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RESEARCH ARTICLE

Effects of canopy resistance parameterization on evapotranspiration partitioning and soil water contents in a maize field under a semiarid climate

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Supplementary materials

Table S1 Parameters and abbreviations used in this study

Symbol	Parameter	Unit	Value
a	Fitted parameter for soil surface resistance	-	0.357
a_1	Parameter for Jarvis canopy resistance method	-	0.81
a_2	Parameter for Jarvis canopy resistance method	-	0.004
a_3	Parameter for Jarvis canopy resistance method	-	0.05
b_1	Fitting parameter for Katerji-Perrier canopy resistance method	-	0.302
b_2	Fitting parameter for Katerji-Perrier canopy resistance method	-	7.77
$b(x)$	Normalized root water uptake distribution	m^{-1}	
c_1	Fitting parameter for Massman canopy resistance method	-	102
c_2	Fitting parameter for Massman canopy resistance method	-	0.011
c_3	Fitting parameter for Massman canopy resistance method	-	0.1

c_p	Specific heat capacity of air	$J \cdot kg^{-1} \cdot K^{-1}$	
d_0	Zero plane displacement	m	$2/3 \cdot h_c$
E	Soil evaporation rate	$kg \cdot m^{-2} \cdot s^{-1}$	
ET	Evapotranspiration rate	$m \cdot s^{-1}$	
e_s	Saturation vapor pressure	kPa	
e_a	Actual vapor pressure	kPa	
$F(\theta)$	Normalized soil moisture	-	
g	The gravitational acceleration	$m \cdot s^{-2}$	9.81
g_{sm}	Maximum stomatal conductance	$m \cdot s^{-1}$	0.046
G	Soil heat flux density	$MJ \cdot m^{-2} \cdot day^{-1}$	
h	Soil matric potential	m	
h_1	Soil matric potential value higher than which root experiences oxygen deficiency	m	–0.15
h_2, h_3	Soil matric potential values between which root water uptake is maximal	m	–0.5
h_3	Soil matric potential values, which is dependent on the water demand of the atmosphere	m	–5 and –9 m at high and low water demand of the atmosphere, respectively
h_4	Soil matric potential value lower than which root water uptake equal to zero	m	–120
h_c	Crop height	m	
h_{top}	Soil water potential at the top soil layer	m	
I	Irrigation water rate	$m\ s^{-1}$	
k	Karman constant	-	0.41
k_Q	Extinction coefficient	-	0.6
K_s	Soil saturated hydraulic conductivity	$m\ s^{-1}$	$1.22 \times 10^{-6}\ m \cdot s^{-1}$; $9.84 \times 10^{-7}\ m \cdot s^{-1}$ @ 100 cm
LAI	Leaf area index	$m^2\ m^{-2}$	
LAI_{eff}	Effective leaf area index	$m^2\ m^{-2}$	
n	Van Genuchten fitting parameters	-	1.41; 1.30 @ 100 cm
P_r	Precipitation rate	$m \cdot s^{-1}$	
q	Water flux	$kg \cdot m^{-2} \cdot s^{-1}$	
q_{bot}	Deep drainage	$kg \cdot m^{-2} \cdot s^{-1}$	

q_L	Soil liquid water fluxes (positive upwards)	$kg \cdot m^{-2} \cdot s^{-1}$	
q_V	Soil water vapor fluxes (positive upwards)	$kg \cdot m^{-2} \cdot s^{-1}$	
Q_p	Photosynthetically active radiation photon flux density	$W \cdot m^{-2}$	
Q_h	Visible radiation flux density at the top of the canopy	$W \cdot m^{-2}$	
Q_{50}	Visible radiation flux density when the stomatal conductance is the half of the maximum value	$W \cdot m^{-2}$	14.3
r_a	Aerodynamic resistance	$s \cdot m^{-1}$	
r_c	Canopy resistance	$s \cdot m^{-1}$	
r_i	Modified meteorological resistance	$s \cdot m^{-1}$	
$r_{l,min}$	Minimum leaf stomatal resistance	$s \cdot m^{-1}$	
r_s	Soil surface resistance	$s \cdot m^{-1}$	
r_{sl}	Resistance to molecular diffusion of the water surface	$s \cdot m^{-1}$	10
r^*	Climatic resistance	$s \cdot m^{-1}$	
R_n	Net radiation	$W \cdot m^{-2}$	
R_n^c	Net radiation at the canopy surface	$W \cdot m^{-2}$	
R_n^s	Net radiation at the soil surface	$W \cdot m^{-2}$	
R_s	Downward shortwave radiation	$W \cdot m^{-2}$	
S	Sink term for transpiration	s^{-1}	
S_p	Potential water uptake rate	s^{-1}	
t	Time	s	
T_r	Actual crop transpiration	$m \cdot s^{-1}$	
T_p	Potential crop transpiration	$m \cdot s^{-1}$	
u_z	Wind speed at the reference height		
VPD	Vapor pressure deficit	kPa	
VPD_a	Actual vapor pressure deficit	kPa	
VPD_{50}	Vapor pressure deficit when the stomatal conductance is the half of the maximum value	kPa	0.031
z	Vertical space coordinate (positive upwards)	m	
z_m	reference heights of the wind measurements	m	
z_h	reference heights of the humidity measurements	m	
z_{om}	roughness length for the momentum transfer	$0.123 \cdot h_c$	
z_{oh}	roughness length for the heat and vapor transfer	$0.1\ z_{om}$	

