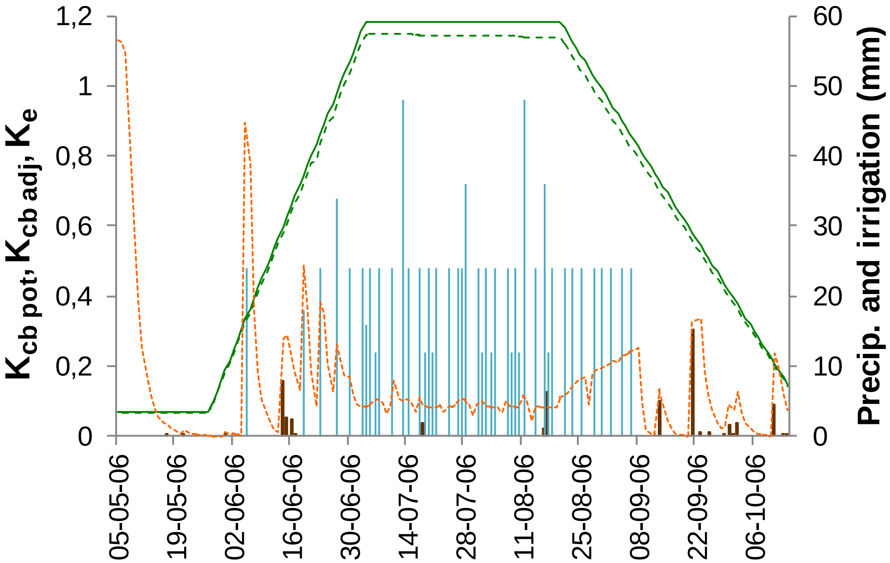


Saline soil and saline water

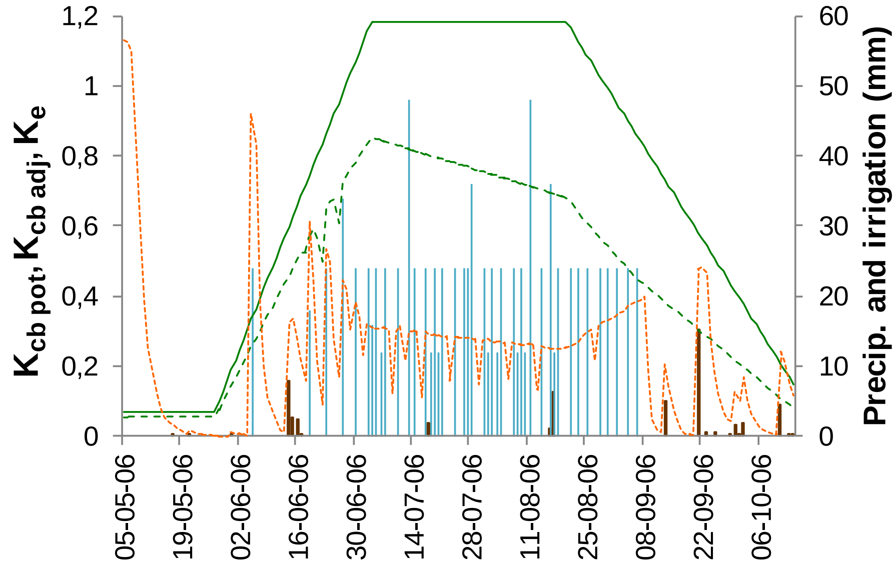


K_{cb}, $K_{cb\ act}$ and K_e curves for maize as affected by salinity

Low salinity



Saline soil and saline water



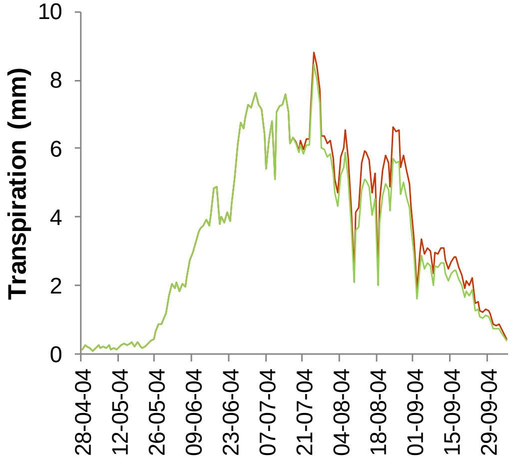
K_{cb} (———), $K_{cb\ act}$ (- - - - -), K_e (--------),

precipitation (▬▬) and irrigation (▬▬)

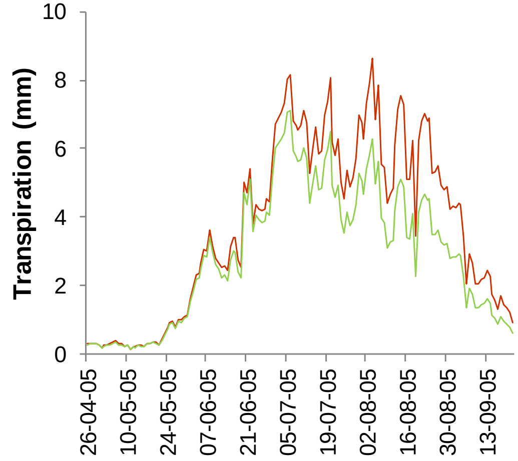
When salinity increases Ke also increases

