EFFICIENT SURFACE FERTIGATION OF HIGH VALUE HORTICULTURE CROPS

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ABSTRACT

The research reported herein aims at the development of a management guideline for surface N-fertigation systems for high value horticultural crops in the low desert regions of Arizona and California. A complete set of performance indicators for the combined resource management system were identified and defined. A numerical model that solves the one-dimensional advection equation in the surface irrigation stream and a zero-inertia based surface hydraulic model were developed. The surface water movement and solute transport models were coupled with the popular subsurface water movement and solute transport model (Hydrus 1-D). Field experiments were performed to develop a database for use in the calibration and validation of the coupled surface-subsurface water movement and solute transport model. The coupled nitrogen transport and surface irrigation simulation model will then be used to develop improved management guidelines for surface N-fertigation systems.

INTRODUCTION

In the southwestern United States, especially in the low desert regions of Arizona and California, surface N-fertigation of high value horticultural crops is widespread. Flexibility, cost effectiveness, and the potential for improved seasonal fertilizer application efficiency are advantages of fertigation over traditional fertilizer application methods. However, in the absence of appropriate design and management procedures, surface N-fertigation efficiencies and uniformities can be low compared to conventional fertilizer application methods (Gardner and Roth, 1984; Jaynes et al., 1992). Inefficient fertigation practices can cause nitrate pollution of surface-water and groundwater resources. Research interest in the transport and fate of N-fertilizer applied with a surface irrigation stream is growing (Jaynes et al., 1992; Boldt et al., 1994; Izadi et al., 1996; Playan and Faci, 1997; Garcia-Navarro et al., 2000). However, comprehensive surface N-fertigation management procedures have yet to emerge.

The objective of the research reported here is to develop efficient surface N-fertigation management guidelines for high value horticultural crops in the low-desert regions of Arizona and California. Specific objectives of the project are: (1) identification and definition of a complete set of performance indices for an N-fertigation management system, (2) development of a coupled surface-subsurface water movement and solute transport model for use in fertigation systems analysis and design (3) field experimentation to collect data that can be used in model calibration and testing, (4) model calibration, testing, and fertigation scenario analysis. This paper presents a summary of the results obtained already and briefly outlines the work that is to be done in the coming months.

METHODS

A complete set of indices that can be used to characterize the performance of a surface fertigation event was identified and defined. Fertigation performance at a field-event scale was defined in terms a reference fertigation event, which in turn was described as one that applies the required amount of water and N-fertilizer over the crop root zone without loss. Based on the preceding definition of performance, a set of three indices was identified that constitute a complete set of performance indicators for a surface N-fertigation event. This set includes: nitrogen application efficiency (E_{aN}), nitrogen requirement index (I_{rN}), and nitrogen distribution uniformity (DU_N). Efficiency, adequacy, and uniformity constitute a complete set of performance criteria for a surface N-fertigation event. However, a complete accounting of the N-fertilizer applied in a fertigation event and diagnostic information, as to how the performance of a surface N-fertigation event can be improved, are obtained only from evaluations of the components of the N-fertilizer losses. In general, there are three indices that are of relevance in this category: nitrogen leaching loss, nitrogen runoff loss, and nitrogen surplus within the crop root zone. Detailed description of the individual indices and related equations can be obtained from Zerihun et al. (2003a).

A coupled surface-subsurface water movement and solute transport model is needed to develop management guidelines for the combined irrigation water and N-fertilizer management system for high value horticultural crops. Development of a numerical model that is capable of simulating the combined resource management system is near completion. A surface hydraulic model that can simulate the complete cycle of a surface irrigation event for free-draining borders, level/graded basins, and closed-end/free-draining furrows was developed and tested using field data (Zerihun et al., 2003b). The model solves a pair of differential equations that are used to describe mass balance and force equilibrium in a "non-inertial" flow in a prismatic channel of any given geometric shape:

