Application of Hydrus-2D for Simulation of Water Distribution in Different Types of Soils

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ABSTRACT

Study of water distribution in the soil as a result of water application involves simulation of water movement in porous media. Water distribution in the soil depends on the hydraulic properties of the soil. In the present study, water distribution in the root zone depth of the green pepper was simulated at various emitter discharges under different fertigation strategies for various types of soils. A two-dimensional water and solute transport model Hydrus-2D was selected for the simulation. Experiments were conducted with the research farm of Bastam Agricultural Center, Shahrood, Iran to investigate the water distribution pattern under different types of soils. Investigation of water distribution in soil was done in seven types of soils. For simulation of water movement in soil Hydrus-2D was calibrated and validated. Results of simulation indicated that for all the soils, water content was more in first layer of soil. Irrigation cycle was 48 hrs and adequate water content was available in the active root zone of the green pepper. Another result of this study showed that if the drip fertigation system designs properly, it will reduce drainage water below the crop root zone. Final result of simulation showed that in all types of soils amount of percolation from drainage boundary was less than one percent of applied water.

Keywords: fertigation, boundary condition, drip irrigation, simulation

INTRODUCTION

Fertigation under drip irrigation is being used commonly for the application of nitrogenous fertilizers in all fruits and vegetable crops. Many research studies have been carried out for the crop response under drip fertigation. Fertigation management is aimed at maximizing growers' income and minimizing environmental pollution.

A simulation model FUSSIM2 was developed by Heinen (2001) for drip fertigation to study various fertigation scenarios. In this study water movement was described using Richards' equation with the constitutive relationships given by the Van Genuchten and Mualem functions. The Richards' equation was implicitly solved using the control volume finite element method. The solute dynamics described using convective-dispersive process equation and was explicitly solved. The analysis was carried out with alternative fertigation strategies which reduce the number of field experiments. The study although did not develop any best fertigation strategy however, demonstrated the simulation model could help in finding the alternative fertigation strategies.

A properly calibrated and validated flow and solute transport model can reduce time and cost required for studying the water and nutrient dynamics under drip irrigation system. Simunek *et al.* (1999) developed the HYDRUS-2D software package for simulating two-dimensional movement of water, heat and multiple solute in variably saturated media. Ajdary (2005) used hydrus-2D model to simulation of water and nitrogen distribution in drip fertgation system.

Gardenas *et al.* (2005) investigated nitrate leaching for various fertigation scenarios under micro-irrigation. The effect of fertigation strategy and soil type on nitrate leaching potential for four different micro-irrigation systems was assessed. It was observed that seasonal leaching was the highest for coarse-textured soils. Antonopoules (2001) reported that nutrient leaching models provide an understanding of the relationship amongst the amount and timing of water and nutrient application. Many studies have reported that frequent or continuous fertigation of drip-irrigated vegetables is an efficient method of fertigation (Tompson *et al.*,2003; Hopman and Bristow, 2002; Ajdary *et al.*, 2007; Halvorson, 2002).

Water and solute transport models enrich the understanding of their movement in the soils and nutrient uptake by plants and can be valuable tools in designing drip fertigation system. Several models have been used for simulating the water and nutrient movement in drip fertigation system. However, most of these models describe the early stage of infiltration and provide an estimate of water content behind the wetting front (Clothier and Scotter, 1982). Although they are easy to implement, they deal mainly with design considerations of the drip source (Cote *et al.* 2003). Analytical solutions of transient axi-symmetrical infiltration (Warrick, 1974; Revol *et al.,* 1997) can simulate the dynamic condition associated with the drip irrigation but their application was limited in simulation of water and nutrient movement under drip fertigation system under simple boundary conditions. Numerical solution of water and solute transport equations can be an effective tool for simulating the time dependent flux and other boundary conditions. These solutions can implement wide range of boundary conditions, irregular boundary and soil variability. Comparison of HYDRUS-2D simulation of drip irrigation with experimental observations was investigated by Skaggs *et al.* (2004).
In this study, data were collected from drip fertigated green pepper crop field for simulating of water distribution in different types of soils using selected model Hydrus-2D.

