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Use of Hydrus-2D Model for Predicting Moisture Distributions and Evaporation Losses from Different Amount and Frequency of Drip Irrigation

RITA DAHIYA, R.S. MALIK AND B.S. JHORAR
CCS Haryana Agricultural University, Hisar- 125 004, India

ABSTRACT

Drip irrigation is an efficient irrigation system for supplying water to crops and its managements rely on knowledge of water distribution within the wetted soil volume. Computer simulated models would be valuable to partially acquire this knowledge. In present study, numerical simulations of variably saturated flow using Richards equation-based Hydrus-2D model was carried out to evaluate the effects of different amounts and frequencies of drip irrigation on water distribution and evaporation losses in sandy soil under bare field condition. The experiment was conducted at Regional Research Station Balsamand of C C S Haryana Agricultural University, Hisar, India. It consisted of three treatments of different irrigation amounts (156, 124 and 77 litres per plot) and three treatments of irrigation frequencies (after 1, 2 and 5 days). A drip lateral was placed in the centre of each plot. Unsaturated soil hydraulic properties were described using van Genuchten-Mualem approach. Measured hydraulic properties were used to obtain model parameters. Simulated horizontal and vertical wetting fronts agreed well with those of experimentally measured wetting fronts. Moisture contents were measured at 0.1 m distance from centre of the dripper. Simulated moisture distribution agreed well to the measured values and hence, verified the applicability of the model in drip irrigated sandy soil. After verification, the model simulations were used to project the effect of different frequencies and amounts of drip irrigation on soil evaporation and water storage. The evaporation of the applied irrigation was 35.4% when irrigation was applied after 5 days and was 56.1% when irrigation was applied after 1 day interval. Soil water storage also increased with decrease in irrigation frequency. The percentage of soil water storage was maximum for applied irrigation of 124 litres in the present study. It implied that drip irrigation system may be made portable for high valued crops by keeping appropriate irrigation frequency.

Key words: Drip irrigation, irrigation frequency, modeling, water flow.

Introduction

Scheduling irrigation with limited water is big challenge to agricultural scientists to ensure crop productivity and sustained irrigation agriculture. Drip irrigation offers a great potential for meeting these needs because water is applied to a small surface area. However, a saturated or nearly saturated soil surface generally exists beneath each dripper. In arid climates, evaporation from the soil surface beneath drippers can be considerable due to hot and dry air blowing across the wetted surface (Bresler, 1975). Matthias *et al.* (1986) reported that evaporation accounted for about 35-40% of applied water over the week following the drip irrigation. Meshkat *et al.* (1999) observed increase in evaporation with increase in drip irrigation frequency. The optimum frequency of the drip irrigation depends on crop, soil type and water quality. Several studies reported increase in crop yield with frequency of drip irrigation with good quality water whereas, others suggested no significant increase or even decrease in crop yield as irrigation frequency increased (Buck *et al.*, 1982; Posternak and Malach, 1995). Hence, drip irrigation management scheme rely on the water information in the wetted soil volume. Part of the information can be obtained from computer models to partially replace expensive field experiments. Therefore, present study was carried out to 1) verify the applicability of Richards equation-based Hydrus-2D model to evaluate the moisture distribution pattern in drip irrigated soil and 2) predict the effects of different amounts and frequencies of drip irrigation on evaporation losses and soil water storage.

The Hydrus-2D model (Simunek *et al.*, 1999) simulates numerically water, heat and solute movement in two-dimensional variable saturated media.

Materials and Methods

Experimental set-up

A field experiment was conducted at bare field condition at Regional Research Station Balsamand of CCS Haryana Agricultural University, Hisar, India. The experiment was started from 5th May 2002 and was carried out for 30 days. The experimental area has arid climatic conditions with average annual rain fall 200 mm, 80% of which is received from July to September. The experiment consisted of three treatments of different irrigation amounts and three treatments of different irrigation frequencies and three replicates. The description of the treatments (T_1, T_2, T_3, T_4, T_5) is given in Table 1. The experimental soil was sand (92.2% sand, 5.3% silt and 2.5% clay) and was classified according to Soil Survey Staff (1998) as Torrypsamment.