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}+\frac{\partial Z}{\partial t}=\mathbf{0} \quad \textit{and} \quad \frac{\partial(\gamma_1 A^{\gamma_2})}{\partial x}-S_o+\frac{Q|Q|n^2}{C_d\rho_1 A^{\rho_2}}=\mathbf{0} \qquad \textbf{(1)}$$

where Q = flow rate (m^3/min), n = The Manning roughness coefficient ($m^{1/6}$), x = distance (m), A = cross-sectional area (m^2), Z = subsurface volume per unit length (m^3/m), t = time (min), S_o = channel bed slope (-), C_d = dimensional constant (3600 m/min^2). In Eq. 1, it is assumed that the following relations hold y = $(_1A^{(2}$
$A^2R^{4/3}$ = D_1 A^{D2}; where $(_1$ ($m^{(1-2\gamma 2)}$), $(_2$ (-), ρ_1($m^{(16-6\rho 2)/3}$) and ρ_2 (-) are empirical geometric parameters. Problem definition is completed with a statement of pertinent initial and boundary conditions (see Zerihun et al., 2003b). The Preissmann implicit finite difference scheme was used to transform Eq. 1 to a pair of nonlinear algebraic equations (Cunge et al., 1980). At any given time step, applying the implicit scheme to the entire stream and imposing pertinent boundary conditions yields a system of nonlinear equations. The system of nonlinear equations are then solved using the Newton-Raphson iterative scheme combined with double-sweep algorithm (Walker and Skogerboe, 1987; Zerihun et al., 2003b).

The one-dimensional advection equation was used to describe the transport of nitrogen in the surface irrigation stream:

$$\frac{\partial(AC)}{\partial t}+\frac{\partial(QC)}{\partial x}=\frac{\partial(ZC)}{\partial t} \qquad (2)$$

where C = mean cross-sectional concentration of N (g/m^3). Measured or assumed mass flow rate at the upstream end of the stream can be used as the upper boundary condition in the solution of Eq. 2. Equation 2 is solved using an explicit finite difference scheme. The water movement and solute transport processes in the subsurface domain are simulated using an existing numerical model, Hydrus-1D, developed at the U.S. Soil Salinity Laboratory (Simunek, J., Huang, K., and vanGenuchten M.Th., 1998). Hydrus-1D solves the one-dimensional Richards' equation for water movement and the CDE (ADE) equation for solute transport. Description of pertinent initial and boundary conditions is provided in Zerihun et al. (2002). A general flow chart showing the calculation process at any given time step is presented in Figure 1.

