IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 13, Issue 12 Ser. III (December 2020), PP 38-42
www.iosrjournals.org

Effect of Different Dripper Flows on Moisture Distribution in Soil in Drip Irrigation System and Modeling with HYDRUS-2D\3D Program

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Abstract
One of the basic requirements in the design of the drip irrigation system is to obtain more information about the shape and size of the wetted soil zone. In order to determine the optimum irrigation water, it is necessary to know the moisture values along the soil profile. In field conditions, determining the water movement or soil moisture along the desired soil profile is quite laborious and time consuming. In recent years, it is easy to model the moisture change in the soil profile with computer models. This study was carried out to determine the moisture movement in the soil profile with the HYDRUS-2D\3D program using 2 different dripper flow rates (2 and 4 L s^{-1}) in drip irrigation method. In the study; the moisture distribution in the soil profile was determined by gravimetric method before, during, at the end of irrigation and 24, 48, 72 hours after irrigation. As a result of the study, it was determined that there was a harmony between the soil water content distribution data modeled using the HYDRUS-2D\3D program and the actual data measured in the field. The modeling results show that the HYDRUS-2D\3D program can be used to research and design different applications of the drip irrigation system.
Keywords: *Drip irrigation, HYDRUS-2D\3D, Modeling, Flow rate*

Date of Submission: 08-12-2020 Date of Acceptance: 24-12-2020

I. Introduction

In recent years, the increase in the use of urban water due to the rapid population growth necessitates the use of advanced irrigation technologies to produce more food by using less water and to do this without disturbing the soil and water resources. Drip irrigation provides significant water savings in irrigation water, while at the same time increasing efficiency and quality. However, this is possible under the appropriate project and operation condition required by the system. Therefore, in drip irrigation, current operating parameters such as irrigation frequency and duration, dripper flow and intervals and placement of lateral pipes must be determined and applied correctly.

More information on the shape and size of the wetted soil profile is needed in the design of the drip irrigation system. Under a dripper, the wetting volume and dimensions of the soil depend on the hydraulic properties of the soil, the dripper flow rate and the amount of irrigation water applied (Çetin et al., 2013). There is no single line or the most suitable method or calculation for the wetted area. Also, in systems with a higher percentage of wetted area, more water is stored (Keller and Bleisner, 1990). HYDRUS-2D\3D has tested the availability of numerical models to simulate water flow and solute transport in soil for surface or subsurface drip irrigation conditions, and many researchers have used these models to assess water flow in soils with drip irrigation systems (Meshkat et al., 1999; Schmitz. et al., 2002; Cote et al., 2003; Lazarovitch et al., 2007; Skaggs et al., 2004; Ŝimůnek et al., 1999).

The aim of this study is to simulate water flow for a drip irrigation system under variable parameters using the HYDRUS-2D\3D simulation program and to evaluate numerically how these techniques affect water distribution.

II. Materials and Methods

Experiment site

The study was carried out on the land of the Western Mediterranean Agricultural Research Institute, located 20 km east of Antalya, on the Antalya-Alanya Highway. The trial site is located at 36°52' North latitude and 30°50' East longitude and its average altitude is 15 m. Some physical and chemical properties of the soil samples taken from the trial area are given in Table 1.

Table1. Physical properties of the research area soils

Soil Depth (cm)	Sand (%)	Clay (%)	Silt (%)	Soil Texture	Field Capacity ($g\ g^{-1}$)	Permanent Wilting Point ($g\ g^{-1}$)	Bulk Density ($g\ cm^{-3}$)
0-30	13	44	43	SiC	23.38	12.80	1.31
30-60	13	40	47	SiC	23.56	11.30	1.38
60-90	13	38	49	SiCL	22.16	11.95	1.43

Application

This research on soil water content in drip irrigation method was conducted in a clay loam soil. In the irrigation application, lateral pipes of 20 m length with 2 and 4 L h^{-1} flow have been used. In the study, water application was made for three hours, and it corresponds to 6 and 12 L h^{-1} applied water. Soil sampling time; before irrigation, 1 hour after the start of irrigation, 2 hours after the start of irrigation, at the end of the irrigation, 24, 48 and 72 hours after the irrigation ends. Gravimetric sampling was performed by opening soil profiles perpendicular to the lateral pipes for each time. A coordinate system has been established on the profile directly on the soil surface above the lateral pipe. Soil samples were taken on a 90x75 cm plane, with 15 cm intervals from each profile. After the samples were weighed, they were dried in the oven and their moisture content was determined (Figure1).

