Agricultural Water Management 148 (2015) 130–140

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Deep drainage modeling for a fertigated coffee plantation in the Brazilian savanna

Victor Meriguetti Pinto[a,*], Klaus Reichardt[a], Jos van Dam[c], Quirijn de Jong van Lier[a], Isabeli Pereira Bruno[d], Angelica Durigon[a], Durval Dourado-Neto[b], Rafael Pivotto Bortolotto[e]

[a] Soil Physics Laboratory, University of São Paulo, Center for Nuclear Energy in Agriculture, PO Box 96, 13416-970 Piracicaba, SP, Brazil
[b] Department of Crop Science, University of São Paulo, "Luiz de Queiroz" College of Agriculture, PO Box 9, 134180-970 Piracicaba, SP, Brazil
[c] Department of Environmental Sciences, Wageningen University and Research Centre, PO Box 47, 6700 AA Wageningen, The Netherlands
[d] Agronomic Institute of Paraná, IAPAR, Rodovia Celso Garcia Cid, km 375, Londrina 86047-902, PR, Brazil
[e] Soil Division, Federal University of Santa Maria, Av. Roraima, 1000, Santa Maria 97105-900, RS, Brazil

ARTICLE INFO

Article history:
Received 5 February 2014
Accepted 16 September 2014

Keywords:
Brazil
SWAP
Deep drainage
Water productivity
Savanna

ABSTRACT

Modeling in agriculture represents an important tool to understand processes as water and nutrient losses by drainage, or to test different conditions and scenarios of soil and crop management. Among the existing computational models to describe hydrological processes, SWAP (Soil, Water, Atmosphere and Plant model) has been successfully used under several conditions. This model was originally developed to simulate short cycle crops and its use also to cover longer cycles, e.g. perennial crops, is a new application. This report shows a SWAP application to a mature coffee crop over one-production cycle, focusing on deep drainage losses in a typical soil–plant–atmosphere system of the Brazilian savanna (Cerrado). The estimated annual deep drainage Q = 1019 mm obtained by SWAP was within 99% of the value determined by the climatologic water balance of 1010 mm. Monthly results of SWAP for Q compared to the estimative using the climatological method presented a determination coefficient of 0.77. A variety of coffee fertigation scenarios were simulated using SWAP and compared to farmer's management scenario, leading to the conclusion that larger irrigation intervals result in lower Q losses, better water productivity and higher crop yield.

1. Introduction

The savanna ecoregion (Cerrado) prevails in central Brazil, also reaching the northeast part of the country and including part of the state of Bahia. The savanna domain in Bahia is highly suitable for irrigated agriculture due to the great availability of surface and underground water resources. According to Brazil's National Grain Supply Company (CONAB), western Bahia is an important food (grain) provider and holds, for example, the highest coffee yield under savanna conditions in the country. However, there are some concerns in respect to the modern agriculture practiced in this producer region. Due to the ineffective land management during the last decades, the irrigated farms concentrated at specific areas and, therefore, conflicts over water use already took place in western Bahia (Lima, 2011). At the same time, management practices applied by farmers are not sustainable in terms of fertilizer and water usage, especially due to the lack of scientific studies that support their decisions (Bruno et al., 2011).

Numerical modeling applied to agriculture is a useful tool to simulate biophysical processes and can be used to obtain short-term results and future predictions under defined scenarios. The information generated is helpful for establishing a more sustainable agriculture as well as supporting strategies for the mitigation of pollution, named by Strauch et al. (2013) as the "Best Management Practices". The hydrological model SWAP (Soil, Water, Atmosphere and Plant) is one of the existing algorithms used worldwide for a variety of soils, crops and climatic conditions (Chirico et al., 2013; Crescimanno et al., 2012; Eitzinger et al., 2004; Kamble et al., 2013; Ma et al., 2011; Noory et al., 2011). The model has shown consistent results when applied to maize crops in sub-tropical climates (Pinheiro et al., 2013) and to soybeans and common beans in tropical climates (Scorza Junior et al., 2010; Durigon et al., 2012). SWAP was successfully validated already under several climatic and environmental conditions as cited Ines et al. (2006). More recent studies

* Corresponding author. Tel.: +55 19 34294617.
E-mail address: meriguett@hotmail.com (V.M. Pinto).

http://dx.doi.org/10.1016/j.agwat.2014.09.029
0378-3774/

with this model found close agreement between measured and simulated values (Mishra et al., 2013; Singh et al., 2010; Utset et al., 2007; Vazifedoust et al., 2008; Verma et al., 2012).

This study aimed to use SWAP to evaluate the deep drainage of a savanna coffee plantation and analyze irrigation scenarios in view of water productivity and conservation, minimizing environmental impacts. Values of SWAP input parameters were acquired from a one-year experimental database coming from a study performed on a mature coffee crop growing in central Brazil (Bortolotto et al., 2011, 2012; Bruno et al., 2011). The computer simulations focused on improving water usage and understanding of water dynamics in a sandy soil typical of the Brazilian savanna, an area that is recently intensively used to grow perennial crops. We studied several scenarios of irrigation to improve water productivity for the chosen area.

2. Materials and methods

2.1. The Soil, Water, Atmosphere and Plant model (SWAP)

The model SWAP was developed more than 40 years ago and was gradually upgraded reaching its last version SWAP 3.2 (Kroes et al., 2008). This last version of the model had the source code restructured, numerical stability improved, macropore process integrated, and simplification of precipitation and evapotranspiration inputs included (van Dam et al., 2008).