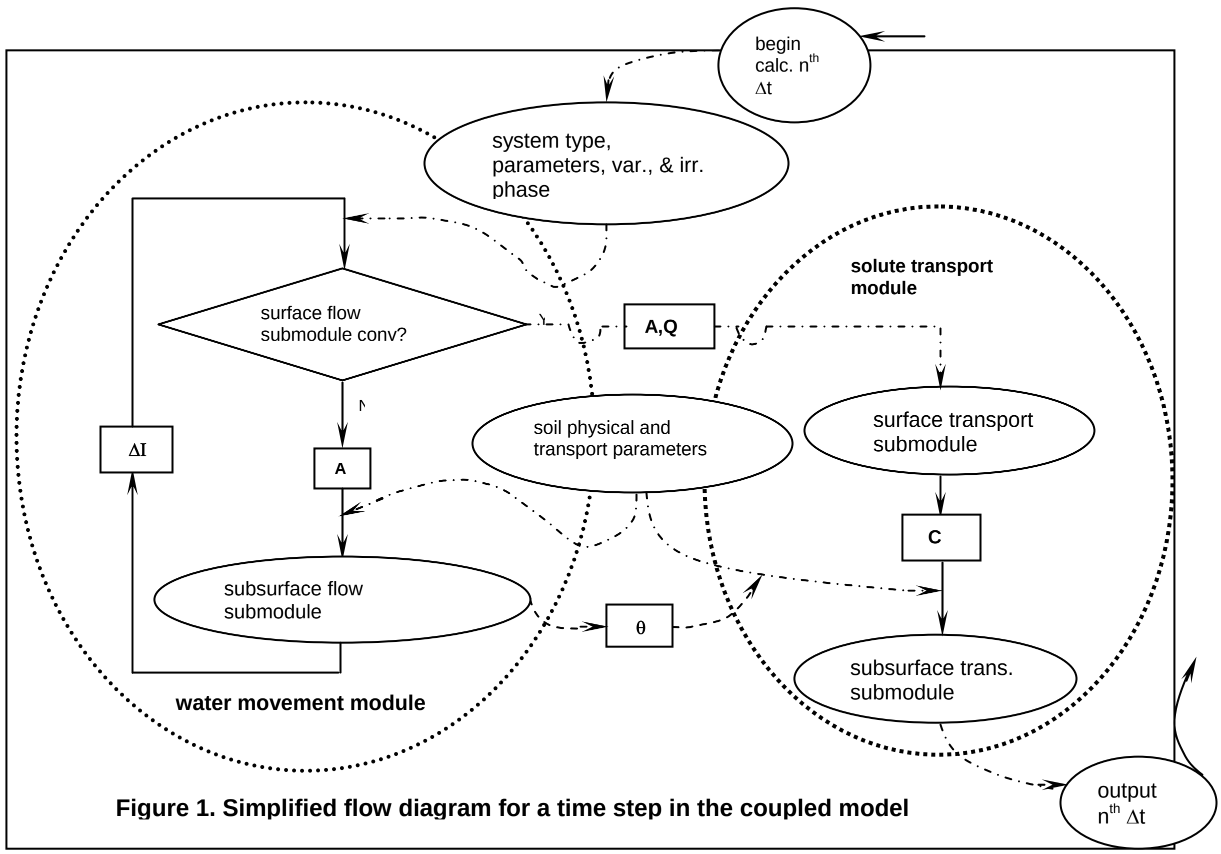


Figure 1. Simplified flow diagram for a time step in the coupled model

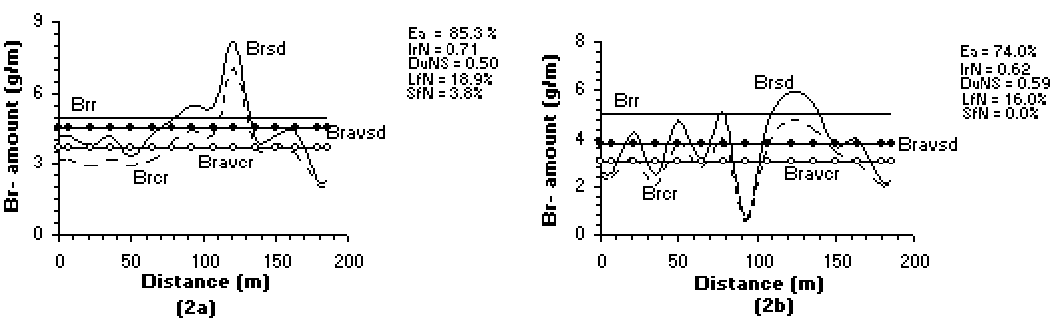
As shown in Figure 1, during each time step solution begins with the surface flow module passing initial estimates of flow depth to Hydrus-1D. Hydrus-1D calculates cumulative intake in a time step using flow depth values passed from the surface flow module as the top boundary condition and soil moisture content at the end of the previous time step as the initial condition for the current time step. Hydrus-1D then returns the cumulative intake amounts in the time step to the surface hydraulic model, which in turn are used by the surface hydraulic model to test convergence of Newton's iteration. If the residuals of mass and momentum balance are not reduced to a level that is within the error tolerance criteria, a revised estimate of the flow depth and flow rate will be made for each of the computational nodes and the arrays of flow depth will be passed to Hydrus-1D. Hydrus-1D recalculates the infiltration for each node as a function of the revised estimates of flow depth and returns the result to the surface model. This process is repeated until convergence is achieved. Upon convergence, calculation proceeds to the next time step, in which case the solution to the previous time step is used as an initial estimate for the new time step. This recursive relationship is repeated until the entire surface irrigation process is simulated.

Before the coupled model can be used for analysis and design and management, it needs to be calibrated and tested using field data. Since the fall season of 2000, field experiments have been performed at the University of Arizona Yuma Agricultural Center (YAC) in Yuma and at the University of California Desert Research and Extension Center (DREC) near Holtville. In addition to providing the data needed for model calibration and testing, field experiments are needed to assess the performance of existing fertigation management practices in the project area. The field experiments in YAC were focused mainly on N-fertigation of basins and closed-end level furrows. Experiments in DREC, on the other hand, were conducted on free-draining graded furrows. Br^- is used as a tracer to simulate the transport of NO_3^- both on the surface and through the soil profile. Water samples taken from the irrigation stream as well as soil samples taken a couple of days after the fertigation experiments were analyzed in laboratory to determine concentrations of Br in the irrigation water and soils. In order to take into account the effect of varying application modes on the performance of a fertigation event, different modes of N application were tested.