MATERIALS and METHODS

In this study field experiments were conducted with green pepper crop. This crop was transplanted on 11 April 2007 in 12 plots. Area of each plot was 9 m^2. Plant to plant and row to row spacing were 25 cm and 40 cm, respectively. The applied fertilizers were 96 kg/ha of N, 50 kg/ha of P and 70 kg/ha of K. Experimental site was located at the Bastam Agricultural Center Farm, Shahrood, Iran which lies the latitudes of 36^0 27’ 33.29” N and longitudes of 54^0 58’ 31.85” E. Climate of Shahrood is categorized as semi-arid, subtropical with hot dry summer and cold winter. The mean annual temperature is 14.4^0 C. July and August are the hottest months with 40 years normal maximum temperature of 42^0C. January and February are the coldest months with a mean temperature of -14^0 however, the minimum temperature dips to as low as 1^0 C. The mean annual rainfall is 156.5 mm of which as much as 75 % is received during spring season (March to June).Soil samples were collected from different layers from surface till the depth of 0.9 m and analyzed to determine physical and chemical properties.

Drip System

In this research work a drip irrigation system was designed for green pepper crop transplanted in sandy loam soil using the standard design procedures. The control head of the system consisted of sand filter, screen filter flow control valve, pressure gauges etc. The system was connected with fertigation tank which was used for the application of fertilizers. A PVC sub main line (50 mm outer diameter, 4 kg/cm^2 working pressure) was laid for the experimental area. Lateral lines (10 mm diameter) were taken out from the sub main line for the irrigation of the onion crop. The lateral lines were spaced at 60 cm interval. The lateral lines were laid in such a manner that the same lateral line supplied water and fertilizer to all the randomized replicated plots. This caused zigzag path of laterals in the experimental area.

Drip emitters with 4 l/h rated discharge were placed on the lateral line at a spacing of 50 cm. Each lateral line was provided with flow control valve at the start of the line. Average emitter discharge observed in the field condition was 4 l/h. Drip laterals were spaced at 0.60 m. The emitter to emitter spacing was 0.50 m. Each lateral served two plant rows. Total number of emitter in each plot was 35. Irrigation scheduling is determination of amount, time, interval and duration of irrigation. Water requirement of onion crop was estimated using the pan evaporation method. Five years average daily pan evaporation values were multiplied with the pan and crop coefficients to estimate the daily crop water requirements. Irrigation requirement was estimated by subtracting corresponding effective rainfalls. Irrigation was applied on every alternate day. On an average irrigation was applied 3 days in a week. Amount of water applied was 5000 m^3/ ha.

Observations

To determine the amount of water in the various layers of the soil and their spatial and temporal distribution, soil samples were collected from different depths (0-15, 15-30, 30-45, 45-60 cm) at different times using tube auger as per sampling schedule. Determination of soil moisture was done by gravimetric method.

Hydrus-2D Model

In this research work a water and solute transport model Hydrus-2D was used to simulate the water distribution. Hydrus-2D is a finite element model, which solves the Richard's equation for variably- saturated water flow and convection-dispersion type equations for heat transport. The flow equation includes a sink term to account for water uptake by plant roots. The model uses convective-dispersive equation in the liquid phase and diffusion equation in the gaseous phase to solve the solute transport problems. It can also handle nonlinear nonequilibrium reactions between the solid and liquid phases, linear equilibrium reactions between the liquid and gaseous phases, zero-order production, and two first–order degradation reactions: one which is independent of other solutes, and one which provides the coupling between solutes involved in sequential first-order decay reactions. The program may be used to simulate water and solute movement in unsaturated, partially saturated, or fully saturated porous media. The model can deal with prescribed head and flux boundaries, controlled by atmospheric conditions, as well as free drainage boundary conditions. The governing flow and transport equations are solved numerically using Galerkin-type linear finite element schemes. The current version 2.0 of Hydrus-2D also includes a Marquardt-Levenberg parameter optimization algorithm for inverse estimation of soil hydraulic and/or solute transport and reaction parameters from measured transient or steady state flow and/or transport data. A detail description of model and related theory is presented in the report documents version 2.0 of Hydrus-2D (Simunek *et al.*, 1999)

The simulations were done for a soil profile of depth Z = 60 cm and radius r = 30 cm, with a trickle emitter placed at the surface (Figure 1). The flux radius was taken equal to the wetted radius considering emitter in centre. Surface area for irrigation without causing ponding was determined from the flux radius and subsequently flux per unit area, resulting from single emitter was estimated. Fig. 1 shows the conceptual diagram of simulated area and the imposed boundary conditions. No flux was allowed through the lateral boundaries. Bottom boundary was considered as free drainage boundary. Surface boundary was considered as variable flux boundary (up to the radius of 25 cm) and atmospheric boundary for the remaining 5 cm radius. The system was conceptually divided into four layers depending the variability of the soil physical properties.

