Agricultural Water Management 138 (2014) 26–36

Contents lists available at ScienceDirect

Agricultural Water Management

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

Irrigation recommendation in a semi-arid drip-irrigated artichoke orchard using a one-dimensional monthly transient-state model

Fernando Visconti[a,*], José Miguel de Paz[a], Delfina Martínez[b], Mª José Molina[b]

[a] Instituto Valenciano de Investigaciones Agrarias – IVIA (GV), Centro para el Desarrollo de la Agricultura Sostenible – CDAS, Crta. Moncada-Nàquera Km 4.5, 46113 Moncada, València, Spain
[b] Centro de Investigaciones sobre Desertificación-CIDE (CSIC, UVEG, GV), Crta. Moncada-Nàquera Km 4.5, 46113 Moncada, València, Spain

ARTICLE INFO

Article history:
Received 31 October 2013
Accepted 23 February 2014
Available online 20 March 2014

Keywords:
Mathematical models
Percolation
Soil salinity
Soil water
Trickle irrigation
Water quality

ABSTRACT

Irrigation in semi-arid areas can be optimally scheduled using models that maximize accuracy while minimizing data requirements. In this work, the validation of the one-dimensional transient-state SALTIRSOIL_M model able to monthly simulate the soil water content (θ), downward water flux (D), and the electrical conductivity in the saturation extract (ECe) is presented. The θ and the ECe were monthly monitored at 15 and 45 cm depth in a plot in commercial production of globe artichoke under semi-arid climate and drip-irrigation in SE Spain during the 2011–2012 growing season. Data on water quality, weather, irrigation management, crop development and soil were also collected and used to simulate the θ, D, and ECe throughout the growing season at both depths with the SALTIRSOIL_M model. Reference and simulations of θ and D reasonably agreed with one another at both depths. ECe at 45 cm depth was estimated correctly enough by the model but was underestimated at 15 cm depth. The higher concentrations of nitrate, potassium, and hence other cations, which were observed at 15 cm as a consequence of fertilization could explain this. The model was subsequently used to estimate the optimum water management in the plot. Use of 325–450 mm yr^{-1} instead of 694 mm yr^{-1}, and by means of evenly distributed pulse irrigations instead of continuous ones, would have met the crop evapotranspiration requirements while avoiding excessive drainage, and maintaining soil salinity well below damaging values.

1. Introduction

Irrigation is needed in arid-to-dry-subhumid areas to sustain agricultural productivity. However, soil salinization develops as a consequence of irrigation in such areas, and an estimated 10% of world-irrigated lands are already salt affected (FAO, 2002). Mitigation of soil salinization in irrigated agriculture is usually carried out by irrigation in excess of evapotranspiration requirements, along with installation of drainage systems if deep downward water flux exceeds the natural drainage capacity of the soil (Ayars, 2012). Nevertheless, this practice usually leads to overirrigation even with the use of localized irrigation systems, which severely decreases water use efficiency, and causes erosion and waterlogging. Besides, along with drainage, overirrigation produces excess generation of drainage waters, and pollution of natural water bodies with salts, nutrients and agrochemicals (Tanji and Kielen, 2002). Optimal irrigation management in salt-threatened areas must proceed through adequate management of irrigation and drainage, but also soils and crops. In this regard, the use of simulation models is adequate, because they enable to find out the present and future effects of irrigation, soil and crop management on soil water content (θ), downward water flux (D) and soil salinity.