A drip lateral was placed in the centre of each plot (1 x 1 m^2) with dripper to dripper distance of 0.15 m. The discharge rate of each dripper was 3.0 litre/h. The I/CPE in each treatment was calculated on 75% wetted area basis. Soil samples for 0-10, 10-20, 20-30 and 30-40 cm depths were collected with core sampler for determination of saturated hydraulic conductivity and soil moisture retention curves. Soil moisture retention curves were determined in the laboratory using tension table assembly and pressure plate apparatus. Soil water contents were measured gravimetrically at 0.1 m distance away from centre of the dripper. Horizontal and vertical wetting front positions from the centre of the dripper were visually measured from the wetted bulb just after the first irrigation in the treatments with different amounts of irrigation applied. Daily pan evaporation during the experiment was collected from weather station situated near the experimental site.

Table 1. Description of the treatments

Treatments	IDASE	I/CPE	Total water applied /plot (liter)
T1	11,17,23	1.0	156
T2	11,17,23	0.8	124
T3	11,17,23	0.5	77
T4	11,14,17, 20,23,26	0.8	124
T5	11,13,15,17, 19,21,23,25,27	0.8	124

IDASE = Irrigation day after start of experiment,
I = irrigation depth and
CPE = cumulative pan evaporation.

Numerical experiments

Numerical experiments were conducted using Hydrus-2D software package of Simunek *et al.* (1999) to simulate two dimensional water distributions in drip irrigated sandy soil. The window-based Hydrus-2D model solves the Richards equation as governing water conservation equation

$$\partial\theta/\partial t = \partial/\partial x_j \left[K \left(K_{ij}^A \partial h/\partial x_j + K_{iz}^A\right)\right] - S \quad \text{... (1)}$$

where θ is the volumetric water content [L^3L^{-3}], h is pressure head [L], S is sink term [T^{-1}], x_j (j=1,2) is spatial coordinate (L), t is time (T), K_{ij}^A and K_{iz}^A are components of a dimensionless anisotropy tensor K^A, K is unsaturated hydraulic conductivity function [LT^{-1}] given by

$$K(h, x, z) = K_s(x,z)\, K_r(h,x,z) \quad \text{...(2)}$$

where Ks = saturated hyraulic conductivity (LT^{-1}) and Kr = relative hydraulic conductivity. The anisotropy tensor K_{ij}^A used in Eq. (1) is used to account for an anisotropic medium. The diagonal entries of K_{ij}^A equal 1 and off-diagonal entries are 0 for an isotropic medium. The soil hydraulic functions are described by the van Genuchten-Mualem approach (van Genuchten, 1980 and Mualem, 1976)

$$\theta(h)=\left\{\theta_r+\frac{\theta_s-\theta_r}{\left[1+|\alpha h|^n\right]^m}\right\} \quad h<0 \qquad (3)$$

$$= \theta s \qquad h\geq 0$$

$$K(h)=K_S S_e^l\left[1-\left(1-S_e^{\frac{1}{m}}\right)^m\right]^2 \qquad \text{... (4)}$$

$$S_e=\frac{\theta-\theta_r}{\theta_s-\theta_r} \qquad \text{... (5)}$$

where m=1-1/n for n>1

θ_r,θ_s, α, n and Se represent residual water content, saturated water content, inverse of air entry value, pore size distribution index and effective water content, respectively. The pore connectivity parameter (l) was taken equal to 0.5 (Mualem, 1987). The θ_r,θ_s, α and n were determined fitting Eq. 3 (van Genuchten, 1980) to the experimental h-θ data using solver technique in Excel. The saturated hydraulic conductivity K_S was measured in laboratory on undisturbed soil columns using constant head method and average value is used for the entire soil profile. The hydraulic properties of the experimental soil are listed in Table 2.