α_s	Air entry value of soil	m^{-1}	$0.45\ m^{-1}$; $4.50\ m^{-1}$ @ 100 cm
$\alpha(h)$	Reduction coefficient related to soil water potential	-	
Δ	Slope of the vapor pressure curve	$kPa \cdot °C^{-1}$	
λ	Latent heat of vaporization	$MJ \cdot kg^{-1}$	2.45
θ_L	Soil liquid volumetric water content	$m^3 \cdot m^{-3}$	
θ_V	Soil vapor volumetric water content	$m^3 \cdot m^{-3}$	
θ_{fc}	Soil water content at the field capacity	$m^3 \cdot m^{-3}$	
θ_{sat}	Saturated soil water content	$m^3 \cdot m^{-3}$	$0.50\ m^3 \cdot m^{-3}$; $0.62\ m^3 \cdot m^{-3}$ @ 100 cm
θ_r	Residual soil water content	$m^3 \cdot m^{-3}$	$0.14\ m^3 \cdot m^{-3}$; $0.18\ m^3 \cdot m^{-3}$ @ 100 cm
θ_{top}	Topsoil water content	$m^3 \cdot m^{-3}$	
θ_{min}	Minimum water content above which soil is able to deliver vapor at a potential rate	$m^3 \cdot m^{-3}$	
θ_{rt}	averaged volumetric soil water content in the root zone	$m^3 \cdot m^{-3}$	
θ_w	volumetric water content at the wilting point	$m^3 \cdot m^{-3}$	
θ_f	volumetric water content at the field capacity	$m^3 \cdot m^{-3}$	
ρ_L	Density of soil liquid water	$kg \cdot m^{-3}$	1000
ρ_v	Density of soil water vapor	$kg \cdot m^{-3}$	
γ	psychrometric constant	$kPa \cdot °C^{-1}$	

Abbreviations

STEMMUS-ET	Simultaneous Transfer of Energy, Mass, and Momentum in Unsaturated Soil with EvapoTranspiration module
JA	Jarvis type canopy resistance method
KP	Katerji-Perrier canopy resistance method
MA	Massman canopy resistance method
KL	Kelliher-Leuning canopy resistance method
FA	Farias canopy resistance method
RMSE	Root mean square error
PM	Penman-Monteith model
d	Index of agreement

BIAS	Model bias
SW	Shuttle-Wallace model
EF	Evaporation fraction
IUE	Integrated irrigation water use efficiency index

Table S2 Comparative statistics values of models with different canopy resistance parameterization for soil moisture in 2012

Models	Statistics	Soil moisture ($m^3 \cdot m^{-3}$)				
		20 cm	40 cm	60 cm	80 cm	100 cm
	BIAS	–0.0116	–0.0179	–0.0068	–0.0271	0.0024
JA	*d*	0.882	0.609	*0.264*	0.120	0.269
	RMSE	0.0203	0.0247	0.0205	0.0316	0.0073
	BIAS	**–0.0015**	–0.0089	**0.0023**	–0.0181	0.0081
KP	*d*	**0.925**	**0.774**	**0.449**	**0.182**	**0.363**
	RMSE	**0.0162**	0.0178	0.0185	0.0243	0.0099
	BIAS	–0.0064	–0.0132	–0.0022	–0.0228	0.0045
MA	*d*	0.889	0.690	0.313	0.142	0.258
	RMSE	0.0189	0.0200	**0.0170**	0.0267	0.0073
	BIAS	0.0058	**–0.0021**	0.0085	**–0.0124**	*0.0102*
KL	*d*	*0.849*	0.744	0.266	0.154	*0.219*
	RMSE	0.0215	**0.0164**	0.0195	**0.0192**	*0.0120*
	BIAS	*–0.0164*	*–0.0224*	*–0.0112*	*–0.0315*	**–0.0001**
FA	*d*	0.855	*0.570*	0.276	*0.116*	0.338
	RMSE	*0.0230*	*0.0277*	*0.0216*	*0.0352*	**0.0068**