SWAP makes use of Richards' equation in one dimension added by the sink terms (S) to calculate the water movement in the soil matrix, as follows:

$$\frac{\partial\theta}{\partial t}=\frac{\partial\left[K(h)\left(\left(\partial h/hz\right)+1\right)\right]}{\partial z}-S(h) \quad (1)$$

where θ (cm^3 cm^{-3}) is the volumetric soil water content, t (d) time, S (cm^3 cm^{-3} d^{-1}) the soil extraction rate by plant roots, K (cm d^{-1}) the soil hydraulic conductivity, h (cm) the soil water pressure head and z (cm) the vertical coordinate taken positively upwards. SWAP uses Richards' equation for describing water flux in the unsaturated and saturated zones of the soil and solves Eq. (1) numerically, using the relations between θ, h and K, with the Mualem–van Genuchten relations $\theta(h)$ and $K(h)$ (Mualem, 1976; van Genuchten, 1980).

The upper-boundary conditions in SWAP are determined according to the rates of potential evapotranspiration ET_p (mm), irrigation I (mm) and precipitation P (mm) of the area under study. Daily ET_p is calculated with the Penman–Monteith equation (Monteith, 1965, 1981) using meteorological data of air temperature T_{air} (°C), solar radiation RAD (kJ m^{-2}), wind speed S_w (m s^{-1}) and air humidity H_a (kPa).

The water balance is determined as in the following equation:

$$\pm\Delta W_s = P + I - ET_a \pm RO - P_i \pm Q \quad (2)$$

where W_s (mm) is the soil water storage in a defined elemental soil volume, ET_a (mm) the actual evapotranspiration, RO (mm) the run-off and run-on, P_i (mm) the canopy water interception and Q (mm) the soil water drained at the lower boundary, equal to $-Q_d$ or $+Q_{cr}$. The percolation Q_d is downwards and Q_{cr} the upwards, when capillary rise is present. Q_d can still be subdivided into the components Q_{dI}, due to irrigation, and Q_{dP}, due to the rainfall. Actual evapotranspiration is calculated considering the reduction of root water uptake when there is water or salinity stress, and the reduction of soil water content due to the soil surface drying. The actual transpiration T_a (mm) is obtained as follows:

$$T_a=\int_{-R_d}^{0} S_a(z)\mathrm{d}z \quad (3)$$

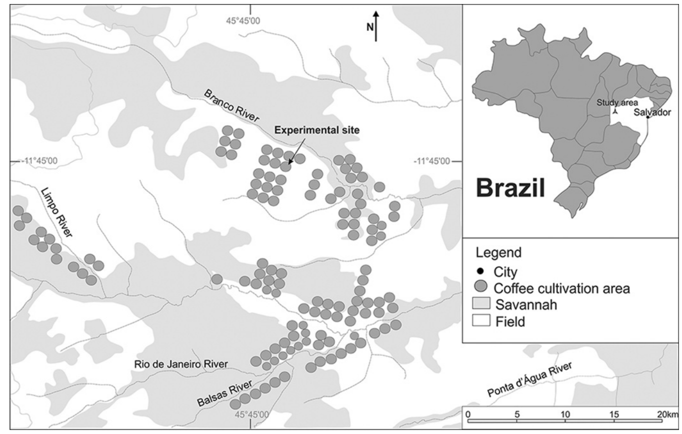

Fig. 1. Experimental site localization, showing central pivot circles in 2013.

where the lower integration limit R_d is rooting depth and S_a the root water flux, which is related to the potential transpiration T_p (mm). During water stress, $S_a(z)$ is described in SWAP as proposed by Feddes et al. (1978). In this function, the root water uptake is regulated by the critical pressure head values h_1 (point where water extraction begins due to anoxia), h_2 (begin of constant maximum root extraction), h_3 (end of constant maximum root extraction), h_4 (wilting point, where root extraction ends). The actual evaporation is determined by Darcy's relation and empirically either according to Black et al. (1969) or to Boesten and Stroosnijder (1986), to be selected by the SWAP user. The bottom-boundary condition is adjusted by the user and can be, for example, prescribed with pressure head values of the bottom soil compartment, calculated as a function of the groundwater level, or the boundary condition can be the free drainage of the soil profile.

SWAP contains simple and detailed crop growth modules, which should be selected by the user according to the available plant data. In the simple model the user provides the leaf area index (LAI), crop factor (K_c) and rooting depth as a function of the crop development stage (DS). These data are used to calculate the canopy interception P_i, potential transpiration T_p and potential evaporation E_p.

2.2. Experimental site and field experiment

An experimental test used to calibrate and compare the results of the SWAP model was performed between August 1st, 2008 and July 31st, 2009, at a private farm near the city of Barreiras (11°46′00″S, 45°43′32″W), in Bahia, northeast Brazil (Fig. 1). The soil is classified as a Typic Hapludox according to the USDA Soil Taxonomy (Soil Survey Staff, 2010), with low natural fertility and is located in a savanna region. The precipitation is very variable, ranging from 800 to 1800 mm per year, with most events occurring from October to April. Meteorological data, acquired from the National Institute of Meteorology (INMET, Brazil), were collected at the meteorological station of the municipality of Barreiras, 90 km far from the experimental site. The input variables farmer irrigation depths and precipitation along the experimental year used for SWAP simulations are shown in Fig. 2. It is important to observe that irrigation is not discontinued during the rainy season, due to the fertilizer application that is carried out year round.

The coffee species was *Coffea Arabica* L., variety *Catuaí Vermelho*. Plants were seven years old at the beginning of the experiment and were planted at a spacing of 3.8 m between lines and 0.5 m between plants in a circular arrangement for central pivot irrigation with a total area of 80 ha, adapted for fertigation. Irrigation was applied homogeneously over the planted area, and the experimental site consisted of the pivot circle number 4, starting from