Cumulative effects of salinity on $T_{c\ act}$ and E_s

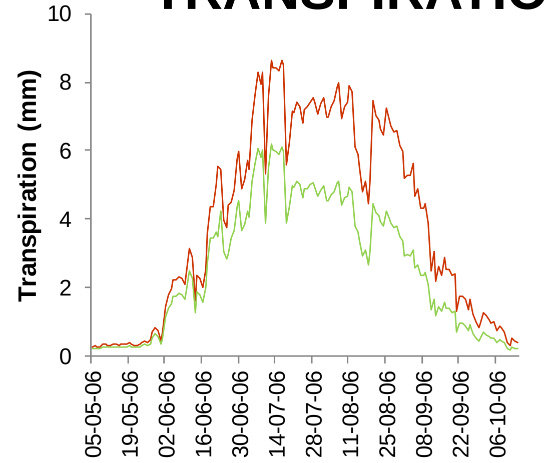
TRANSPIRATION



Maize - 2004

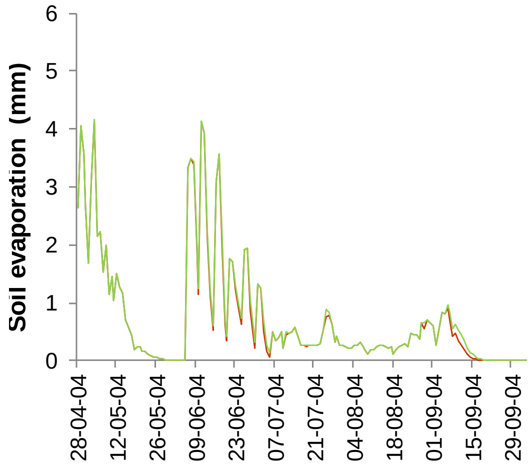


Maize - 2005

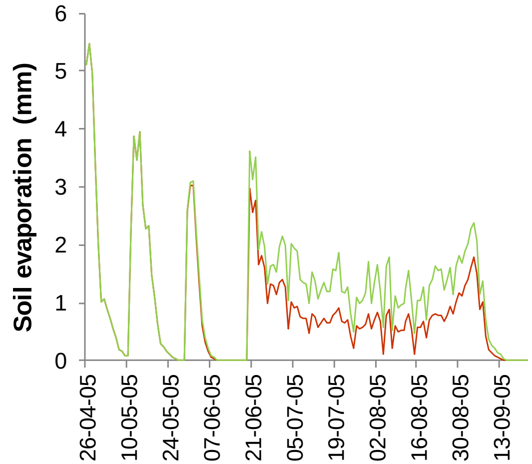


Maize - 2006

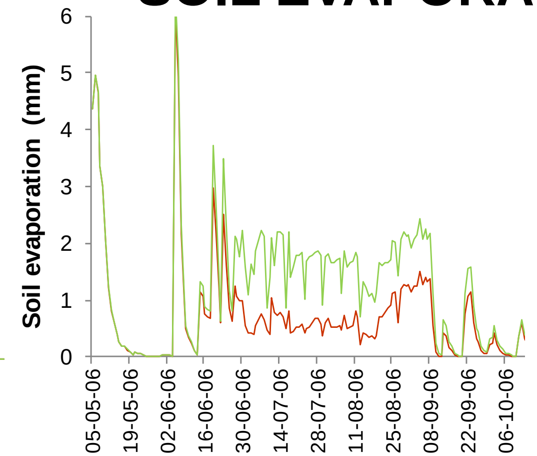
SOIL EVAPORATION



Maize - 2004



Maize - 2005



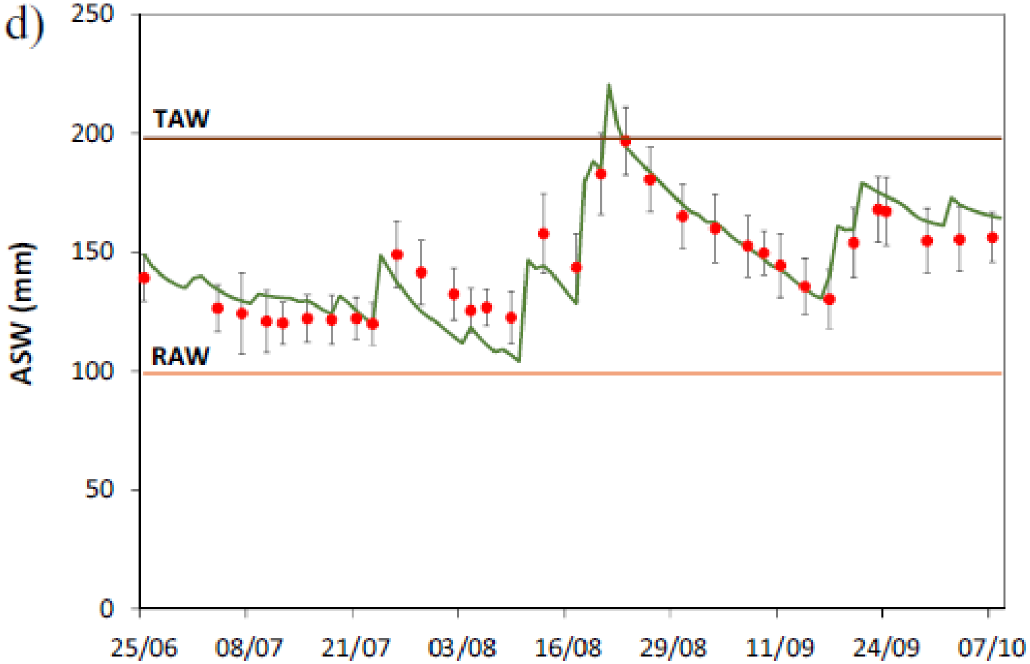
Maize - 2006

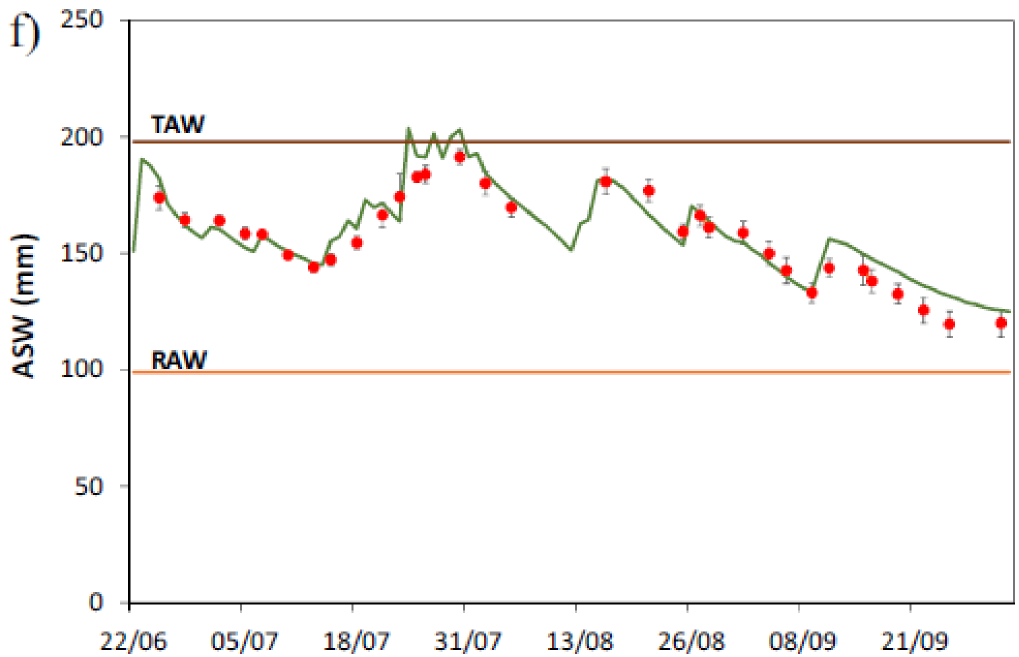
low salinity ( ) and saline irrigation treatments ( )

