



Response of different colour plastic mulches on water dynamics under drip fertigated greenhouse capsicum (*Capsicum annuum*)

K LAULINA¹, M HASAN² and D K SINGH³

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Received: 27 September 2018; Accepted: 16 October 2018

ABSTRACT

The study analyses spatio-temporal distribution of soil moisture pattern under colored plastic mulches inside the ventilated greenhouse. The experiment was conducted at Centre for Protected Cultivation Technology, Indian Agricultural Research Institute, New Delhi. Water distribution in the root zone of capsicum (*Capsicum annuum* L.) was simulated for three colored plastic mulches (silver, yellow and black) and unmulched condition (control) with three level of irrigation (100% ET_c, 80% ET_c and 60% ET_c). It was found that for two levels of irrigation (100% and 80% ET_c) highest yield was obtained, so for these two irrigation levels simulation of water dynamics was done by the Hydrus-2D model. The irrigation cycle was 72 h (i.e. 3 days) and indicates that moisture was readily available in the vicinity of root zone. Simulation study showed that water content for sandy loam soil was more in the second layer of soil (15 to 30 cm) and was near the field capacity. The R²-value obtained for silver plastic mulch at 100% of ET_c was highest (0.91 to 0.94) and the second highest R²-value is for yellow plastic mulch at 80% of ET_c (0.89 to 0.91). The results showed that at 100% of ET_c, silver color mulch has comparatively more water content than other treatments. Simulation studies showed that silver plastic mulch optimised the water content in the vicinity of capsicum root zone for 1 lh⁻¹ dripper discharge. So, silver plastic mulch was efficiently utilized, as the capsicum root zone was found within 20 to 30 cm depth. This indicates that the Hydrus-2D can be used effectively for predicting soil moisture distribution covered with plastic mulch.

Key words: Capsicum, Hydrus-2D, Plastic mulch, Simulation, Water dynamics

Agriculture is a major user of both ground and surface water for irrigation, accounting for about 70% of water withdrawal worldwide. According to the Organization for Economic Cooperation and Development (OECD), 47% of the population could be living under severe water stress by 2050 (OECD, 2016). Indian agriculture accounts for 90% water use due to accelerated ground water depletion and poor irrigation systems. “The world is thirsty because it is hungry,” reports the UN Food and Agriculture Organization (FAO 2012). Regarding this irrigated agriculture is being defined as to produce more food using less water without degrading soil and water resources. Adequate irrigation design, proper irrigation scheduling and management along with moisture conservation technique (i.e. plastic mulch) have been used as keys to increasing vegetable production on a sustainable basis. Agricultural practices such as the use of plastic mulch, drip irrigation, fertigation scheduling and Protected Cultivation are modern innovative approaches in India to provide growers with a viable option to reduce crop water requirements and efficiently utilize the water resources compared to traditional irrigation methods.

Water flow under drip irrigation is normally three-dimensional and becomes two dimensional when dripper used as line source for water application. Thus, comprehensive knowledge of water distribution is essential for design and management of surface drip irrigation system (Subbaiah 2013, Elnesr *et al.* 2015). This can be achieved by conducting field experiment or by modelling. Thus for reducing cost and time, properly calibrated and validated flow transport model has to be selected for studying the water dynamics.

Numerical simulations are efficient tools to investigate optimal drip management practices and system design (Meshkat *et al.* 1999, Assouline 2002, Schmitz *et al.* 2002, Cote *et al.* 2003, Skaggs *et al.* 2004, Li *et al.* 2004, Lazarovitch *et al.* 2005 and 2007, Gardenas *et al.* 2005). Numerical solution of water transport equations can be effective tool for simulating the time dependent flux and boundary conditions. In this context the adoption of drip technology in combination with a simulation model such as Hydrus-2D is taken for this application (Fernandez-Galvez *et al.* 2006, Mmolawa and Or 2003, Skaggs *et al.* 2004). Hydrus-2D model has recently been used extensively to simulate water distribution under surface and subsurface drip irrigation systems (Skaggs *et al.* 2004, 2010; Bufon *et al.* 2010, Phogat *et al.* 2012).