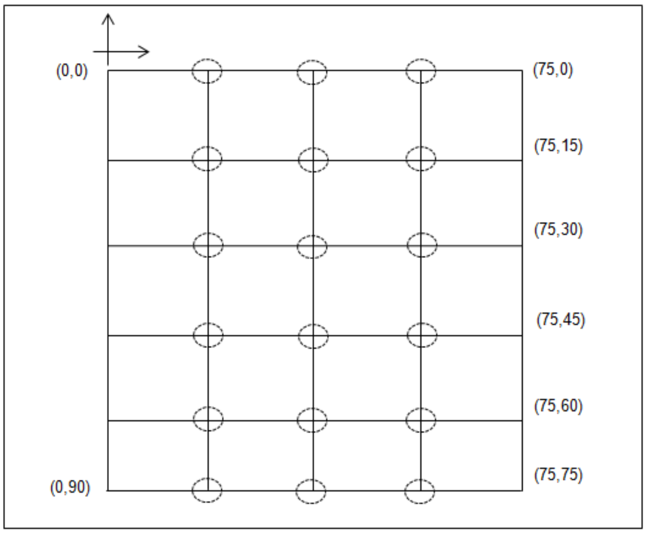

Figure1. Coordinates from which soil samples will be taken

Numerical Modeling

HYDRUS-2D\3D is a program that runs the numerical solution of Richard's equation in a computer environment for saturated and unsaturated conditions where there is no continuous flow in the soil. Assuming a homogeneous and isotropic soil, the two-dimensional Richards equation for modeling water flow is as follows.

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

In equation; θ, volumetric water content; h, pressure head; t, time; x, horizontal coordinate; z, vertical coordinate and K, hydraulic conductivity. In the HYDRUS-2D\3D model, Van Genuchten-Mualem equations are used for hydraulic conductivity and soil water characteristic curves.

$$\theta(\mathrm{h}) = \begin{cases} \theta_r + \frac{\theta s - \theta_r}{(1+|\alpha h|^n)^m}, & h < 0 \\ \theta s, & h \geq 0 \end{cases} \qquad (2)$$

$$\mathrm{K(h)} = \mathrm{K_s S_e^l}\left[1 - (1 - \mathrm{S_e^{1/m}})^m\right]^2 \qquad (3)$$

$$\mathrm{S_e} = \frac{\theta - \theta_r}{\theta s - \theta_r}, \quad m = 1 - 1/n \qquad (4)$$

In the equations; α, (1 cm^{-1}); n and m, 1-1 / n shape parameters; h, matric potential (cm); θs, saturated water content ($cm^3\ cm^{-3}$); θr, residual water content ($cm^3\ cm^{-3}$) and Ks, (cm h^{-1}) indicates saturated hydraulic conductivity.

Running the model required the hydraulic parameters θs, θr, Ks, n, a, and l, as well as the initial water content distribution. HYDRUS-2D\3D uses Galerkin finite element method to solve Equations 1 and 3. Šimůnek et al., (1999) explains the content of the method in detail. In this study, the right and left sides of the dripper are simulated. Thus, the boundary of the finite element mesh is rectangular except for the left and right edges in the left and right upper corner where the drip tube is located (Figure2).

