Irrigation of forage crops with saline drainage waters: Volumetric lysimeter studies and modeling of root water uptake and drainage

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1 INTRODUCTION

The disposal of agricultural drainage waters into surface waters or onto lands leads to salinization and degraded soil and water quality. In some instances the impacts of agricultural drainage disposal may be reduced if drainage waters are isolated and reused for irrigation (Rhoades, 1989; Rhoades et al., 1992; Rhoades, 1999). Over the last 25 years, the recycling of drainage water for irrigation has been examined in numerous experiments and demonstration projects (Oster and Wichelns, 2003; Rhoades 1992). Scientific and economic questions remain about the suitability of different waters, soils, and crops for reuse operations; optimal management practices are not yet known (Rhoades, 1999).

With many operational variables to consider, discovering best management practices using trial-and-error in the field may prove difficult and time-consuming. Modeling offers a cost-effective means of accelerating the development of optimal management practices (Rhoades, 1999; Oster and Wichelns, 2003). Rhoades (1999) reviewed steady-state model calculations that demonstrate the basic conceptual soundness of drainage reuse programs, and noted that while more comprehensive model calculations are desirable, they are not yet justified because insufficient evidence exists documenting the accuracy of more comprehensive numerical models. Indeed, the root water uptake functions found in advanced simulation models have not been extensively evaluated against experimental data, especially over the range of field conditions that may be encountered in a reuse system.

We report here selected results from recent studies (Skaggs et al., 2005a,b) in which forage crops were grown in volumetric lysimeters using synthetic saline-sodic drainage waters. The first study examined, within the context of drainage reuse management systems, relationships between irrigation water quality and depth, forage crop biomass production (alfalfa and tall wheatgrass), evapotranspiration, drainage depth, and drainage water quality. The second study compared drainage and root water uptake data with simulations made using HYDRUS-1D, an advanced computer simulation model that potentially could be used in the design and analysis of optimal management practices for drainage reuse systems.

2 VOLUMETRIC LYSIMETER STUDIES

An experiment was conducted in a lysimeter facility consisting of 24 volumetric lysimeters, each measuring 81.5 cm wide × 202.5 cm long × 85 cm deep. The lysimeters were filled with Lytle Creek river sand (96% sand, 3% silt, 1% clay) to a depth of 80 cm. On 14 Nov. 2001, 12 lysimeters were planted in 'Salado' alfalfa (Medicago sativa) and 12 in 'Jose' tall wheatgrass (Agropyron elongatum). The crops were established over several months using good quality irrigation water.

Experimental treatments started on 2 May 2002 (Day of Year 122) and proceeded in two phases. The first phase (DOY 122–237) imposed only salinity stress, with all lysimeters

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being luxuriously irrigated with waters ranging in salinity from 2.5 to 28 dS m^{-1}. The second phase (DOY 247–297) imposed a combination of salinity and drought stresses. The same irrigation waters were used, but now lysimeters were irrigated with a prescribed fraction (f = 0.5, 0.75, 1.0, or 1.25) of water consumed in two well-watered “control” lysimeters. Thus lysimeters with $f < 1$ received less water than was being consumed in the control (deficit irrigation), whereas lysimeters with $f \geq 1$ received water equal to or in excess of that amount. During both phases the lysimeters were irrigated every other day.

3 HYDRUS-1D SIMULATION MODEL

HYDRUS-1D (Šimůnek et al., 1998) simulates water flow and solute transport in the vadose zone by numerically solving the Richards equation:

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

where θ = volumetric water content; h = matric head; K = hydraulic conductivity; t = time; z = space coordinate; and $S(x,t)$ = a sink term specifying the rate at which water is removed by plant roots per unit volume of soil per unit time. The rate of extraction is affected by the soil-water conditions:

$$S(h,h_\phi) = \alpha(h,h_\phi)S_p \qquad (2)$$

where S_p = potential rate of extraction; h_ϕ = osmotic head; and α = the reduction factor ($0 \leq \alpha \leq 1$) that scales the potential uptake rate depending on the matric and osmotic potentials of the soil solution. In our study, we used a multiplicative model for the reduction factor:

$$\alpha(h,h_\phi) = \left[1 - A(h_\phi - B)\right]\cdot\frac{1}{1+(h/h_{50})^p} \qquad (3)$$

The term in square brackets on the right side of Equation 3 is a threshold-type model for uptake reductions due to salinity stresses. In this model, B is the threshold osmotic head and A is the decrease in uptake per unit increase in osmotic head. For $h_\phi < B$, the term in square brackets is equal to one (no reduction). The second term in Equation 3 is an S-shaped model specifying the uptake reduction due to drought stresses. In this term, h_{50} is the matric head at which uptake is halved and p is a shape parameter.

The potential transpiration rate was specified as the product of a reference ET_0 (calculated on an hourly basis from CIMIS weather station data) and seasonally averaged crop coefficients determined from an analysis of the ET measured in the two control lysimeters.