¹Ph D Scholar, ³Principal Scientist, Division of Agricultural Engineering, ²Principala Scientist, Centre for Protected Cultivation Technology.

HYDRUS-2D is a well-known Windows-based computer software package developed by Simunek *et al.* (1999) for simulating water, heat, and solute movement in 2-dimensional, variably saturated porous media. Hydrus-2D (Singh *et al.* 2006, Simunek *et al.* 1999, 2006) is a numerical model that calculates the governing equations for soil-water movement and root-water uptake in two-dimensional domains. Hydrus-2D model can be used to simulate the water distribution pattern for the drip irrigation design and to evaluate possible scheduling strategies to optimize the wetted surface area (WSA), root distribution, rainwater harvesting, and WUE. The objective of this work was to compare HYDRUS-2D simulations of water infiltration and redistribution with the field data with different treatment combinations of plastic mulch at different levels of irrigation, and to assess the utility of using simulation to design drip management practices.

MATERIALS AND METHODS

The research was conducted by using a line source drip irrigation system described by Hanks *et al.* (1976). The soil of the experimental site at CPCT was sandy loam in texture, low in organic matter (0.64%) with neutral pH (7.4). The field capacity and permanent wilting point values were 21.9 and 8.13 (by volume), respectively. The capsicum (*Capsicum annuum* L.) variety California Wonder was selected for the experiment. The study was conducted for the season September 2013 to April 2014 under naturally ventilated greenhouse. Cropping duration in the field was 8 months from 1st week of September to last week of April covering winter and summer season.

The design selected for the field experiment was randomized block design with 3 treatments of different colored plastic mulches and 3 treatments of irrigation levels, i.e. 100% of ET_c , 80% ET_c and 60% of ET_c . Three different colored plastic mulches applied with three levels of irrigation treatment was replicated thrice and three control with three irrigation levels are replicated twice on the homogeneous plots of area 17×12 m² and of bed size 12×1.2 m². Low pressure drip irrigation system with 12 mm lateral lines having dripper discharge of 1 l/h was used to irrigate the greenhouse setup by the 500 l water tank kept at one meter height from the surface. Twenty days after transplanting, five irrigation treatments were tested. The volume of water applied was estimated based on pan evaporation, pan coefficient, crop coefficient of the capsicum, cropped area, percentage wetted area and application efficiency of the drip system for areas of 14.4 m² and the reduced quantity under other treatments were estimated by reducing 60% and 80% of full volume of water. Irrigation scheduling was done using tensiometers. Irrigation was given where tensiometers reading reached 21 centibar at 15 cm below the surface in the full treatment.

The irrigation water was applied through drip irrigation as per the crop water requirement, which varied from twice a week in normal season, thrice a week during hottest season and once a week during winter season. Irrigation scheduling

was determined using tensiometers installed at different places at 15 and 30 cm depths. Irrigation was given when the tensiometer reading exceeded a given critical value, which varied from 20-25 centibar for capsicum. The volume of water applied was estimated based on pan evaporation, pan coefficient, crop coefficient of the capsicum, cropped area, percentage wetted area and application efficiency of the drip system for areas of 14.4 m² and reduced quantity was estimated by reducing 80% and 60% of full irrigation level (100% ET_c). The ET_c was estimated and multiplied with cropped area of one bed (14.4 m²) to estimate the volume of water applied in full treatment. As per irrigation was given twice or thrice a week, cumulative pan evaporation was taken for the estimation.

Low pressure drip irrigation system was used having 12 mm lateral line and dripper discharge 1 l/h. Drip irrigation set up was designed as per crop water requirement. The opening and closing of drip lateral lines were controlled by 12 mm valves provided at the beginning of the lateral pipes.

The amount of water in different layers of soil, their spatial and temporal distribution was determined by gravimetric method. The measurements of moisture were taken before irrigation, and 24, 48 and 72 hr after irrigation.