LEAF


MUITO OBRIGADO

FAO56 dual Kc applied to a soybean crop in China





Simulated (—) vs. observed (•) available soil water (ASW):

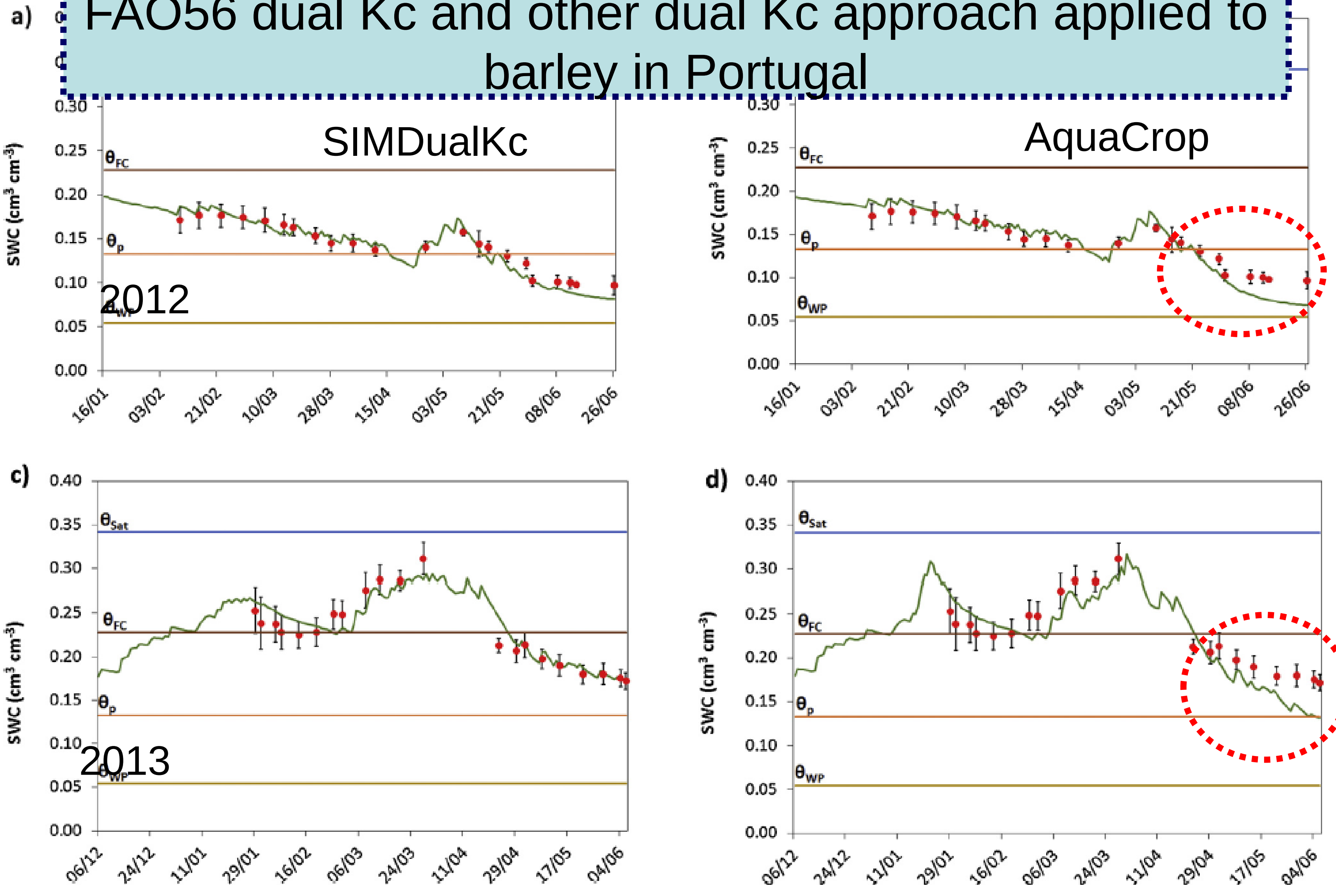
(d) 2010-T1

(f) 2011

(error bars represent the standard deviation of the mean observed values).

Z. Wei, AGWAT, 2015

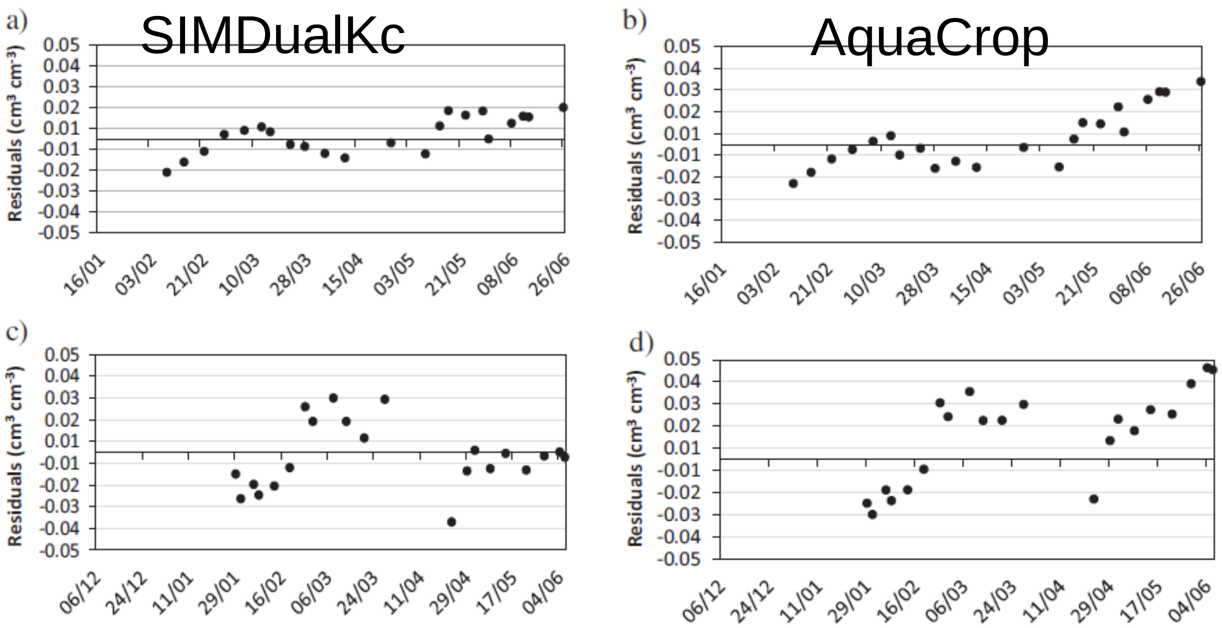
FAO56 dual Kc and other dual Kc approach applied to barley in Portugal