Initial and Boundary Conditions

To run the Hydus-2D, we implemented a relatively fine numerical mesh depicting the general geometry of the simulated flow region (1 m × 1 m × 1.5 m). The solution of Eq. (1) requires knowledge of initial distribution of the pressure head within the flow domain. This can be expressed as

$$h\ (x, z, t) = h_0 \quad \text{for } t = 0,\ z > 0 \text{ and } x > 0 \qquad \text{... (6)}$$

The initial condition of pressure head was given by fixed pressure equal to -4.0 m same through out the flow region. An atmospheric boundary condition accounting for infiltration and evaporation was imposed at the soil surface for water flow. Left and right boundaries of the flow domain were given no flow water conditions. Free drainage was allowed from the entire bottom boundary. This assumes unit vertical hydraulic gradient whereby free drainage discharge Q (h) is given as

$$Q\ (h) = \text{width}\ (n)\ K\ (h) \qquad \text{... (7)}$$

where h is value of local pressure head at n^{th} node and K (h) is hydraulic conductivity at the pressure head h. The drip irrigation was implemented by applying water variable flux BC to a hole, 0.05 cm below the soil surface, area of cross section 0.06 m^2. This was implemented in the model to avoid the difficulties encountered in simulation process while implementing the discharge of 3 litres/h to individual dripper.

Results and Discussion

Visually measured wetting fronts just after the first irrigation were compared with those of simulated wetting fronts. The wetting front location was assumed to be where θ = 0.05 m^3/m^3. Measured horizontal and vertical wetting fronts matched well with simulated wetting fronts (Table 3) in drip irrigated sandy soil. The spatial distribution of simulated and measured volumetric soil water content (θ) in plots having different drip irrigation frequencies on 23^{rd} day are given in Table 4. The patterns and magnitude of the simulated water contents were found significantly close to the

Table 2. Parameters of the van Genuchten-Mualem function of the experimental soil

θ_r (m^3/m^3)	θ_s (m^3/m^3)	Alpha (α) (m^{-1})	n	KS (m/day)	l
0.045	0.43	3.3	3	2.0	0.5

Table 3. Comparison of simulated and measured horizontal and vertical wetting fronts after first irrigation for the treatments with different amounts of irrigation applied

Treatments	Horizontal (m)		Vertical (m)	
	Simulated	Measured	Simulated	Measured
T_1	0.30	0.29±0.02	0.63	0.60±0.02
T_2	0.29	0.27±0.02	0.53	0.51±0.01
T_3	0.24	0.23±0.01	0.48	0.47±0.01

Table 4. Comparison of simulated and measured volumetric soil moisture content (m^3/m^3) at different depths in treatments with different drip irrigation frequencies on 23rd day after start of experiment

Treatments	Soil depth (m)							
	0. 05 - 0.10		0. 15- 0. 20		0. 45 - 0. 50		0. 75 - 0. 80	
	Simulated	Measured	Simulated	Measured	Simulated	Measured	Simulated	Measured
T_2	0.21	0.20±0.01	0.21	0.20±0.01	0.17	0.18±0.01	0.11	0.11±0.01
T_4	0.17	0.17±0.01	0.17	0.17±0.01	0.13	0.12±0.01	0.11	0.11±0.01
T_5	0.15	0.15±0.01	0.15	0.16±0.01	0.12	0.11±0.01	0.10	0.10±0.01

measured values. It verified water flow simulation in drip irrigated sandy soil.

After verification, the model was used to project the effect of frequency and amount of irrigation on evaporation and soil water storage. Water balance components were compared for different irrigation amounts and irrigation frequencies (Table 5). Cumulative evaporation for the lowest irrigation frequency (T_2, after 5 days) was minimum (35.4%) and for the highest irrigation frequency (T_5, after 1 days) was maximum (56.1%). Consequently, it increased soil water storage or moisture conservation in similar way. Meshkat *et al.* (1999) had also reported decrease in cumulative evaporation with decrease in drip irrigation frequency. Increasing amount of irrigation from 77 litres to 156 litres decreased evaporation by 29.4 % (compare T_1 and T_3 in Table 5) but percentage of soil water storage was maximum for applied irrigation of 124 litres in the present study. It was because of i) evaporation occurred in the potential first stage on the irrigation day as is reflected in cumulative evaporation graph of treatments T_2, T_4, T_5 in Fig. 1 as an example, and ii) depth of water penetration increased with increasing amount and decreasing frequency of irrigation (Fig. 2). Similar effect of amount of water applied on soil evaporation was observed by Hillel, (1971, 1977).