Hydrus-2D is a finite element model, which solves the Richard's equations for variably saturated water flow and convection-dispersion type equation for heat transport. The program may be used to simulate water and solute movement in unsaturated, partially saturated or fully saturated porous media. It can simulate the flow and transport in the vertical plane, horizontal plane and in three dimensional region exhibiting radial symmetry about vertical axis. 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 liners finite element schemes (Simunek *et al.* 2006). A detail description of model and related theory is presented in the report documents version 2.0 of Hydrus (Simunek *et al.* 1999, Simunek *et al.* 2004).

The governing flow equation considers two-dimensional isothermal Darcian flow of water in a variably saturated rigid porous medium and assumes that the phase plays an insignificant role in the liquid flow process. The flow equation used in the Hydrus-2D is given by the following modified form of the Richard's equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i} \left[K (K_{ij}^A \frac{\partial h}{\partial x_i} + K A_{iz}) \right] - s \quad (1)$$

where, θ = Volumetric water content, [L³/L³]; h = Pressure head [L], S = Sink term [T⁻¹], x_i ($i = 1, 2$) are the spatial co-ordinates [L], t = Time [T], K_{ij}^A = Components of a dimensionless anisotropy tensor KA and K = Saturated hydraulic conductivity function [L/T] given by

$$K(h, x, z) = K_s(x, z) K_r(h, x, z) \quad (2)$$

where, K_r = Relative hydraulic conductivity and K_s = Saturated hydraulic conductivity [L/T].

The anisotropy tensor K_{ij}^A is used to account for an anisotropic medium.

Initial distribution of water content in different soil layers within the floor 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 15 cm from emitter position was used. This was done to take into account the irrigation and non-irrigation periods and temporal changes in the 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 in zero perpendicular to the boundary.

Soil hydraulic properties used to parameterize the soil in Hydrus-2D are listed in the Table 1, where Θ_r and Θ_s are residual and saturated water contents, respectively; α , soil water retention function is a constant related to soil sorptive properties; n is dimensionless parameter related to the shape of water retention curve and represents saturated hydraulic conductivity. Simulation was carried out applying irrigation from point source as in real case for each individual dripper. The input parameters of Hydrus-2D are shown from Table 1 and 2.

The objective of simulation was to analyse the movement of water under drip irrigation in capsicum crop to suggest appropriate irrigation strategies grown using different color plastic mulches. Due to the symmetry of emitter layout and assuming that each emitter discharges water at the same flow rate, entire field can be sub divided into identical volume elements with emitter placed at the surface on the plane of symmetry. Water distribution pattern in the entire field can be described by analyzing the flow in this single volume element irrigated by single emitter. Because of the axial symmetry around the vertical axis, the infiltration process can be viewed as an axi-symmetrical flow.

The simulation were done for a soil profile of depth $Z = 45$ cm and radius $r = 15$ cm with drip emitter placed at the surface near the plant. 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 boundary conditions. No flux was allowed through lateral boundaries.

Table 2 Time variable boundary conditions in Hydrus-2D model (Shown for only 12 days)

Time (day)	Precip. (cm/day)	Evap. (cm/day)	Transp. (cm/day)	HcritA (cm/day)	rGWL (cm/day)	GWL (cm/day)
1	0	0.09072	0	10000	-38.8	0
2	0	0.09072	0	10000	0	0
3	0	0.10584	0	10000	0	0
4	0	0.0756	0	10000	0	0
5	0	0.12096	0	10000	-38.8	0
6	0	0.09828	0	10000	0	0
7	0	0.12096	0	10000	0	0
8	0	0.1134	0	10000	0	0
9	0	0.096768	0	10000	-38.8	0
10	0	0.0756	0	10000	0	0
11	0	0.093744	0	10000	0	0
12	0	0.09072	0	10000	0	0

Bottom was considered as free drainage boundary. Surface boundary was considered as variable flux boundary up to radius of 12 cm and atmospheric boundary for the remaining 3 cm radius.