In salt-threatened areas, soil salinity models are used along with crop water requirement estimations to schedule irrigations. Presently available soil salinity models are classified into

---

Abbreviations: D_d, soil water downward flux below depth d; EC$_{25}$, electrical conductivity at 25 °C; ECe, electrical conductivity at 25 °C in the saturation extract; ET$_0$, reference evapotranspiration; ETa, actual evapotranspiration; ETc, crop evapotranspiration; F_c, maximum canopy ground cover; $F_{c,m}$, canopy ground cover in month m; f_W, fraction of soil area wetted by irrigation; I, irrigation amount; I_f, number of irrigation days; IA, index of agreeement; K_{cbmax}, maximum basal crop coefficient; $K_{cb,m}$, basal crop coefficient in month m; LF, quotient of drainage water to infiltrating water (rainfall plus irrigation); MSDr, random mean square deviation; MSDs, systematic mean square deviation; pCO$_{2sp}$, apparent CO$_2$ partial pressure at equilibrium with the saturated paste; pH$_{sp}$, pH in the saturated paste; R, rainfall amount; R_f, number of irrigation days; RMSD, root mean square deviation; SP, saturation percentage (gravimetric water content at saturation); θ, soil volumetric water content; θ_{fc}, soil volumetric water content at field capacity; θ_{pwp}, soil volumetric water content at permanent wilting point; ρ_b, soil bulk density; ρ_{bL}, large cylinder bulk density; ρ_{bS}, small cylinder bulk density.

[*] Corresponding author. Tel.: +34 963 424 040; fax: +34 963 424 001.
E-mail address: fernando.visconti@uv.es (F. Visconti).

http://dx.doi.org/10.1016/j.agwat.2014.02.019
0378-3774/

transient-state and steady-state (Letey and Feng, 2007). With transient-state models the user can simulate the effect of seasonally variable factors, such as irrigation scheduling, rainfall pattern, crop growth, and water quality on soil salinity throughout time. However, most transient-state models use the Richards and convection–dispersion equations to simulate water and solute flow (Oster et al., 2012) and, therefore, they require data (parameters of the soil water characteristic curve, dispersivity and molecular diffusion coefficients, pore size distributions, etc.) which are highly variable and not routinely determined during land surveys. The usual lack of data on these properties confines the applicability of most transient-state models to research, and/or to coarse-textured soils, although their calculations are most needed by farmers, and for management of clayey soils, which are more prone to salinization than coarse-textured ones.

Steady-state models usually require few data on soil, water, climate and crop which are already available or easy to obtain. Logically, they also provide scarce outputs often summed up in just one datum, this is the leaching requirement (LR). The LR, i.e., the minimum leaching fraction (LF) needed to attain maximum or optimum yield (Rhoades, 1974; Ayers and Westcot, 1985), has been traditionally the main recommendation for irrigation water management in salt-threatened lands. The LR concept presents, however, some drawbacks that limit its practical use (Letey et al., 2011). In this regard, the assessment of the irrigation rates that would render one LR is, in practice, a task that demands the analysis of various time-dependent agricultural factors, which should be logically carried out using transient-state irrigation calculations.

Several models have been conceived as solutions to this dual approach for irrigation scheduling in salt-threatened soils. An example of these is the SALTIRSOIL model (Visconti et al., 2011), which combines in one unique program a transient-state model for the assessment of time-dependent agricultural factors together with a steady-state model for assessing soil salinity. It provides similar results to WATSUIT although with extended capabilities (Visconti et al., 2012).

Recently, it has been shown that steady-state calculations overestimate the salinization risk, and that transient-state models should replace steady-state models (Letey et al., 2011). Besides, to have accurate simulations of soil salinity, a reliable modeling of main ions chemistry has been found more important than accurate modeling of soil water content and solute flow (Schoups et al., 2006; Corwin et al., 2007). Since a reliable submodel for main ion chemistry was already included in SALTIRSOIL, the replacement of its steady-state approach for soil salinity assessment by a simple transient-state approach would probably suffice to have reliable estimations of soil salinity. This improvement has been implemented to give rise to the SALTIRSOIL_M model (Visconti and de Paz, 2012a; Visconti, 2013), which extends the tipping bucket model concepts of soil water movement on a monthly time step also to solutes. For all other purposes, the SALTIRSOIL_M model keeps the affordable data requirements and simple computing that characterized the previous SALTIRSOIL model.