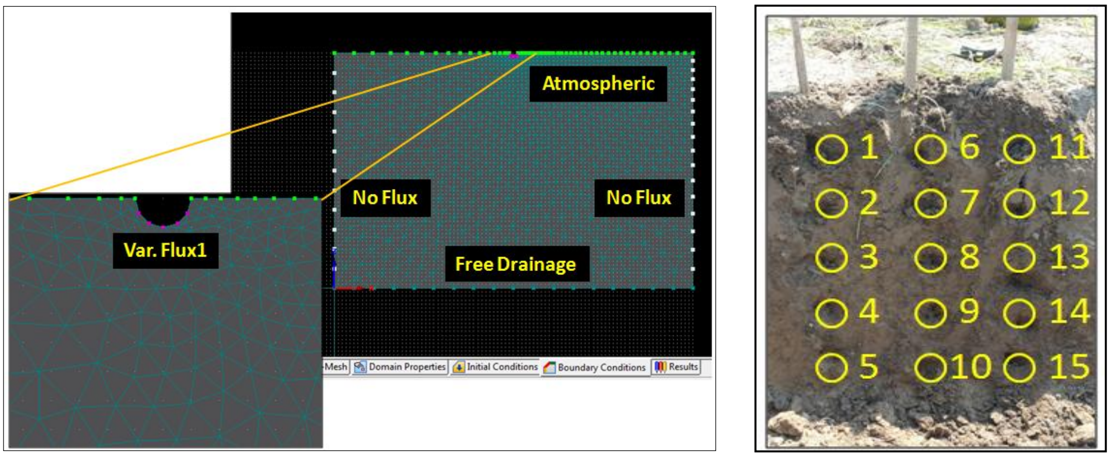

Figure2. Representation of boundary conditions and grids with moisture sampling

The pipe is in the form of a semicircle with a radius of 1 cm on the border towards the inner side of the border. During water application, the drip pipe water flow rate was found to be 4 L h^{-1} m^{-1} and 12 L h^{-1} m^{-1}. When irrigation ends, the lateral tube boundary becomes a zero flux condition. The water flux values applied to the dripper are calculated as follows.

$$q = \frac{\text{akış oranı}}{\text{yüzey alanı}} = \frac{6000\ \text{cm}^3\ \text{h}^{-1}}{2\pi(1\ \text{cm})(100\ \text{cm})} = 9{,}54\ \text{cm h}^{-1}$$

$$q = \frac{\text{akış oranı}}{\text{yüzey alanı}} = \frac{12000\ \text{cm}^3\ \text{h}^{-1}}{2\pi(1\ \text{cm})(100\ \text{cm})} = 19{,}09\ \text{cm h}^{-1}$$

Experimental and predicted values of the surface wetting radius applied with 2 and 4 L h^{-1} flow rate in clay-loam soil and at different times are given in Figure 3. The measured wet radii and the predicted wetted radii are highly consistent with observed data, especially for short periods of time. It was determined that the data measured in a long time at the surface wetted radius values moved faster than the predicted data.

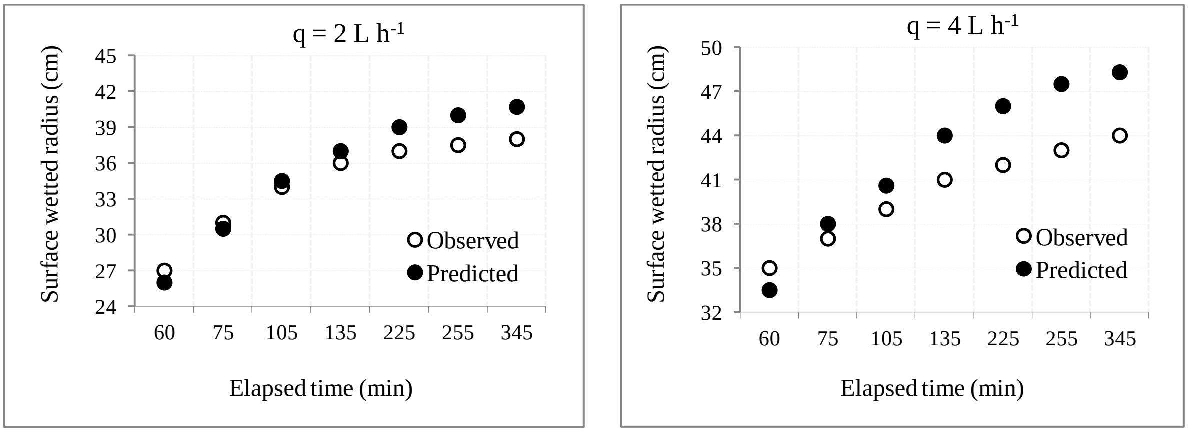

Figure3. Dimensions of the wetted soil radius

Wetted soil volume

In the drip irrigation system, the shape formed by the water coming out of a dripper in the soil is cut ellipsoid. The maximum wetting width (d) in the soil occurs 10-20 cm below the soil surface (h) depending on the soil texture (Figure4).

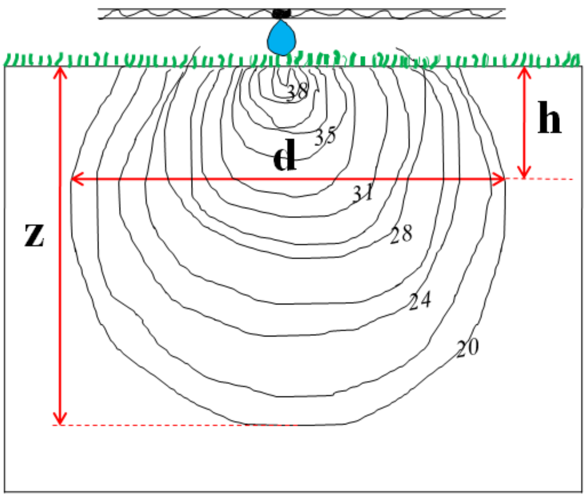

Figure4. Wetted soil pattern created by a dripper

These values are used when calculating the volume of wetted soil. In this study, the equation5 developed by Zur (1996) is used to calculate the volume.

$$V = \frac{\pi}{12} d^2 \left[2z + h - \frac{h^3}{(z-h)^2}\right] \quad (5)$$

In the equations; V, volume of wetting shape (m^3); d, width of wetted area (m); z, wetting depth from the wetting surface (m); h, depth from the soil surface at the point where the maximum wetting width is reached (m).