Table 5: Water balance components of the entire flow region on 30 th day.

Treatments	Soil water storage (%)	Evaporation (%)	Free drainage (%)
T_1	59.1	31.7	9.0
T_2	64.6	35.4	Nil
T_3	54.8	44.9	Nil
T_4	51.8	48.1	Nil
T5	43.7	56.1	Nil

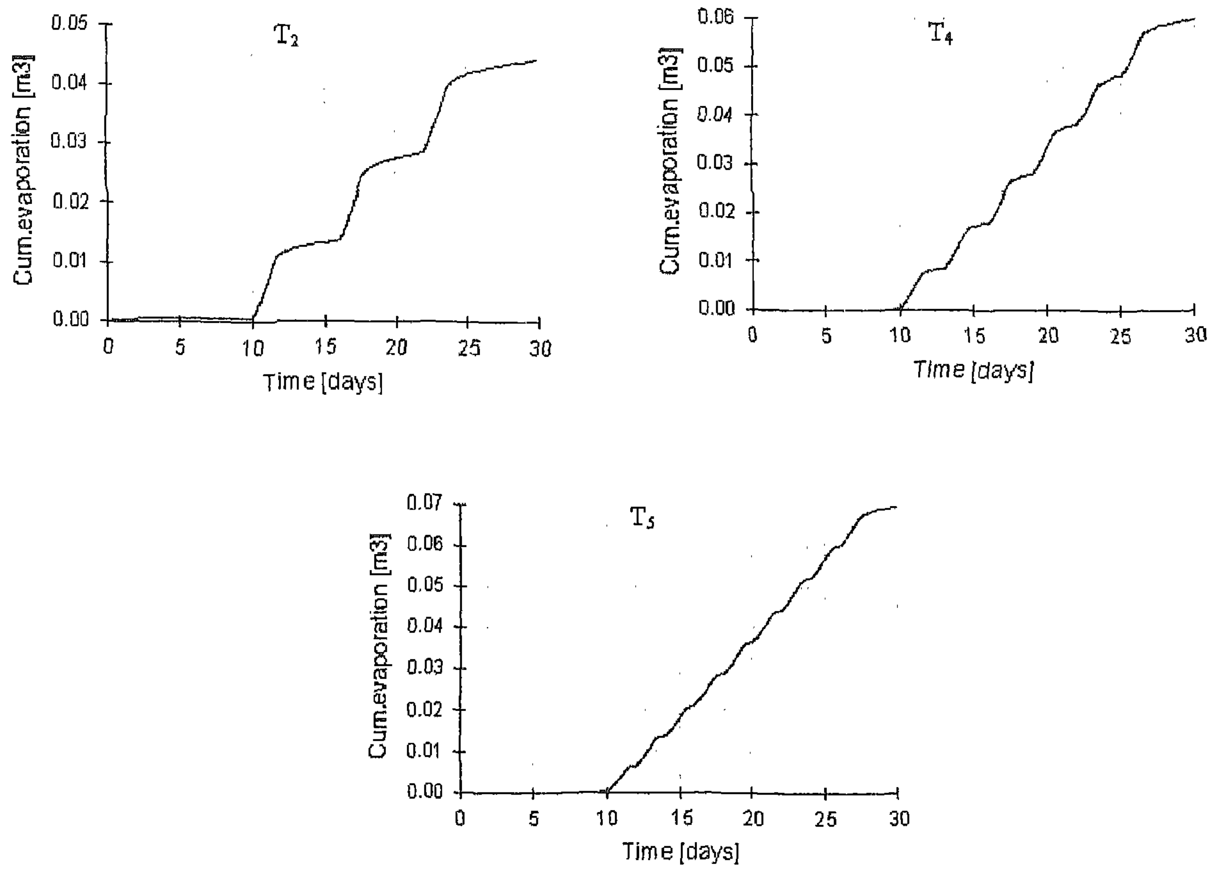

Fig.1. Cumulative evaporation from treatments T_2, T_4 and T_5

Conclusions

The numerical model Hydrus-2D performed well in predicting water flow under bare field conditions in drip irrigated sandy soil in arid climatic condition. Irrigation water penetrated deeper with decreasing frequency and with increasing amount of irrigation. Increase in irrigation