Observed (•) and simulated (—) daily soil water content (SWC) by the SIMDualKc and AquaCrop

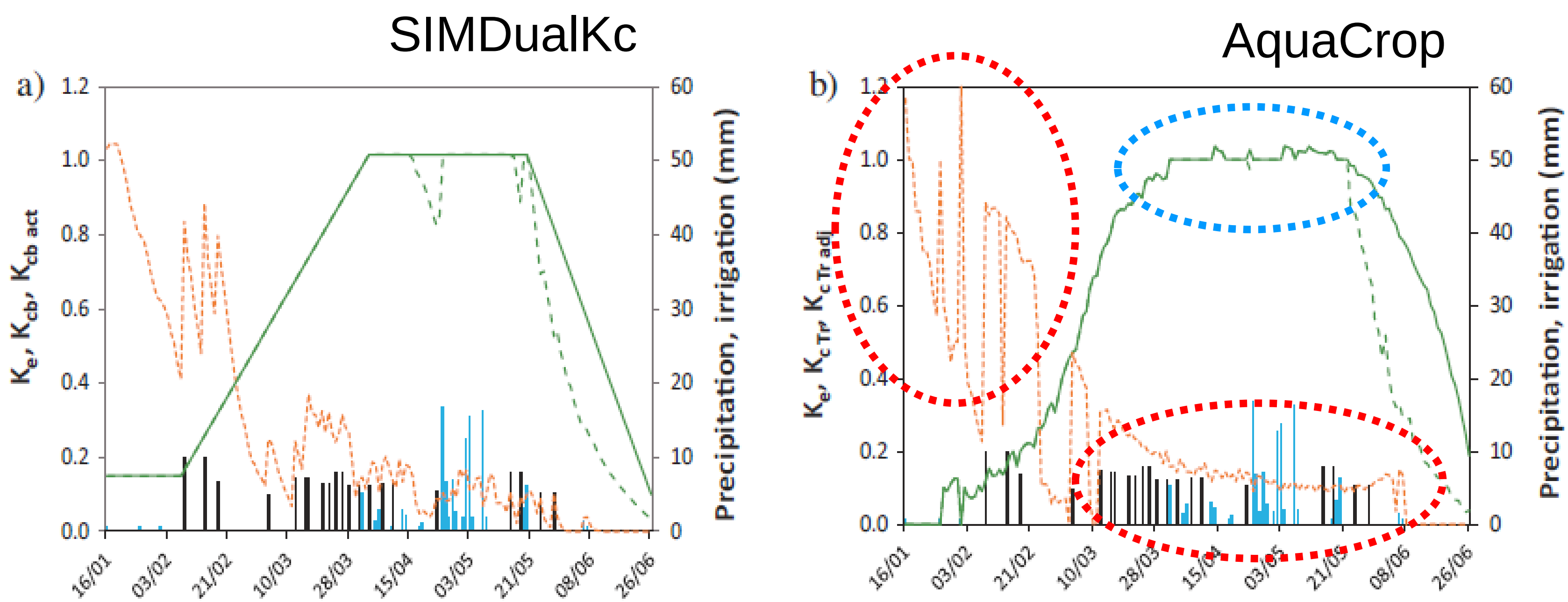
“Goodness-of-fit” indicators relative to the daily simulation of SWC with SIMDualKc and AquaCrop

Model	Crop Season	b_0	R^2	RMSE ($cm^3\ cm^{-3}$)	RSR ( )	PBIAS (%)	AAE ($cm^3\ cm^{-3}$)	ARE (%)	EF
SIMDualKc	2012	0.99	0.96	0.009	0.07	1.8	0.008	5.8	0.90
	2013	1.00	0.85	0.015	0.09	-0.9	0.012	5.1	0.85
AquaCrop	2012	1.00	0.88	0.013	0.11	1.9	0.011	8.8	0.76
	2013	0.96	0.80	0.023	0.13	4.6	0.021	9.8	0.64



SWC residuals (•) when using SIMDualKc and AquaCrop for (a, b) 2012 and (c, d) 2012–2013

Pereira et al., AGWAT, 2015



Daily variation of the
basal crop coefficient (Kcb or Kc,Tr, —),
adjusted to water stress basal crop coefficient (Kcb act or Kc, Tr adj, - - -),
the evaporation coefficient (Ke, ---),
Precipitation (|) and irrigation (|) in 2012