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 15 cm from emitter position was used. This was done to take into account the irrigation and non-irrigation periods and temporal changes in the duration of irrigation in the growing period. In the present case water table was simulated far below the domain of interest and therefore free drainage boundary condition at the base of the soil profile was

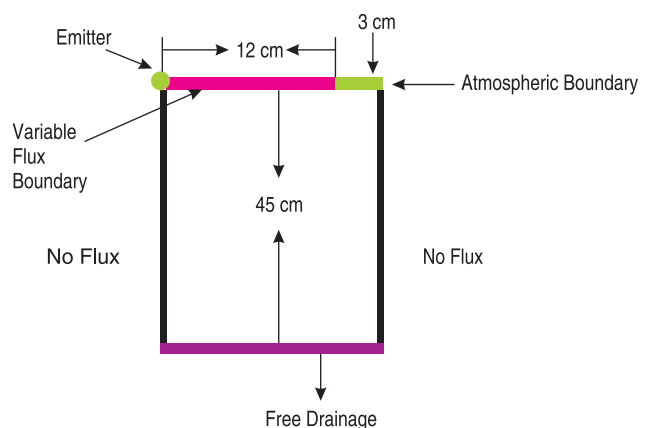


Fig 1 Conceptual diagram of simulated area

Table 1 Input for Hydrus-2D: water flow parameters

Soil layer	Soil depth (cm)	Qr (Θ_r)	Qs (Θ_s)	Alpha(α) (cm ⁻¹)	n	Ks (m day ⁻¹)	I
1	0-15	0.0608	0.4123	0.0246	1.4343	37.3999	0.5
2	15-30	0.0595	0.4092	0.0257	1.4497	40.6001	0.5
3	30-45	0.0584	0.3897	0.0244	1.3786	21.42	0.5

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 in zero perpendicular to the boundary.

RESULTS AND DISCUSSION

Calibration of model

Calibration is a process of finding the true values of certain parameters. Model is executed by giving nearest values of parameters and predicted values are compared with the observed values. Values of said parameters are selected from the run when predicted and observed are close enough.

Field experiments were carried out to measure water distribution in sandy loam soil cropped with capsicum. Field data were taken for all the 9 treatments, but best treatment in terms of yield parameters and water productivity of capsicum was selected to determine spatial and temporal distribution of water content. Thus, the treatment selected for determining water dynamics in the soil, different color mulches under two level of irrigation, i.e. 100% ET_c and 80% ET_c was selected with the addition of control. Calibration of model was done using the values of water at various depths selected in the root zone with respect to emitters, observed at 24, 48 and 72 h after irrigation. Results of calibration of water distribution are presented in Fig. 2 to 7 for plastic mulches at 100% and 80% of ET_c .

A result of the calibration for water distribution at the end of first month after transplanting was taken. The figures

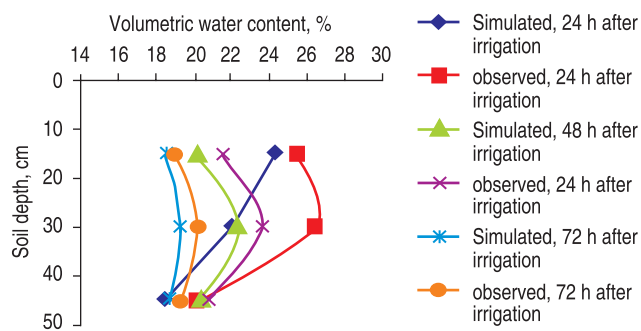


Fig 2 Simulated and observed water content for black plastic mulch at 100% of ET_c .

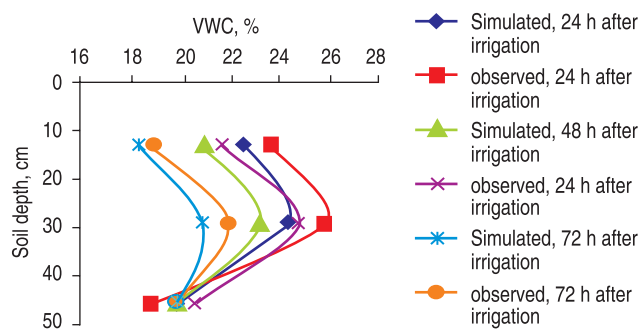


Fig 3 Simulated and observed water content for yellow plastic mulch at 100% of ET_c .