The wetted soil volumes of drippers with different flow rates were calculated for different time. It was observed that as the dripper flow increased, the volume of wetted soil increased horizontally. That is, as both the dripper flow rate and the irrigation duration increase, the width of the wetted soil volume increases. In this case, the wetting depth decreases. Wetted soil volume values calculated according to the observed and predicted values in the study are given in Table 2 and 3.

Table2. Dimensions and values of the wetted soil volume observed and predicted at different times of the 2 L h^{-1} flow dripper

Time	Observed				Predicted			
(min)	h (m)	d (m)	z (m)	V (m^3)	h (m)	d (m)	z (m)	V (m^3)
60	0.039	0.370	0.032	0.024	0.037	0.310	0.290	0.015
180	0.047	0.390	0.039	0.028	0.041	0.330	0.300	0.018
240	0.062	0.400	0.048	0.032	0.078	0.510	0.380	0.057
1620	0.078	0.560	0.130	0.103	0.085	0.590	0.670	0.130
3060	0.090	0.570	0.141	0.109	0.095	0.660	0.650	0.159
4500	0.090	0.570	0.142	0.111	0.097	0.670	0.690	0.173

Table3. Dimensions and values of the wetted soil volume observed and predicted at different times of the 4 L h^{-1} flow dripper

Time	Observed				Predicted			
(min)	h (m)	d (m)	z (m)	V (m^3)	h (m)	d (m)	z (m)	V (m^3)
60	0.097	0.400	0.340	0.030	0.082	0.350	0.280	0.020
180	0.128	0.430	0.360	0.038	0.114	0.390	0.310	0.028
240	0.146	0.460	0.390	0.048	0.138	0.490	0.330	0.046
1620	0.152	0.600	0.620	0.130	0.143	0.660	0.580	0.147
3060	0.160	0.620	0.630	0.141	0.155	0.750	0.670	0.218
4500	0.160	0.620	0.635	0.142	0.158	0.790	0.715	0.257

In the study, using the HYDRUS-2D\3D program, the moisture distribution in the soil profile was estimated before, during, at the end and 24, 48, 72 hours after irrigation. According to these values, the estimated wetted soil volume dimensions and values were calculated (Figure5).

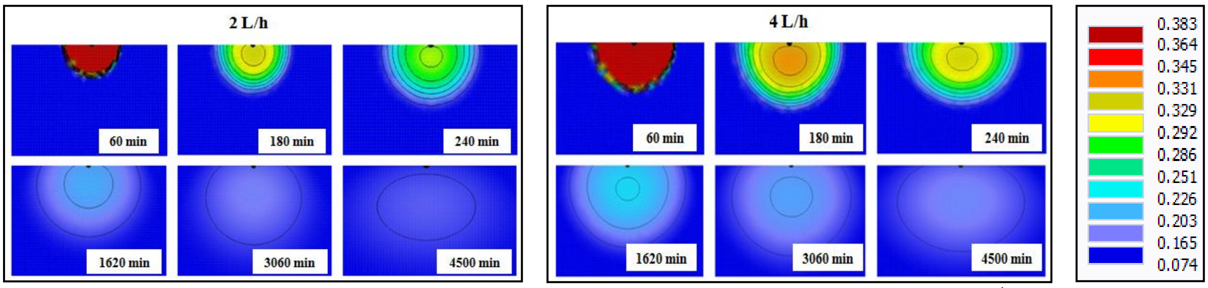

Figure5. Simulated wetting patterns the water application for 2 and 4 L h $^{-1}$

III. Conclusions

In the study, the soil moisture values created by the dripper at different times and flow rates and the wetted soil volumes were compared as measured and simulated. The depth and width values of the estimated wetted soil region gave results close to the measured values. Consequently, the model created helps to estimate the distribution of water in the soil under the dripper, considering the main parameters related to the dimensions of the wet soil volume.

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Filiz KARA. "Effect of Different Dripper Flows on Moisture Distribution in Soil in Drip Irrigation System and Modeling with HYDRUS-2D\3D Program." *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, 13(12), 2020, pp. 38-42.