Pereira et al., AGWAT, 2015

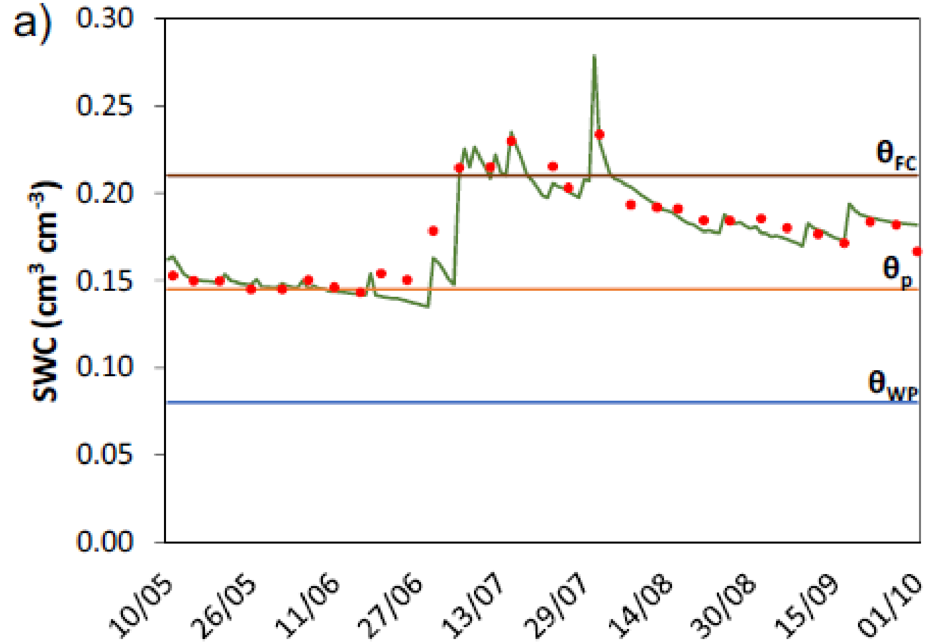
LEAF

Simulated water balance for sprinkler irrigated barley, 2012 and 2013 seasons (all terms are in mm)

Season	Model	P	I	ΔSWC	DP	RO	E_s	T_a	$ET_{c\ act}$	$E_s/ET_{c\ act}$
2012	SIMDualKc	115	145	108	0	2	77	289	366	21
	AquaCrop			118	0	1	81	296	377	21
2013	SIMDualKc	568	0	13	170	60	81	270	351	23
	AquaCrop			43	199	62	79	271	350	23

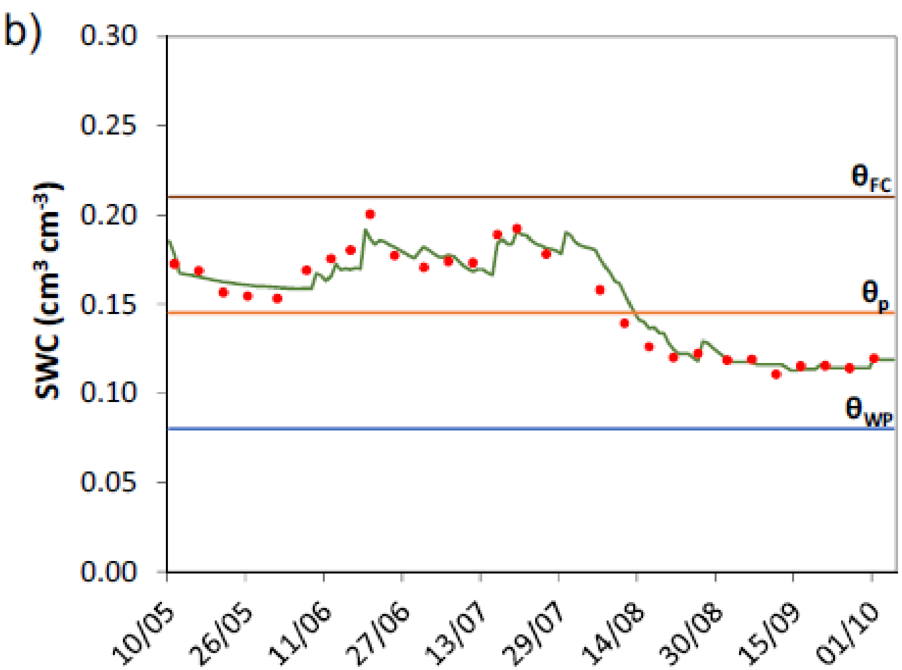
Pereira et al., AGWAT, 2015

FAO56 dual Kc approach applied to groundwater dependent maize, Inner Mongolia



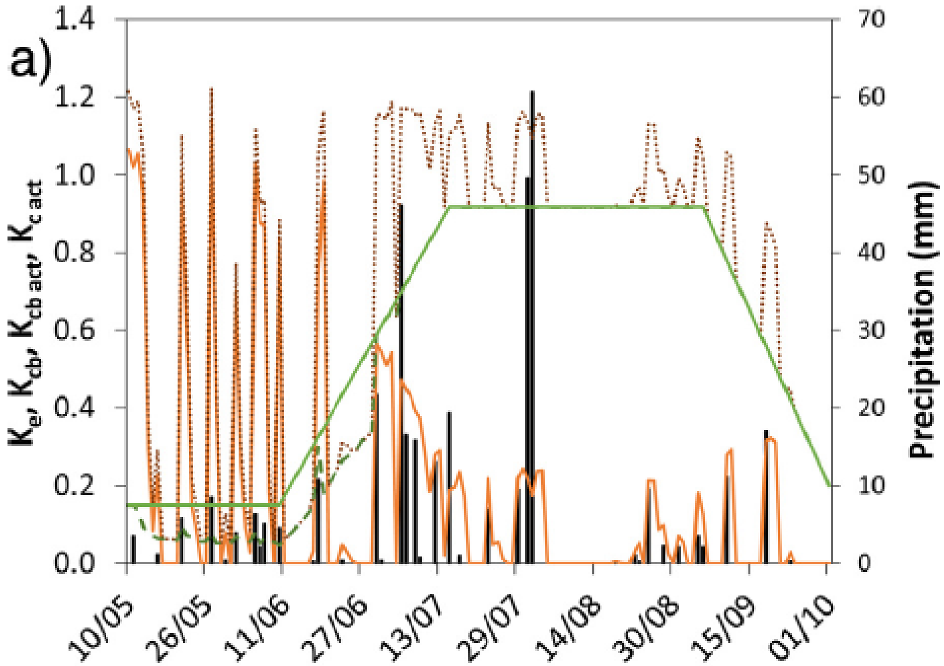
Simulated and observed soil water content (SWC) for the rainfed maize crop in