Field data will then be used in model calibration and testing. Water advance and recession data are used to evaluate the predictive quality of the water flow module. The transport model will be validated by comparing the temporal and spatial evolution of the concentration of the chemical in the surface stream and concentration in the soil profile at the time of sampling. Model calibration and testing phase will be followed by N-fertigation management scenario analysis and development of performance curves for N-fertigation systems management. Currently, the coupled model for basins and borders is operational and work is underway on the development of a coupled model for furrows. Once the coupled surface hydraulics and chemical transport models are tested, they will be used to evaluate the sensitivity of fertigation system performance to hydraulic, irrigation, and transport parameters as well as to study the effects of different management scenarios.

RESULTS AND DISCUSSION

A complete set of performance indices were defined and pertinent equations were developed to quantify fertigation performance indices (Zerihun et al., 2003). The use of the proposed indices and equations in quantifying fertigation performance is shown below using field data from a fertigation experiment performed at the University of Arizona research farm in Yuma in October 2000, Figures 2a and 2b (Zerihun et al., 2003a).



Brr = target Br- application rate, Brsd = bromide profile for sampled depth, Brcr = Br- profile for crop root zone, Bravsd = Br- average for sampled depth, and Bravcr = Br- average for crop root depth

Figure 2a. Br- profile along transect 2 (level basin) and Figure 2b. Br- profile along transect 3 (level basin)

The development of a coupled surface-subsurface water and solute transport model is near completion. The surface flow component of the coupled model was developed and tested by comparing its output with that of SRFR (Strelkoff et al., 1998), Figures 3a and 3b (Zerihun et al., 2003b).

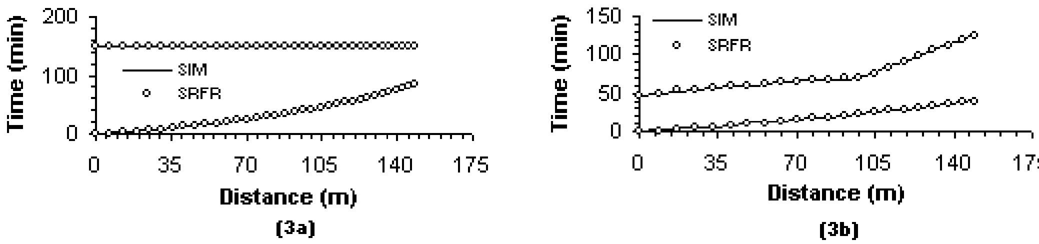


Figure 3. Comparison of advance and recession trajectories (3a) level basin and (3b) graded basin

Figure 4a depicts soil moisture distribution at the end of irrigation at three nodes along a basin of 183 length, obtained using the coupled surface-subsurface water flow module. Figure 4b represents a comparison of longitudinal infiltration profile and required amount of application for the same data set.

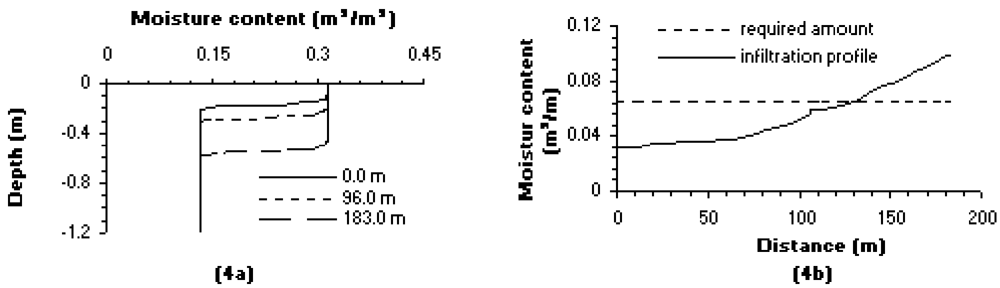


Figure (4a) Vertical distribution of soil moisture at three points along the basin and (4b) infiltration profile along the basin

Figure 5a is a comparison of advance trajectories predicted by the surface hydraulic model using the modified Kostiakov infiltration function and Hydrus-1D. Figure 5b shows a comparison of the water surface profiles from the Kostiakov infiltration function and Hydrus-1D for three time lines.