Initial distribution of the water content in different soil layers within the flow domain was kept as observed in the experimental field. For the purpose of investigating the influence of drip emitter discharge, soil hydraulic properties and frequency of water input on wetting patterns, a time dependent flux boundary condition at the surface in a radius of 25 cm from emitter position emitter was used. This was done to take into account the irrigation and no irrigation periods and temporal changes in duration of irrigation in the growing period. In the present case, water table was situated far below the domain of interest and therefore free drainage boundary condition at the base of the soil profile was considered. On the sides of the soil profile, it was assumed that no flux of water took place and hence no-flux boundary condition was chosen, which in Hydrus-2D is specified for impermeable boundaries where the flux is zero perpendicular to the boundary.

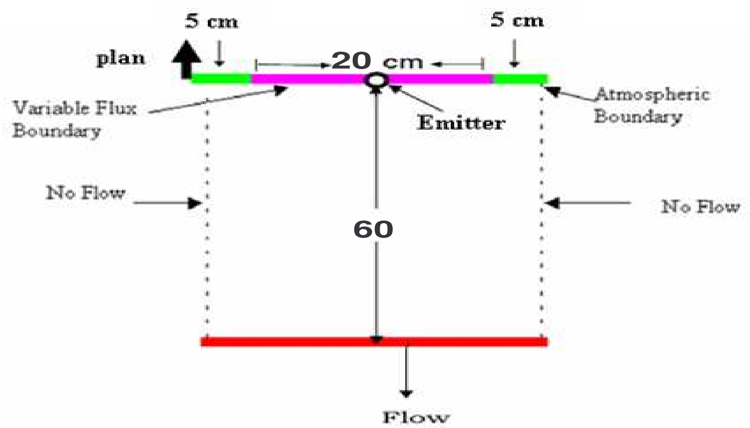

Figure 1. Simulated area with 30 cm radial direction and 60 cm soil depth

RESULTS and DISCUSSION

Calibration of Model

The model was calibrated mainly for hydraulic conductivity values of the sandy loam soil. Model worked well with the measured hydraulic conductivity values. Results of the calibration for water distribution at the end of first month after transplanting is presented through Figures 2 and 3. X-axis of this figure shows volumetric water content and Y-axis shows depth from the soil surface. Field observations for water content in the soil were taken at the end of first month and second month at 2, 4, 12h after irrigation. Simulated and observed values of water at 2, 4 and 12 h after irrigation were used to evaluate the performance of the model.

Figure 2 shows that simulated and observed water contents follow a similar trend and there is not much difference between simulated and observed values. Values of simulated and observed water content at the end of 2, 4 and 12 h after irrigation varied from 20 to 38% , 21 to 35% and 22 to 35% respectively.

Figure 3 also shows that simulated and observed water contents follow a similar trend and there is not much difference between simulated and observed values. Values of simulated and observed water content at the end of 2, 4 and 12 h after irrigation varied from 23 to 37% , 20 to 35% and 19 to 36% respectively.

Correlation coefficient between observed and simulated water contents were determined to find out the closeness between them. The higher R^2 values (varying from 0.94-0.97) showed that simulated and observed values are closely related.

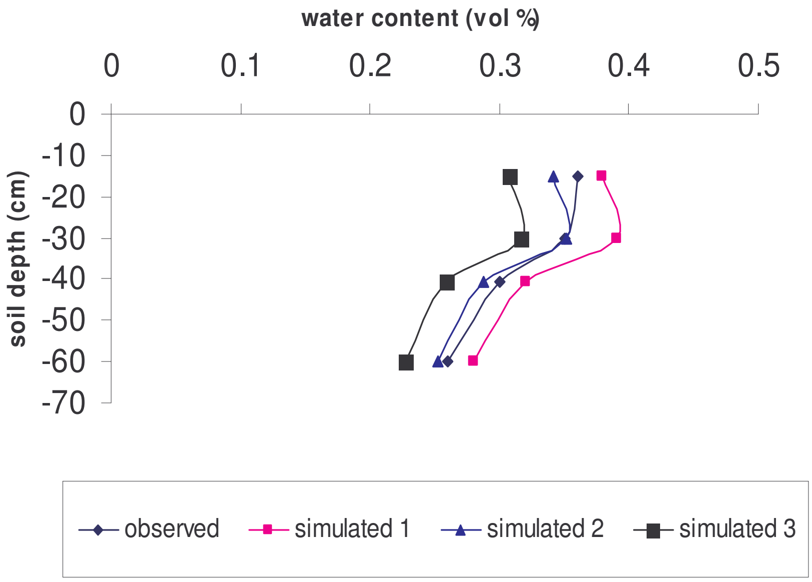

Figure2. Comparison of simulated and observed water content in first month after transplanting: simulated1=2 h, simulated 2= 4 h and simulated 3= 12 h after irrigation.