2008



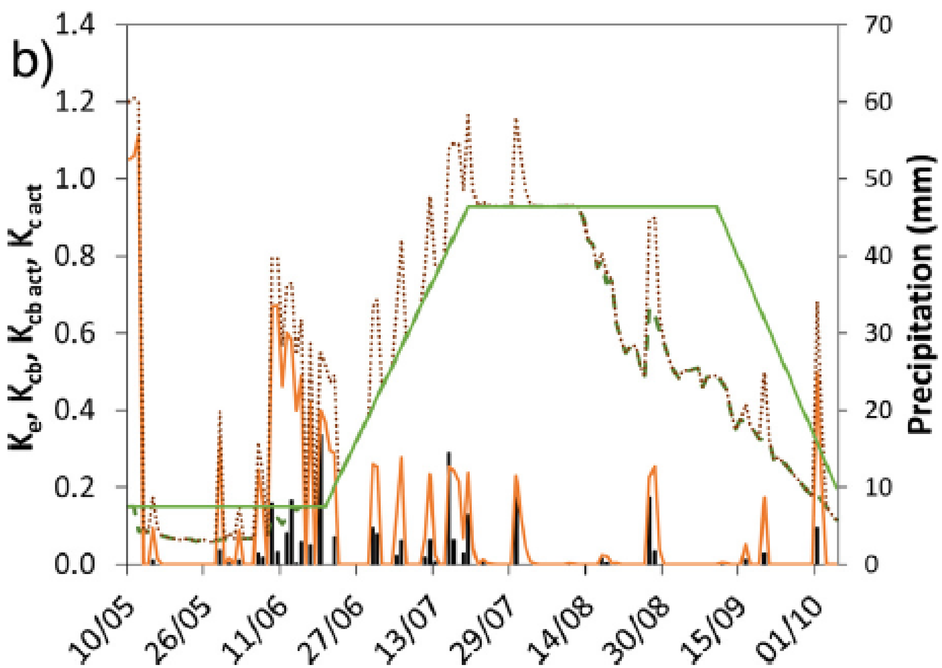
2009

Wu et al., AGWAT, 2015



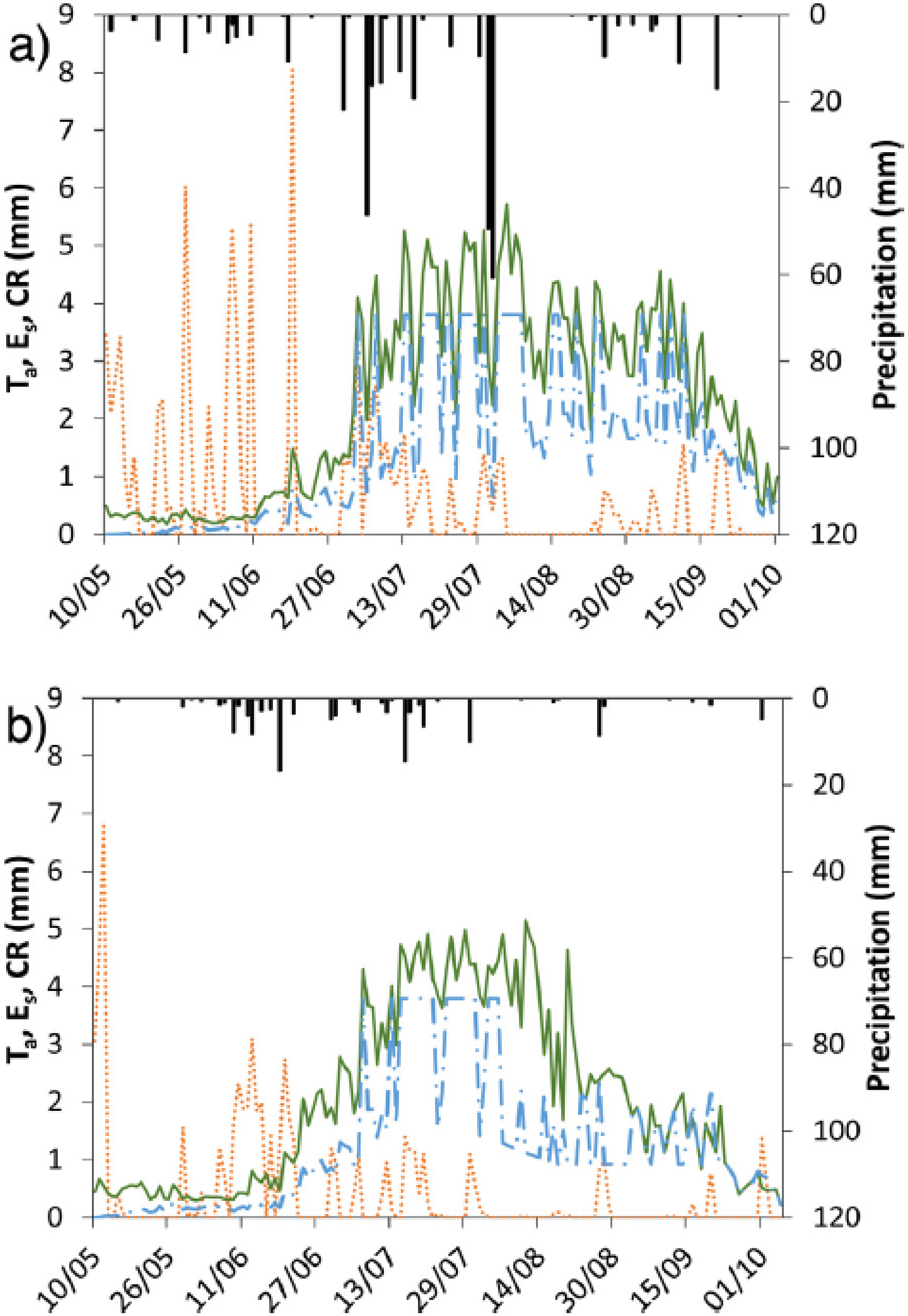
Kcb (–),
Kcb act (- - -),
Ke (–) and
Kc act (---) curves as well as daily precipitation (|)

wet year of 2008 (a)



dry year of 2009 (b).