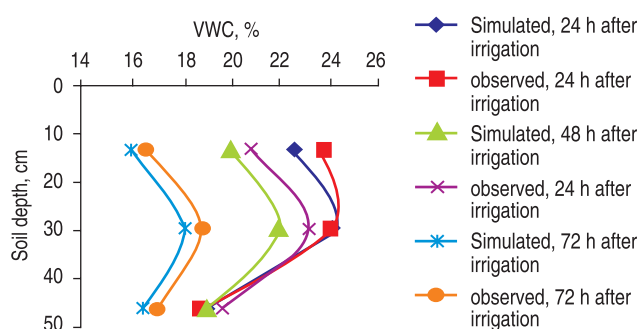


Fig 4 Simulated and observed water content for control at 100% of ET_c .

were plotted using output files obtained from Hydrus-2D. Graphical displays available in the post processing files of model gives spatial and temporal distribution of water content in simulated layers at predefined time steps. X-axis of the figure shows volumetric water content and Y-axis shows depth from the soil surface. Field observations for water content in the soil for three depths were taken at 24 h, 48 h and 72 h after irrigation. Simulated and observed values of water for different depth at 24, 48 and 72 h after irrigation were used to evaluate the performance of the model.

Fig 2, 3 and 4 show the simulated and observed water content for black, yellow plastic mulch and control respectively for 100% of ET_c for simulation of one day interval. The figure shows that simulated and observed water content follow a similar trend and there is not much difference between simulated and observed values. From the figure it was evaluated that at 100% of ET_c , silver color mulch has comparatively more water content and for that simulated and observed water content is well correlated than other treatments and control has the lowest water content. The values of simulated and observed water content for all the treatments at the end of 24 h, 48 h and 72 h after irrigation varied from 18 to 27%, 20 to 24% and 13 to 21%, respectively.

Fig 5, 6 and 7 show the simulated and observed water content for black, silver and yellow plastic mulch and control respectively for 80% of ET_c for simulation of one day interval. For 80% of ET_c the figure also shows that simulated and observed water contents follow a similar trend and there is not much difference between simulated and observed values. From the figure it was evaluated that

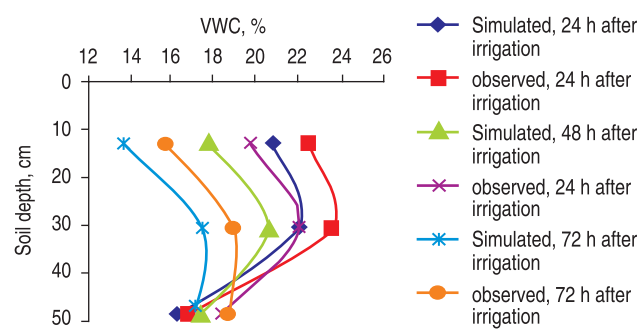


Fig 5 Simulated and observed water content for black plastic mulch at 80% of ET_c .

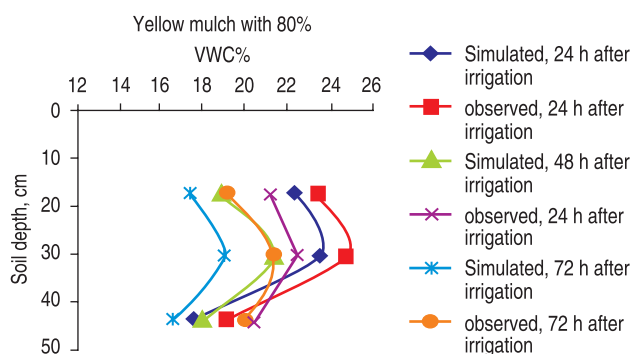


Fig 6 Simulated and observed water content for yellow plastic mulch at 80% of ET_c .

at 80% of ET_c , yellow color mulch has comparatively more water content than other treatments and control has the lowest water content. The values of simulated and observed water content for 80% of ET_c at the end of 24 h, 48 h and 72 h after irrigation varied from 15 to 25%, 16 to 22% and 17 to 21%, respectively.