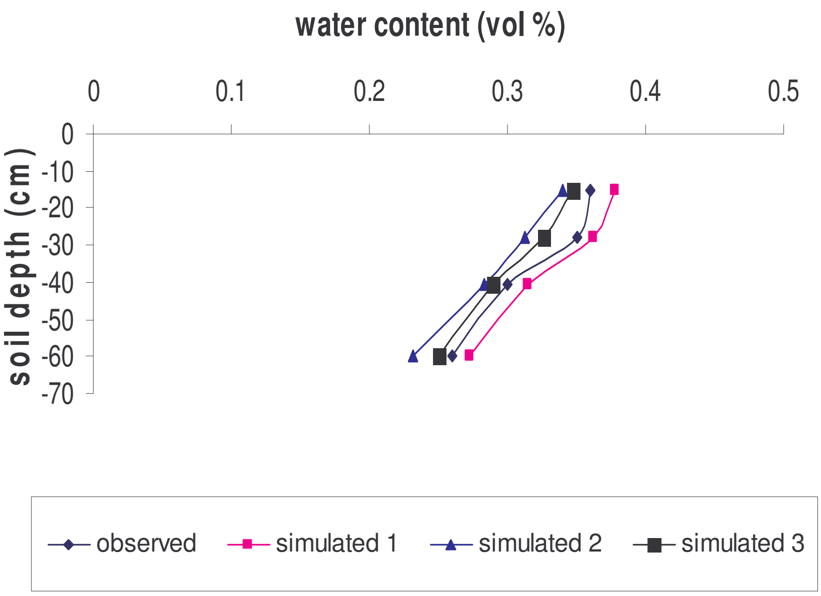

Figure 3. Comparison of simulated and observed water content in second month after transplanting: simulated 1=2 h, simulated 2= 4 h and simulated 3= 12 h after irrigation.

Simulation of Water Distribution

Simulation of water distribution at the end of first month after transplanting 2h after irrigation with emitter discharge of 4 l/h in sandy loam soil is presented in Fig. 4 through color spectrum. It may be mentioned that initial moisture content was kept same in various soil layers. The duration of irrigation was 1 h. The color spectrums in this figure shows simulated values of water content 2 h after irrigation. X-axis of this figure shows 30 cm radial distance from emitter and Y-axis shows depth from the soil surface. This figure shows that 2 h after irrigation amount of water content was highest in first layer of soil which means in this duration only first layer of soil has got maximum water content. Fig.4 (a) shows that 2 h after irrigation amount of soil moisture not coming down and it is not effecting second layer of soil (middle layer). Fig.4 (a) shows that 2 h after irrigation effect of water distribution increasing only in upper layer. Scale of colure spectrum reveals that adequate soil moisture is available even12 h after irrigation in soil layers.

Simulated water content distribution 12 h after irrigation is presented in fig.4(b). This figure reveals that water content at 12 h after irrigation is nearly same in radial direction. This may be due to the fact that the emitter discharge was distributed uniformly over the radius of 30 cm as the time dependent variable boundary condition at the soil surface. This figure shows water distribution in sandy loam soil under 4 l/h emitter discharge and at 12h after irrigation. Analysis of this figure shows that water content in the first layer decreases at a little faster rate with the elapsed time after irrigation compare to other layers. Applied flux was calculated from the emitter discharge rate of 4 l/h distributed uniformly over the radius of 20 cm. In this case, duration of irrigation was 60 minutes.

It may be mentioned that 24 h after irrigation the initial moisture content in first, second, third and forth layers were 0.29, 0.27, 0.25, 0.23. Analyzes of color spectrums revealed that free drainage water below the crop root zone is less than one percent of applied water.

Simulated water content distribution 4 h after first irrigation at surface and 15 cm depth under 4 lh-1 emitter discharge rate are presented through Fig. 5. This figure reveals that water content at 4 h after first irrigation is nearly same in radial direction for each soil layer. This may be due to the fact that the emitter discharge was distributed uniformly over the radius of 30 cm as the time dependent variable boundary condition at the soil surface. However, simulated moisture content varied with the soil layer near the surface as well as 15 cm depth. In both the cases, water content was lowest in case of last layer. In this study irrigation interval was 48 h and adequate amount of moisture was available in active crop root zone in this duration.