Wu et al., AGWAT, 2015



Soil evaporation (Es, ---)

Actual crop transpiration (Ta, —)

Capillary rise (CR, -. -. -) fluxes

Precipitation (|)

2008

2009

Wu et al., AGWAT, 2015

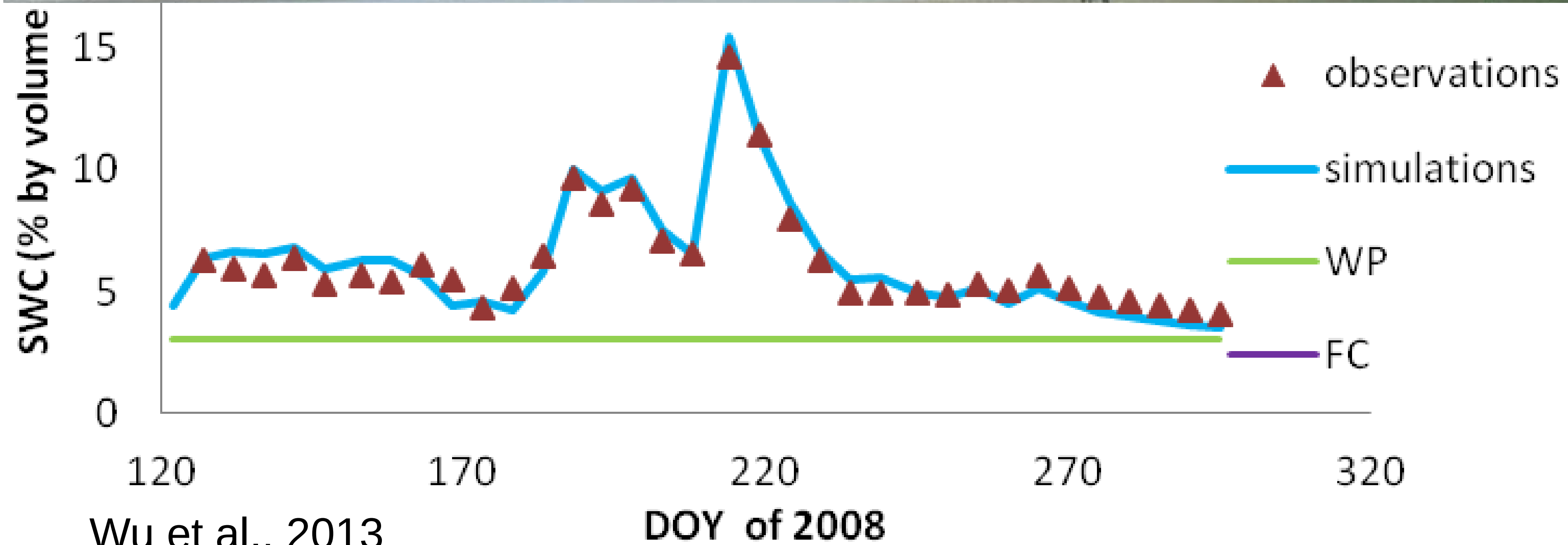
Period		P (mm)	$ET_{c\,act}$ (mm)	E_s (mm)	T_a (mm)	DP (mm)	ΔSWC (mm)	GWC (mm)	GWC/$ET_{c\,act}$
2008	May	19	36	29	7	0	15	1	3
	June	55	54	33	21	0	−12	11	20
	July	179	144	28	116	7	−103	76	53
	August	76	119	6	113	93[a]	60	76	64
	September	34	85	8	77	0	0	51	60
	Season	363	434	102	333	100	−41	216	50
2009	May	2	27	17	10	0	27	2	7
	June	55	53	27	26	0	−14	11	21
	July	49	127	11	116	0	−7	85	67
	August	12	107	2	105	0	45	49	46
	September	7	46	3	43	0	0	38	83
	Season	125	360	60	300	0	47	185	51

– precipitation, $ET_{c\,act}$ – actual evapotranspiration, E_s – soil evaporation, T_a – actual transpiration, GWC – groundwater contribution, DP – deep percolation, ΔSWC, vari
of the soil water content.

Monthly soil water balance components for the groundwater dependent maize in crop seasons of 2008 and 2009.

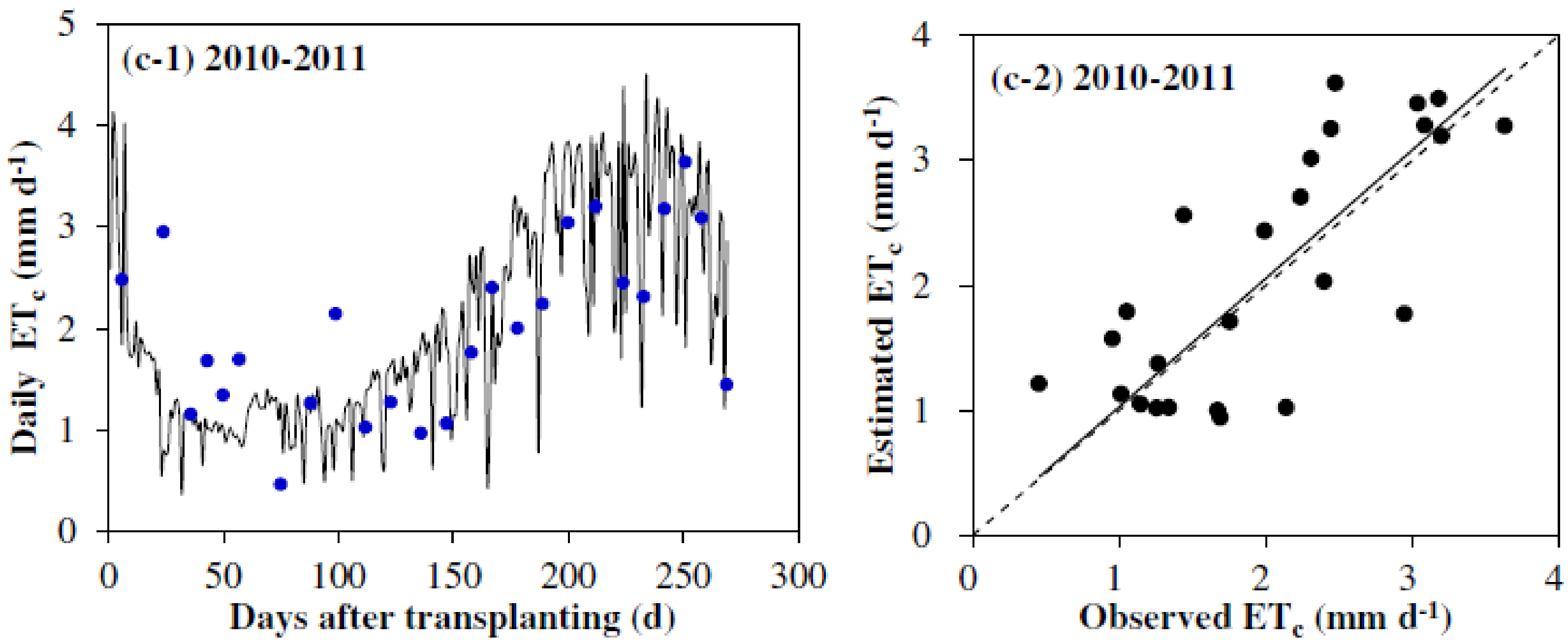
Wu et al., AGWAT, 2015

Dynamics of water and ET in a sand steppe sparse vegetation landscape of Inner Mongolia, SIMDualKc model