The correlation coefficient between observed and simulated water content were determined to find out the closeness between them. It can be said that in both (100% of ET_c and 80% of ET_c) the cases even the lowest moisture content (MC) is near the field capacity (FC). The higher R^2 -value is obtained for silver plastic mulch at 100% of ET_c (0.91 to 0.94) and the second highest R^2 -value is for yellow plastic mulch at 80% of ET_c (0.89 to 0.91). The higher R^2 values showed that simulated and observed values are closely related. This indicates that the Hydrus-2D can be used to simulate the water distribution with very good accuracy.

Conclusion

VWC observed at various depths from the soil surface in the root zone of capsicum were used to calibrate the water transport model, i.e. Hydrus-2D. Field experiment was conducted to study the water distribution in sandy loam soil irrigated by drip system. Simulation of water distribution in various depths of soil was done with average emitter discharge rate of 1 l/h. From the simulation studies it was found that silver plastic mulch optimised the water content in the vicinity of capsicum root zone (20 to 30 cm) for 1 l/h dripper discharge. The water content was maintained in the active root zone at field capacity for 24 and 48 h after irrigation and was significantly decided after 72 h (3 days). Irrigation was given once in 3 days (72 h) which indicate that for capsicum irrigation scheduling with 3 days under peak requirement would be appropriate. If the drip irrigation system is properly designed and maintained then it can distribute the water uniformly in the active root zone of the capsicum (20 to 30 cm) without wastage. Further, this research suggests that irrigation scheduling on 3 days basis in an appropriate cycle. It has also been shown that if the drip system is designed properly, it will distribute water uniformly in radial direction. The observed and simulated values of soil moisture distribution with

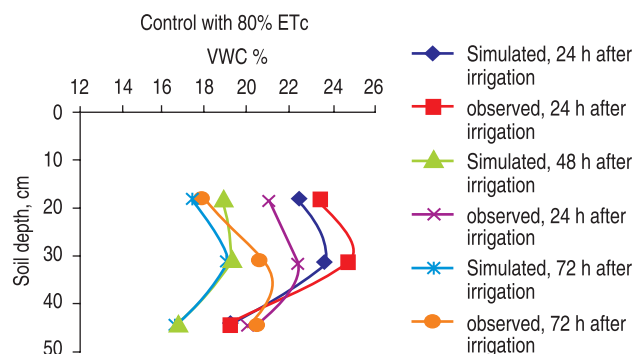


Fig 7 Simulated and observed water content for control at 80% of ET_c .

Hydrus-2D model correlated well for greenhouse capsicum under drip fertigated mulch conditions.

ACKNOWLEDGEMENTS

The authors acknowledge the Indian Agricultural Research Institute, New Delhi, India for financial assistance in the form of IARI fellowship.

REFERENCES

- Assouline S. 2002. The effects of micro-drip and conventional drip irrigation on water distribution and uptake. *Soil Science Society of America Journal* **66**: 1630–6.
- Bufon V B. 2010. Optimizing Subsurface Drip Irrigation Design and Management with Hydrus-2D/3D Model. Texas Tech University, Vinicius Bof Bufon, May 2010.
- Clothier B E and Scotter D R. 1982. Constant-flux infiltration from a hemispherical cavity 1. *Soil Science Society of America*, -dl.sciencesocieties.org.
- Cote C M, Bristow K L, Charlesworth P B and Cook F J. 2003. Analysis of soil wetting and solute transport in sub-surface trickle irrigation. *Irrigation Science* **22**-(3-4): 143–56.
- Elnesr M N and Alazba A A. 2015. The effects of three techniques that change the wetting patterns over subsurface drip-irrigated potatoes. *Spanish Journal of Agricultural Research* **13**(3): e1204.
- FAO. 2002 Irrigation manual. Planning, development monitoring and evaluation of irrigated agriculture with farmer participation, Module 9: Localized irrigation systems planning, design, operation and maintenance (English). Savva, A P, FAO, Harare (Zimbabwe), p 82.
- FAO. 2012. *FAO Statistical Yearbook 2012, World Food and Agriculture Part 4: Sustainability Dimensions*. FAO, Rome.
- Fernandez-Galvez J L P and Simmonds. 2006. Monitoring and modelling the three-dimensional flow of water under drip irrigation. *Agricultural Water Management* **83**: 197–208.
- Gardenas, A, Hopmans J W, Hanson B R and Simunek J. 2005. Two dimensional modeling of nitrate leaching for various fertigation scenarios under micro-irrigation. *Agricultural Water Management* **74**: 219–42.
- Hanks R J, Keller J, Rasmussen V P and Wilson G D. 1976. Line source sprinkler for continuous variable irrigation-crop production studies. *Soil Science Society* **40**:(3) 426–9.
- Iceman J T. 2007. Approaches for two-dimensional monitoring and numerical modeling of drip Systems. University of Florida.
- Kandelous M M and Simunek J. 2010. Comparison of numerical, analytical and empirical models to estimate wetting patterns