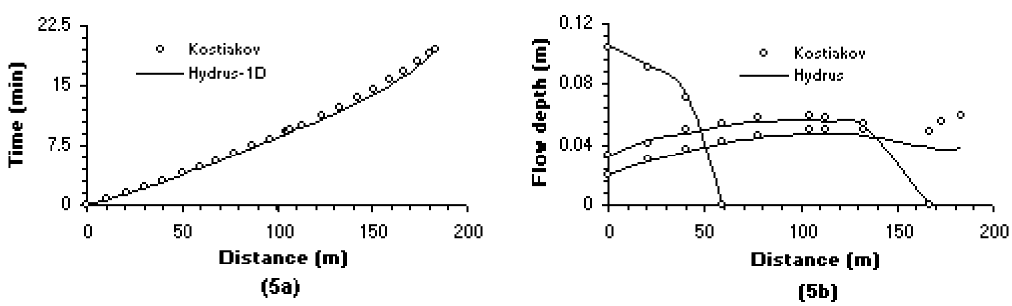


Figure (5a) Comparison of advance trajectories predicted by Kostiakov based and Hydrus based models (5b) comparison of flow depth profile, Kostiakov based and Hydrus based models

The results summarized in Figures 5a and 5b shows that provided the model is well calibrated the hydraulic model based on empirical functions can yield results comparable to that of the coupled model. An advantage of the coupled model, however, is that it can simulate moisture redistribution and plant water uptake after the irrigation is over. This capability allows a more complete determination of the transport of solutes in the soil profile and also fertigation (water and solute application) performance.

REFERENCES

Boldt, A.L., Watts, D.G., Eisenhauer, D.E., and Schepers, J.S. 1994. Simulation of water applied nitrogen distribution under surge irrigation. *Transactions of the ASAE,* 37(4):1157-1165.

Garcia-Navarro, P., Playan, E., and Zapata, N. 2000. Solute transport modeling in overland flow applied to fertigation. *J. Irrig. and Drain. Engrg*., ASCE, 126(1):33-40.

Gardner, B.R. and Roth, R.L. 1984. Applying nitrogen in irrigation waters. In Nitrogen in crop production, Ed., Hauck, R.D., pp. 493-505, *American Society of Agronomy, Crop Science Society of America, Soil Science Society of America*, Madison, Wisconsin.

Izadi, B., King, B., Westermann, D., and McCann, I. 1996. Modeling transport of bromide in furrow-irrigated field. *J. Irrig. and Drain. Eng., ASCE,* 122(2):90-96.

Jaynes, D.B., Rice, R.C., and Hunsaker, D.J. 1992. Solute transport during chemigation of level basin. *Transactions of the ASAE,* 35(6):1809-1815.

Playan, E. and Faci, J.M. 1997. Border fertigation: field experiments and a simple model. *Irrig. Sci., 17:163-171.*

Strelkoff, T.S., A.J. Clemmens, B.V. Schmidt. 1998. *SRFR v.3.31. Computer Program for Simulating Flow in Surface Irrigation: Furrows-Basins-Borders.* U.S. Water Conservation Laboratory, USDA-ARS, 4331 E. Broadway, Phoenix, AZ 85040.

Zerihun, D., Sanchez, C.A., Farrell-Poe, K.L., Adamsen, F.J., and Hunsaker, D.J. 2003a Performance indices for surface N-fertigation. *J. Irrig. and Drain. Engrg*., ASCE, (*in press*).

Zerihun D., Furman, A., Sanchez, C.A., Warrick, A.W ., and Sanchez, C.A. 2002. Sensitivity of surface irrigation modeling to subsurface flow. *Presented at the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, 94th Annual Meeting, Indianapolis, Indiana.*

Zerihun D., Furman, A., Sanchez, C.A., and Warrick, A.W. 2003b. Calculation of recession in basins and closed furrows: problems and simplified solutions. *To be presented in the USCID Second International Conference on Irrigation and Drainage*, May 12-15, 2003, Phoenix, AZ.