Note: $BIAS = \frac{\sum_{i=1}^{n}(P_i - O_i)}{n}$, $d = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i - \bar{O}| + |O_i - \bar{O}|)^2}$, $RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}$, where O_i, P_i, are the measured and model simulated soil water content; $\bar{o}$ is the mean values of the measurements of soil water content; *n* is the number of data points. JA, Jarvis, KP, Katerji-Perrier, MA, Massman, KL, Kelliher-Leuning, FA, Farias. Values with bold fonts and italic fonts indicate the significant and non-significant statistical performance, respectively.

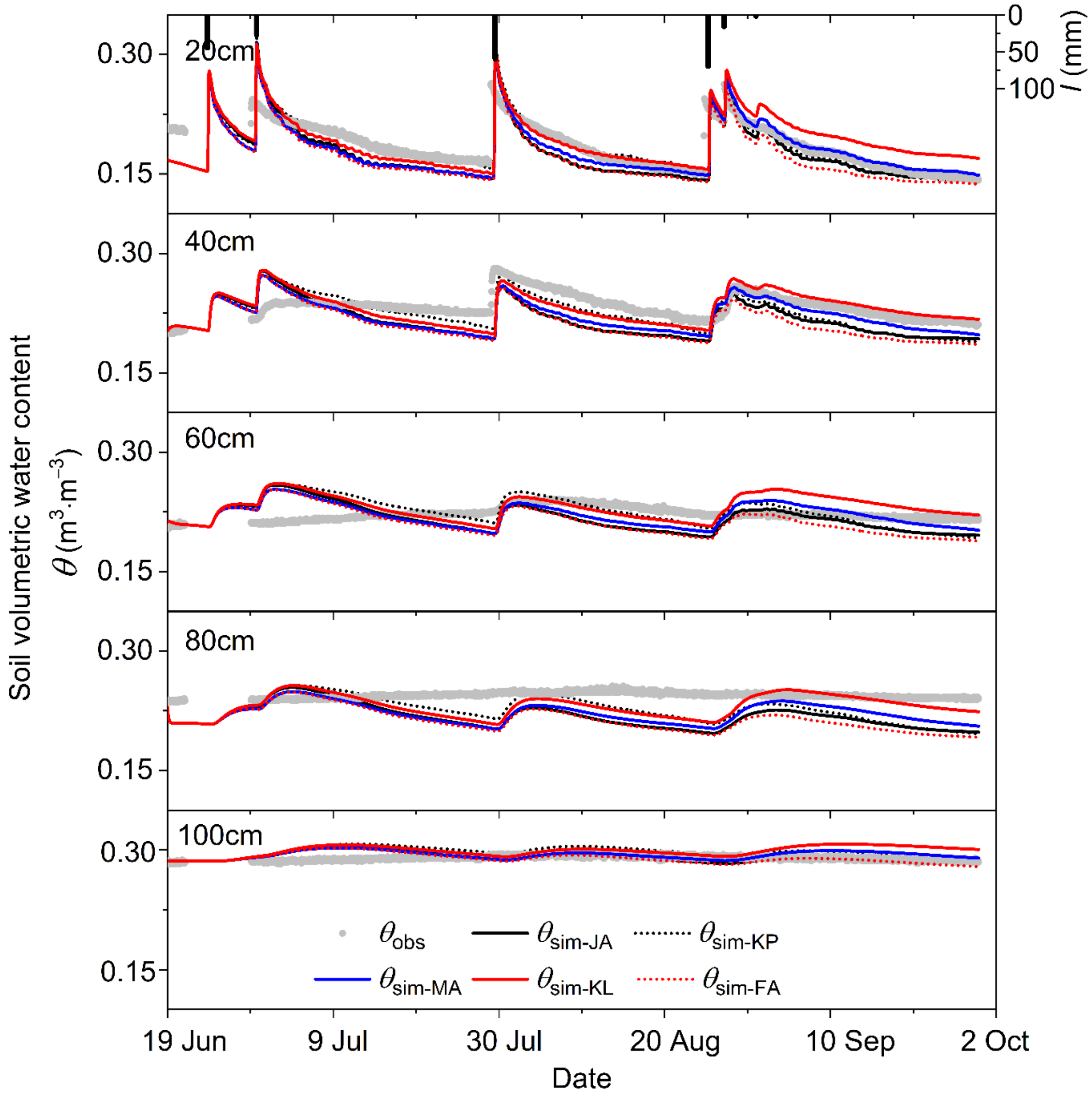

Fig. S1 Time series of measured and model simulated hourly soil water contents at different depths using the Jarvis (JA), Katerji-Perrier (KP), Massman (MA), Kelliher-Leuning (KL), and Farias (FA) canopy resistance methods in 2012.

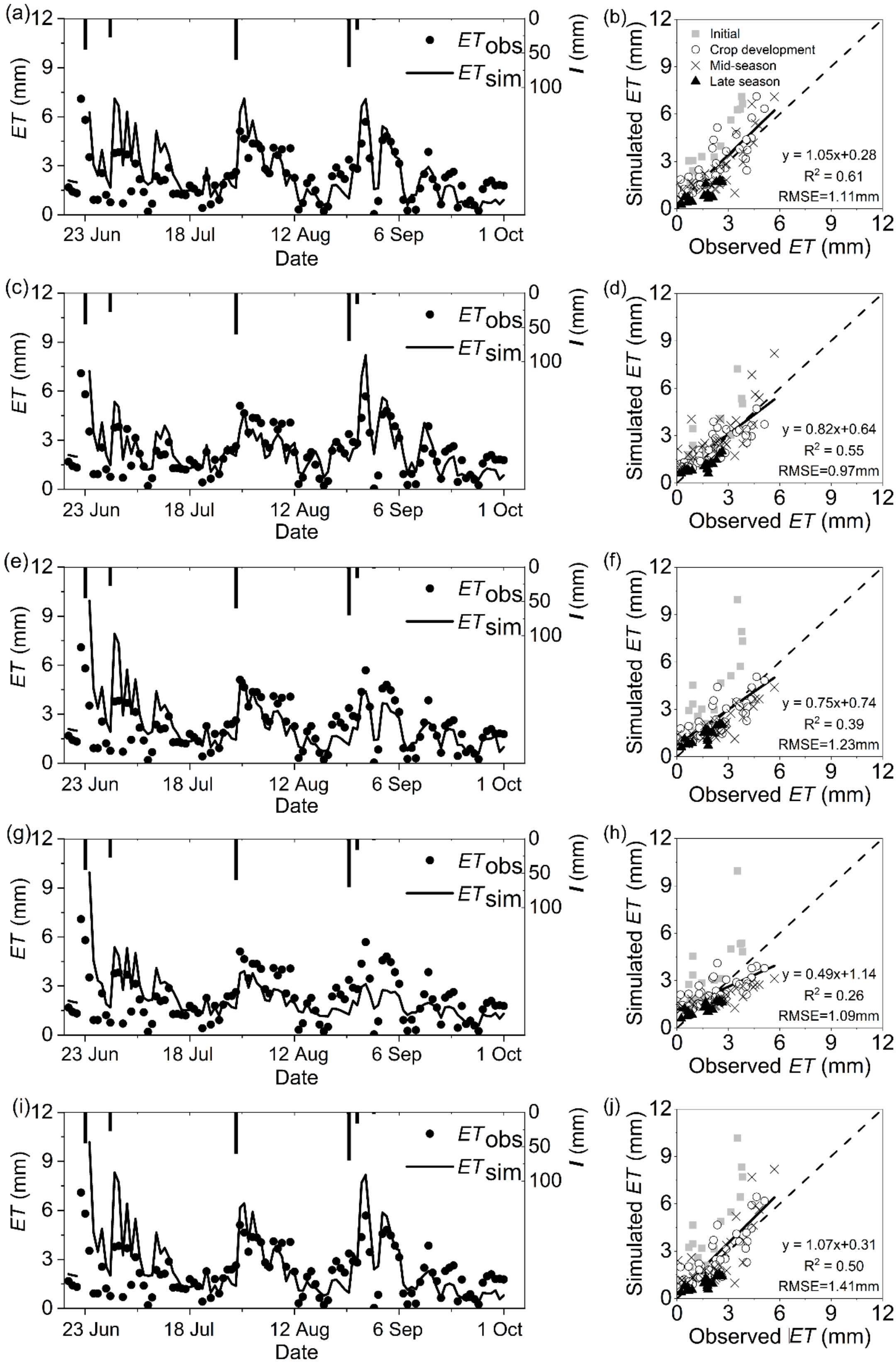

Fig. S2 Daily variation in and correlation relationship between observed ET and simulated ET, based on the (a) and (b) Jarvis (JA), (c) and (d) Katerji-Perrier (KP), (e) and (f) Massman (MA), (g) and (h) Kelliher-Leuning (KL), (i) and (j) Farias (FA) methods.