amount and decrease in irrigation frequency resulted in decrease in evaporation. Soil water storage increased with decreasing irrigation frequency. It implied that drip irrigation system may be made portable for high valued crops by decreasing the drip irrigation frequency. More work, however, needs to be done to refine this technology.

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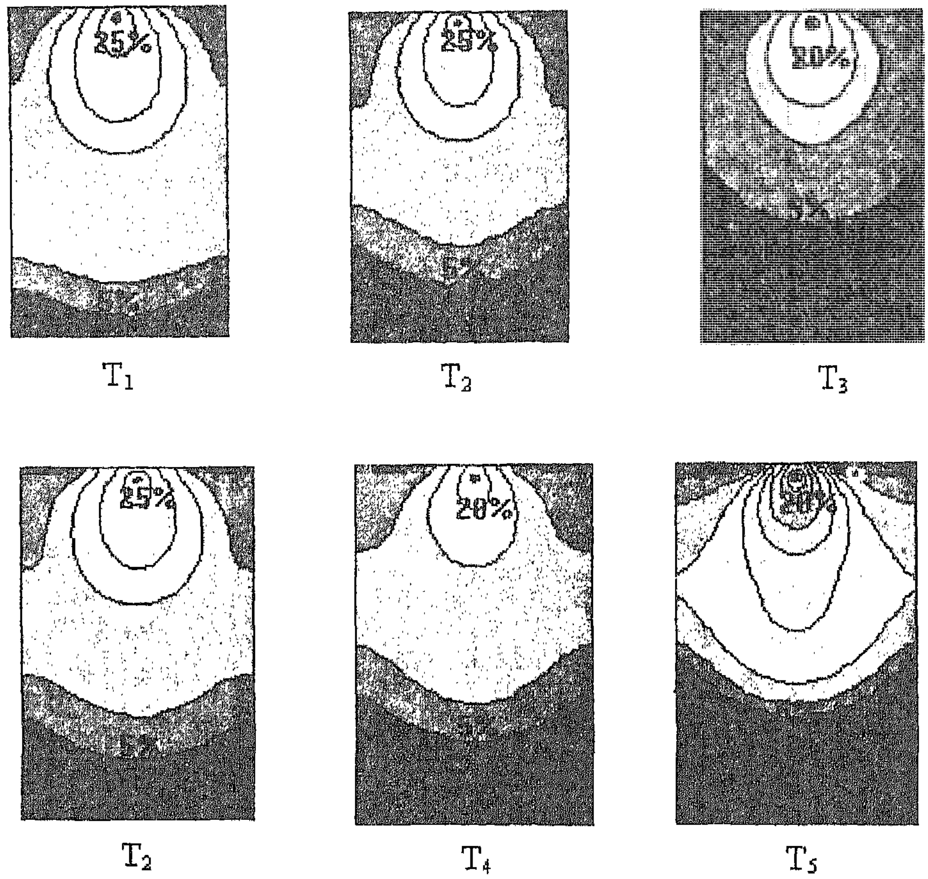

Fig. 2. Effect of irrigation (T_1, T_2 and T_3) and frequency (T_2, T_4 and T_5) on iso-moisture lines on 23rd day after start of experiment

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