- for surface and subsurface drip irrigation. *Irrigation Science* **28**(5): 435–44.
- Lazarovitch N, Simunek J and Shani, U. 2005. System dependent boundary condition for water flow from subsurface source. *Soil Science Society American Journal* **69**(1): 46–50.
- Lazarovitch N, Warrick A W, Furman A and Simunek J. 2007. Subsurface water distribution from drip irrigation described by moment analyses. *Vadose Zone J* **6**: 116–23.
- Li J, Zhang J and Rao M. 2004. Wetting patterns and nitrogen distributions as affected by fertigation strategies from a surface point source. *Agricultural Water Management* **67**: 89–104.
- Merrill S D, Raats P A C and Dirksen C. 1978. Laterally confined flow from a point source at the surface of an inhomogeneous soil column. *Soil Science Society of American Journal* **42**: 851–7.
- Meshkat M, Warner R C and Workman S R. 1999. Modeling of evaporation reduction in drip irrigation system. *Journal of Irrigation and Drainage Engineering* **125**(6): 315–23.
- Mmolawa K and Or D. 2003. Experimental and numerical evaluation of analytical volume balance model for soil water dynamics under drip Irrigation. *Soil Science Society of America Journal* **67**: 1657–71.
- Patel N and Rajput T B S 2008. Dynamics and modeling of soil water under subsurface drip irrigated onion. *Agricultural Water Management* **95**: 1335–49.
- Phogat V, Mahadevan M, Skewes M and Cox J W. 2012. Modelling soil water and salt dynamics under pulsed and continuous surface drip irrigation of almond and implications of system design. *Irrigation Science* **30**(4): 315–33.
- Schmitz G H, Schutze N and Petersohn U. 2002. New strategy for optimizing water application under trickle irrigation. *Journal of Irrigation and Drainage Engineering* **128**(5): 287–97.
- Skaggs T H, Trout T J, Simunek J and Shouse J. 2004. Comparison of HYDRUS-2D simulation of drip irrigation with experimental observations. *Journal of Irrigation and Drainage Engineering* **130**(4).
- Skaggs T H, Trout T J and Rothfuss Y. 2010. Drip irrigation water distribution patterns: effects of emitter rate, pulsing, and antecedent water. *Soil Science Society American Journal* **74**: 1886–96.
- Simunek J, Sejna M and van Genuchten M Th. 1999. The HYDRUS-2D software package for simulating two-dimensional movement of water, heat and multiple solutes in variably saturated media, Version 2.0. Rep. IGCWMC-TPS-53, p 251, International Ground Water Model. Cent., Colo. Sch. of Mines, Golden, CO.
- Simunek J and Shouse P J. 2004. Comparison of HYDRUS-2D Simulations of Drip Irrigation with Experimental Observations. *Journal of Irrigation and Drainage Engineering* July/August 2004.
- Simunek J, van Genuchten M Th and Sejna M. 2006. HYDRUS Software package for simulating two- and three-dimensional movement of water, heat, and multiple solutes in variably-saturated media Technical manual. Version 1.0. PC-Progress, Prague, Czech Republic.
- Subbaiah R. 2013. A review of models for predicting soil water dynamics during trickle irrigation. *Irrigation Science* **31**: 225–58.
- OECD. 2016. Water use in agriculture, Organization for Economic Cooperation and Development (<http://www.oecd.org/agriculture/water-use-in-agriculture.htm>).