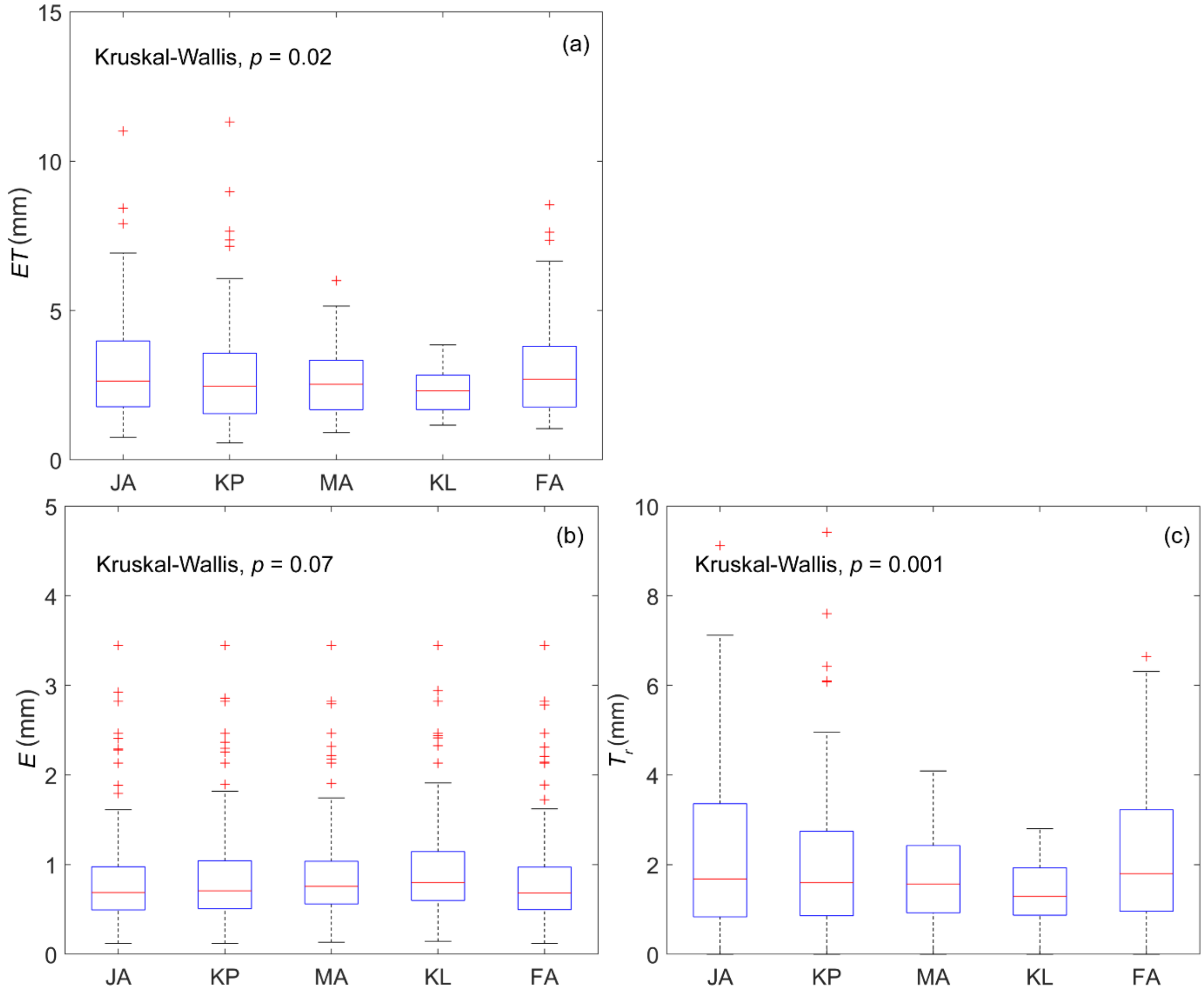

Fig. S3 Statistical significance between the (a) *ET*, (b) *E*, and (c) T_r values of five different canopy resistance methods using the Kruskal-Wallis test.