As previously indicated, all models are aimed at being of practical use for farmers and agricultural technicians. Therefore, models must undergo field-testing to convince the agricultural and environmental stakeholders of their practical utility. This is even more important in the present global scenario of increase use of irrigation systems such as drip (Kulkarni et al., 2006), which enables farmers to precisely control watering quantity, timing and location within a field. Therefore, transient-state models will attain their maximum practical potential when used in conjunction with such fully controlled irrigation methods.

In the present work, the ability of a one-dimensional monthly transient-state model, specifically the SALTIRSOIL_M model, was investigated for estimating the water content, downward water flux and soil salinity throughout the growing season in a globe artichoke orchard with drip irrigation under semi-arid Mediterranean climate. The implications of these findings for improving irrigation management in the artichoke orchard were discussed.

2. The SALTIRSOIL_M model

The one-dimensional monthly transient-state SALTIRSOIL_M model (Visconti, 2013) is based in a tipping bucket algorithm for simulating the soil water downward movement where the soil is split in a number *n* of layers or nodes. The calculations implemented in the model to assess the irrigation management, crop development, actual evapotranspiration, chemical equilibria and electrical conductivity, were presented in a previous work (Visconti et al., 2011). In the present transient-state one-dimensional model, the principle of mass conservation (PMC) of water and also solutes has been applied (Visconti and de Paz, 2012b). The PMC has been applied conceptually splitting the soil in a number *n* of stacked layers, and carrying out a water, and next a solute balance, in each of them.

The PMC for a non-reacting solute in the upper soil layer (layer 1) is adequately expressed through Eq. (1), where $m_{i,1}$ and $m_{i\text{-}1,1}$ are, respectively, the mass of solute in layer 1 the present (i) and past ($i-1$) month, I_i and $D_{i,1}$ are, respectively, the irrigation water amount and downward water flux from layer 1, and C_{Ii} and $C_{i,1}$ are, respectively, the solute concentrations in the irrigation and downward water flux from layer 1.

$$m_{i,1} = m_{i-1,1} + I_i C_{Ii} - D_{i,1} C_{i,1} \tag{1}$$

Regarding the irrigation water at average field water content the month i, the concentration factor of the soil solution in layer 1 ($f_{i,1} = C_{i,1}/C_{Ii}$) can be calculated from the concentration factor ($f_{i-1,1}$) and the soil water amount ($V_{i-1,1}$) in layer 1 the previous month (${}_{i-1,1}$), divided by the soil water amount in layer 1 the present month ($V_{i,1}$). After rearrangement, Eq. (2) is obtained.

$$f_{i,1} = \frac{V_{i-1,1} f_{i-1,1} (C_{Ii-1}/C_{Ii}) + I_i}{V_{i,1} + D_{i,1}} \tag{2}$$

The PMC can be applied to the underlying soil layers j ($j \geq 1$) by means of Eq. (3), which is similar to Eq. (1).

$$m_{i,j} = m_{i-1,j} + D_{i,j-1} C_{i,j-1} - D_{i,j} C_{i,j} \tag{3}$$

After dividing again by the water amount in each layer j ($V_{i,j}$) and rearrangement, we obtain Eq. (4) to calculate the concentration factor in the soil layer j regarding the irrigation water ($f_{i,j} = C_{i,j}/C_{Ii}$).

$$f_{i,j} = \frac{V_{i-1,j} f_{i-1,j} (C_{Ii-1}/C_{Ii}) + D_{i,j-1} f_{i,j-1}}{V_{i,j} + D_{i,j}} \tag{4}$$

Eqs. (2) and (4) are used in the model to calculate the concentration factor of the soil solution regarding the irrigation water in each soil layer. The concentrations of the main ions in the irrigation water (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, $NO_3{}^-$, $SO_4{}^{2-}$), and also the alkalinity, are subsequently multiplied by the concentration factors. The equilibrium composition with soil CO_2 is calculated considering the likely precipitation or weathering of calcite and gypsum and, finally, the electrical conductivity at 25 °C of the soil solution or saturation extract is assessed.

3. Materials and methods

3.1. Study plot

A 1.04 ha plot in commercial production located in the traditional irrigated area of Vega Baja del Segura in SE Spain (coordinates