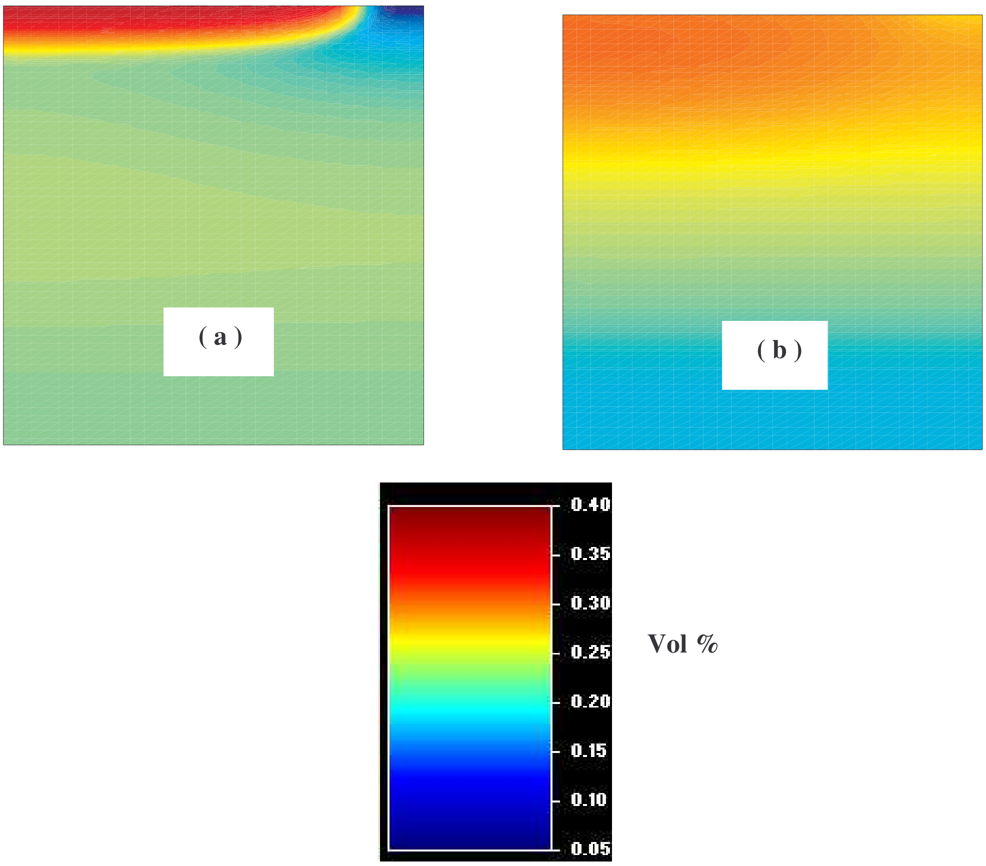

Figure 4. Simulated water content distribution with 4 lh-1 emitter discharge (**a**) 2 h after irrigation (**b**) 12 h after irrigation

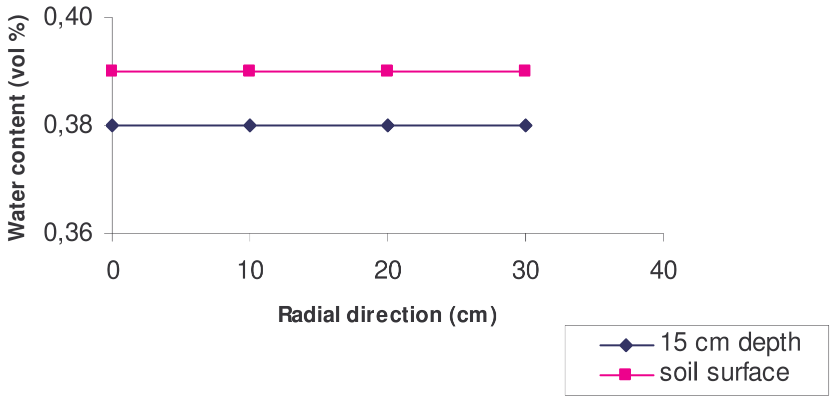

Figure 5. Simulated water content distribution in radial direction 4 h after irrigation

It may be mentioned that in this research work simulation of water distribution was done in different types of soil but in this paper only results of simulation of water distribution in sandy loam soil are presented.

CONCLUSION

Observed moisture contents at various points in the root zone of green pepper were used to calibrate the water and solute transport model, Hydrus-2D. Field experimental was also conducted to study the water distribution in a sandy loam soil irrigated by drip irrigation system. Simulation of water distribution in various soils were done with average emitter discharge rate of 4 l/h. Simulation studies and experimental work have led to conclude that adequate water content was maintained in the active root zone up until 48 hr after irrigation. Further, this research suggests that irrigation scheduling on alternate day bases is an appropriate cycle. It has also been shown that if the drip system design properly, it will distributes water uniformly in radial direction. This study also revealed that in a proper fertigation system free drainage water below crop root zone in sandy loam soil was less than one percent.

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