Wu et al., 2013

Assessing the SIMDualKc model for estimating evapotranspiration of hot pepper grown in a solar greenhouse in Gansu, Northwest China



SIMDualKc model accuracy indicators relative to hot pepper transpiration.

Season	*b*	R^2	*RMSE* (mm d^{-1})	*MAE* (mm d^{-1})	d_{IA}
2010–2011	0.99	0.49	0.47	0.43	0.90
2011–2012	0.97	0.90	0.21	0.19	0.97
All data	0.98	0.72	0.39	0.33	0.94

Qiu et al., 2015
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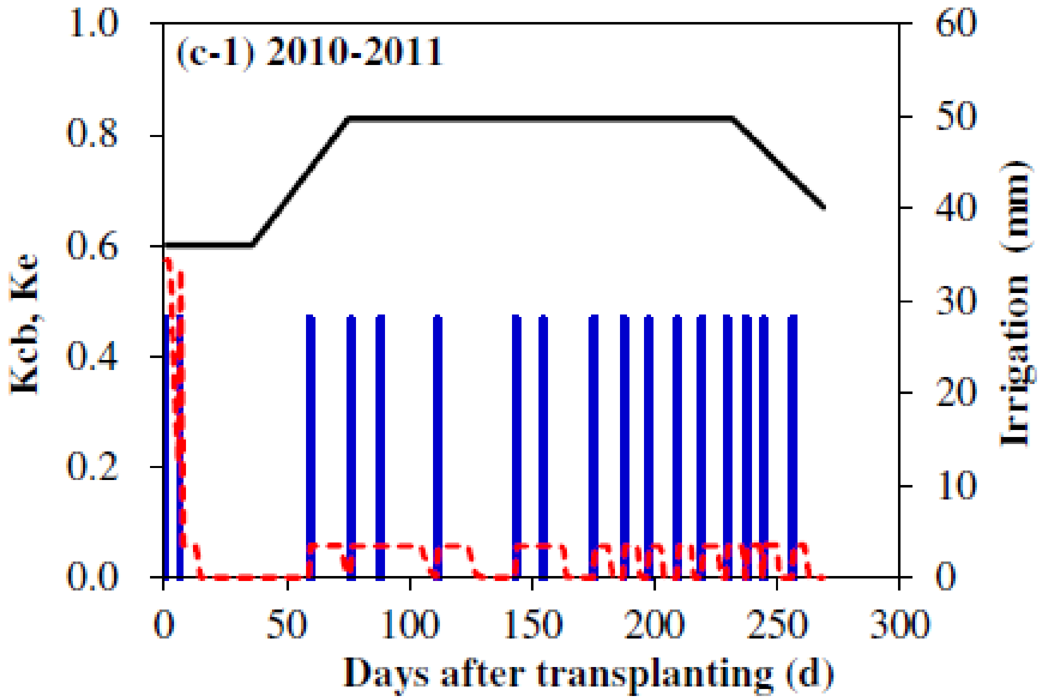
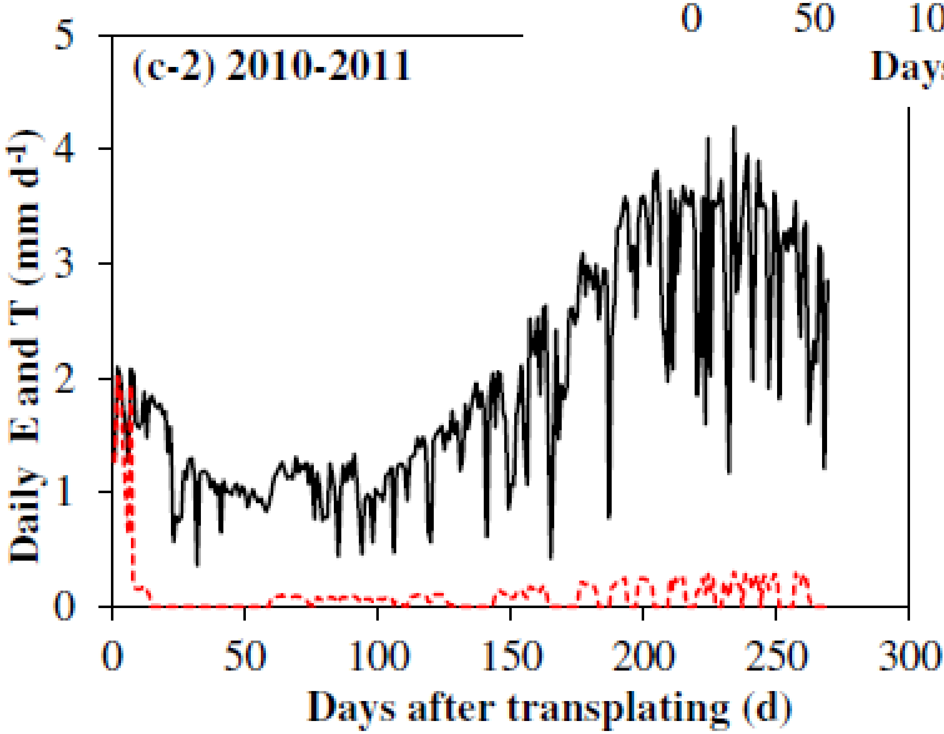
Seasonal variation of K_{cb}, K_e and irrigation





Soil evaporation (E)
Transpiration (T)

Qiu et al., 2015
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