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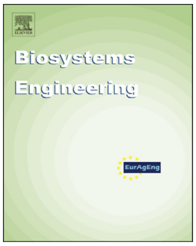

Research Paper

Modelling soil water dynamics of full and deficit drip irrigated maize cultivated under a rain shelter

María G. González [a], Tiago B. Ramos [b], Reimar Carlesso [a], Paula Paredes [b], Mirta T. Petry [a], Juliano D. Martins [a], Núbia P. Aires [a], Luis S. Pereira [b,c,*]

[a] Rural Sciences Center, Federal University of Santa Maria, Santa Maria, Brazil
[b] CEER, Biosystems Engineering, Institute of Agronomy, University of Lisbon, Portugal
[c] CAPES, Federal University of Santa Maria, Santa Maria, Brazil

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The model HYDRUS-1D was used to simulate soil water dynamics of full and deficit irrigated maize grown under a rainout shelter during two crop seasons. Four irrigation treatments were established based on the amount of water applied to fulfil crop water requirements. Treatment D1 was irrigated to fully satisfy crop water requirements, while treatments D2 (mild deficit), D3 (moderate deficit), and D4 (severe deficit) were for increased controlled water stress conditions. The computation and partitioning of evapotranspiration data into soil evaporation and crop transpiration was carried out with the SIMDualKc model, and then used with HYDRUS-1D. The soil hydraulic properties were determined from numerical inversion of field water content data. The compensated root water uptake mechanism was used to describe water removal by plants. The HYDRUS-1D model successfully simulated the temporal variability of soil water dynamics in treatments irrigated with full and deficit irrigation, producing RMSE values that varied between 0.014 and 0.025 cm^3 cm^{-3} when comparing model simulations with field measurements. Actual transpiration varied between 224 and 483 mm. Potential transpiration reductions varied from 0.4 to 48.8% due to water stress, but plants were able to compensate for the water deficits in the surface layers by removing more water from the deeper, less stressed layers. HYDRUS-1D water balance estimates were also comparable with the corresponding ones determined with the SIMDualKc water balance model. Both modelling approaches should contribute to improve the web-based IRRIGA system, used to support farm irrigation scheduling in Brazil.

1. Introduction

Improving irrigation water management for increased productivity is a major objective of irrigated agriculture. This is also true for Brazil, which has a large share of the world's fresh water resources in the Amazon River basin, but also a large climate diversity offering a variety of challenges. Brazil has various climatic zones consisting of the humid equatorial

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* *Corresponding author.* CEER-Biosystems Engineering, Institute of Agronomy, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisbon, Portugal.

E-mail address: lspereira@isa.ulisboa.pt (L.S. Pereira).

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Nomenclature

a_D	empirical parameter of the deep percolation parametric function
b_D	empirical parameter of the deep percolation parametric function
CN	curve number
E	potential soil evaporation, mm
E_a	actual soil evaporation, mm
ET_c	crop evapotranspiration, mm
ET_o	reference evapotranspiration, mm
f_c	fraction of soil covered by the crop
$f_{eff\ mulch}$	effective fraction of soil covered by mulch
$f_{r\ mulch}$	fraction of soil covered by mulch
f_w	fraction of soil cover wetted by irrigation
h	pressure head, cm
H	crop height, cm
K_{cb}	basal crop coefficient
K_e	soil evaporation coefficient
K_s	saturated hydraulic conductivity, cm d^{-1}
L	length season stages, d
L_R	root domain, cm
n	number of observations
p	depletion fraction for no stress
P	predicted values
$\bar{P}$	mean model predictions
RAW	readily available water, mm
REW	readily evaporable water, mm
S	actual volume of water removed from unit volume of soil per unit of time, $cm^3\ cm^{-3}\ d^{-1}$
S_e	effective saturation, cm
S_p	potential volume of water removed from unit volume of soil per unit of time, $cm^3\ cm^{-3}\ d^{-1}$
t	time, d
T_a	actual non-compensated transpiration rate, cm d^{-1}
T_{ac}	actual compensated transpiration rate, cm d^{-1}
T_p	potential transpiration rate, cm d^{-1}
TAW	total available water, mm
TEW	total evaporable water, mm
O	observations
$\bar{O}$	mean observations
z	vertical space coordinate, cm
Z_e	evaporable layer depth, m
α	empirical shape parameters, cm^{-1}
$\alpha(h)$	soil water stress function
β	normalised root density distribution function, cm^{-1}
η	empirical shape parameters
ℓ	pore connectivity/tortuosity
θ	volumetric soil water content, $cm^3\ cm^{-3}$
θ_r	residual water content, cm
θ_s	saturated water contents, cm
$\omega(t)$	root adaptability factor

Subscripts

RAW	readily available water
m	measured FDR values, $cm^3\ cm^{-3}$
h	measured volumetric soil water retention values, $cm^3\ cm^{-3}$
i	time, d

zone in the north; the semi-arid northeast, the tropical and dry central Brazil, the highlands tropical zone in the southeastern region, and the subtropical zone in the south. Despite almost 70% of water being used in agriculture, irrigation is only carried out on 15% (5.5 million ha) of the land while the country's irrigation potential is estimated at 29.3 million ha. As Brazil plans to expand its irrigated areas in the next decades (IICA, 2008), there is a need to improve irrigation water management and optimise water use and water productivity (Pereira, Cordery, & Iacovides, 2012), particularly in areas where water scarcity is likely to increase.

The Federal University of Santa Maria (Rio Grande do Sul State, Brazil) has been developing the IRRIGA System (Carlesso, Petry, & Trois, 2009), which is a web-based decision support system (www.irrigasystem.com) aimed at improving crop water and irrigation requirement estimates and supporting irrigation scheduling, i.e. defining the appropriate irrigation dates and volumes to be applied. The system presently monitors more than 120,000 ha every year in different climatic regions of Brazil, including high-rainfall areas in the south and low-rainfall areas in central Brazil. Deficit irrigation has been considered as a valuable strategy to be implemented with the IRRIGA system in order to maximise water productivity in water scarce regions (Rodrigues, Martins, Silva, Carlesso, & Pereira, 2013). Irrigation is optimised when water deficits are avoided during drought-sensitive growth stages of a crop; outside these periods, irrigation may be limited or even unnecessary. Thus, the adoption of deficit irrigation implies appropriate knowledge of crop water requirements, effects of water deficits at the various crop growth stages on crop physiology and yield, and the economic impacts of yield reduction strategies (English & Raja, 1996; Paredes, Rodrigues, Alves, & Pereira, 2014; Pereira, Oweis, & Zairi, 2002; Rodrigues et al., 2013).

Recently, Martins et al. (2013) used the SIMDualKc model to analyse the water balance in irrigated maize while considering full and deficit irrigation strategies in order to improve the background support of the IRRIGA software for different climatic zones. Maize, one of the most important crops in Brazil currently grown in more than 14 million ha (FAO, 2014), has been reported to be sensitive to drought stress during most of its growth season, particularly during the reproductive stage (e.g., Çakir, 2004; Bergamaschi et al., 2006; Igbadun, Salim, Tarimo, & Mahoo, 2008; Farré & Faci, 2009; Grassini et al., 2011). Therefore, following controlled water deficits in maize irrigation requires precise irrigation scheduling, which is usually carried out using advanced simulation model predictions like those provided by SIMDualKc, which has the advantage of adopting the FAO dual crop coefficient approach for partitioning evapotranspiration into soil evaporation and crop transpiration (Martins et al., 2013; Rosa et al., 2012).