4 RESULTS

Using trial-and-error, we found that good agreement between the measured and modeled uptake and drainage could be achieved using the uptake reduction parameters A = 0.004 m^{-1} and B = 25 m for alfalfa, and A = 0.003 m^{-1} and B = 15 m for tall wheatgrass. Figure 1 shows results for six of the tall wheatgrass lysimeters. The agreement between the model

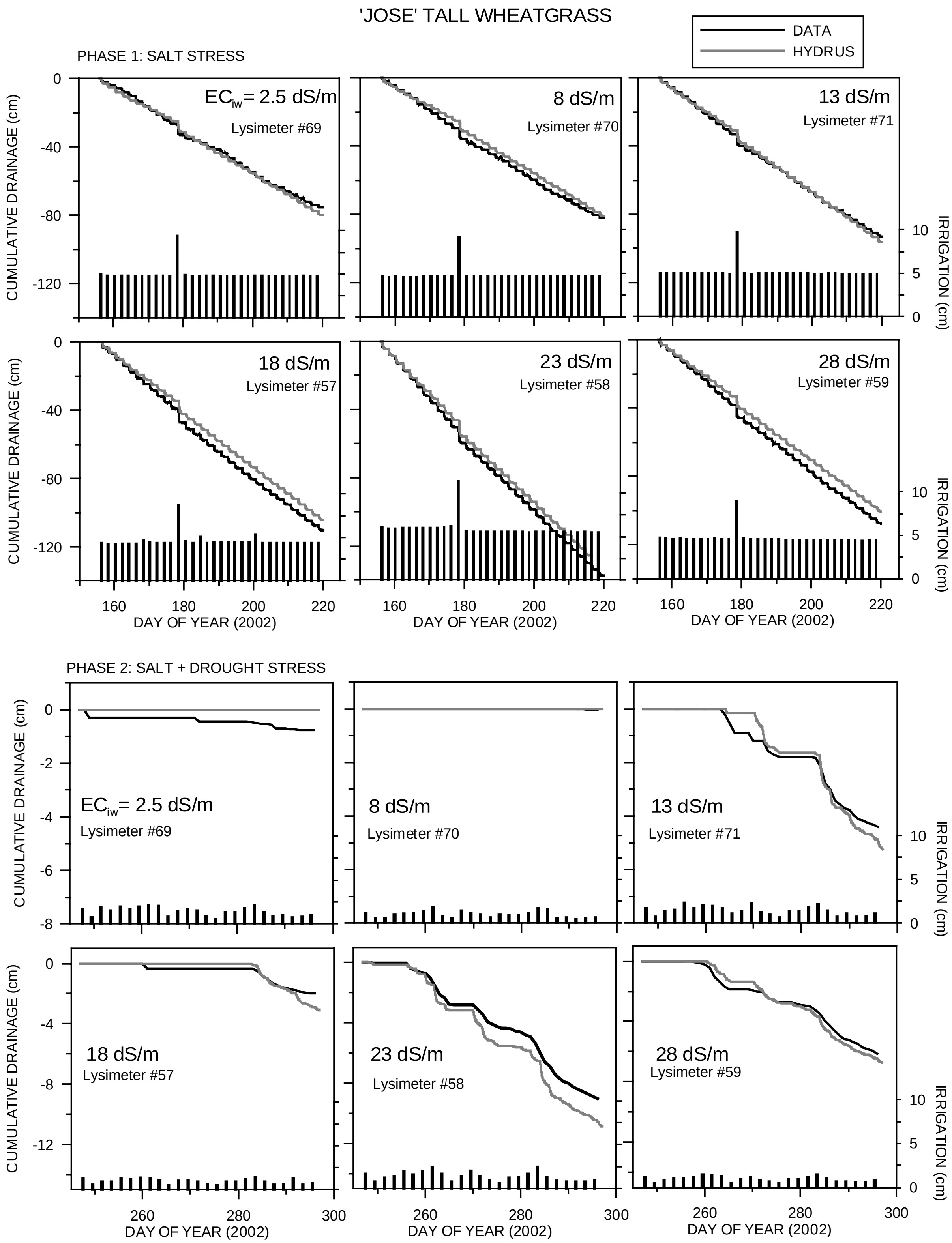

Figure 1. Comparison of measured and modeled cumulative drainage depths for selected lysimeters and experimental treatments. Cumulative drainage depths are plotted as solid lines with the scales on the left axes; irrigation depths are shown on the bottom of the plots with the scales on the right axes. The irrigation water EC and lysimeter I.D. are indicated on each plot. Note that the scales on the cumulative drainage axes in the bottom two rows of plots differ from those in the top two.

and the data for the remaining tall wheatgrass lysimeters, and for all of the alfalfa lysimeters, was similar to that indicated in Figure 1 (data not shown). The results were not sensitive to the parameters h_{50} and p because of the sand's water retention properties (essentially zero water content at 250 cm suction).

5 CONCLUSIONS

Using a fitting procedure, we were able to obtain good agreement between the model and the data for all experimental treatments using a single set of uptake reduction parameters for each crop. This is noteworthy given the broad range of experimental conditions considered: irrigation waters with EC's ranging from 2.5 to 28 dS/m, and irrigation rates ranging from deficit to luxurious.

On the other hand, the required salinity stress parameters did not correspond to published salt tolerance data for these crops, nor with our own yield data (Skaggs et al, 2005a,b). Since the uptake reduction parameters required for the simulations depend on other model parameters that affect the water balance (e.g., the potential transpiration rate), an error or adjustment in one of those parameters would necessitate a correction in the uptake reduction parameters. Thus the uptake reduction parameters estimated here (or estimated elsewhere by others) might not be readily transferable to other locations and/or experimental conditions. In other words, at present it does not seem possible that precise quantitative predictions can be made without crop- and site-specific calibration. Nevertheless, the results show that the HYDRUS model captures the essential features of root water uptake and drainage during salinity and drought stress, and hence the model may be a useful tool for analyzing and designing management practices involving drainage reuse systems.

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