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Water Movement through Soil under Drip Irrigation using Different Hydraulic Soil Models

Israa Saad Faraj*
College of Engineering- University of Baghdad
E-mail:**nsisraasaad1992@gmail.com**

Assist. Prof. Dr. Maysoon Basheer Abid
College of Engineering- University of Baghdad
E-mail: **dr.maysoonbasheer@gmail.com**

ABSTRACT

Drip irrigation is one of the conservative irrigation techniques since it implies supplying water directly on the soil through the emitter; it can supply water and fertilizer directly into the root zone. An equation to estimate the wetted area in unsaturated soil is taking into calculating the water absorption by roots is simulated numerically using HYDRUS (2D/3D) software. In this paper, HYDRUS comprises analytical types of the estimate of different soil hydraulic properties. Used one soil type, sandy loam, with three types of crops; (corn, tomato, and sweet sorghum), different drip discharge, different initial soil moisture content was assumed, and different time durations. The relative error for the different hydraulic soil models was calculated and was compared with the model of Brooks and Corey, 1964. There was good agreement compared with different models. The Root Mean Square Error (RMSE) was (0.23) cm, while the relative error (- 1%) and (1) for modeling efficiency (EF) for wetted radius, but wetted depth was RMSE (0.99) cm, and the relative error was (4.5%), and EF was (1).

Keywords: HYDRUS, Porous media, Richards Equation, Simulation models, Water movement through soil, Water uptake by roots.

حركة المياه من خلال التربة تحت الري بالتنقيط باستخدام نماذج التربة الهيدروليكية المختلفة

ميسون بشير عبد
استاذ مساعد دكتور
كلية الهندسة – جامعة بغداد

إسراء سعد فرج*
كلية الهندسة – جامعة بغداد

الخلاصة

الري بالتنقيط هو أحد أساليب الري المتطورة لانه يوفر المياه مباشرة للتربة من خلال المنقطة , ويستطيع توفير المياه والاسمدة الى المنطقة الجذرية. تم محاكاة معادلة لتقدير المساحة المبللة في التربة غير المشبعة مع امتصاص الماء من الجذور عدديا باستخدام HYDRUS(2D/3D) . في هذا البحث يضم برنامج HYDRUS انواع التحليلية التالية لتقدير الخواص الهيدروليكية المختلفة للتربة . استخدم نوع واحد من التربة وهي التربة المزيجية الرملية ، مع ثلاثة انواع من المحاصيل (الذرة، الطماطم، والذرة الرفيعة الحلوة) ، وافترضت قيم مختلفة لتصريف المنقطة ،ومحتوى رطوبي أولي للتربة وفترات زمنية مختلفة . تم حساب الخطأ النسبي

لنماذج التربة الهيدروليكية المختلفة وكانت النتائج التي توصل اليها (1964)Brooks and Corey جيدة مقارنة بالنماذج المختلفة .
كان جذر مربع الخطأ (0.23) سم في حين الخطأ النسبي (1% -) و(1) لكفاءة النمذجة لنصف القطر المبلل ، لكن العمق المبلل كان
جذر مربع الخطأ (0.99) سم و الخطأ النسبي(4.5%)ولكفاءة النمذجة(1).

الكلمات الرئيسية: هيدراس ، وسائط مسامية ، معادلة ريشارد ، نماذج محاكاة، حركة المياه خلال التربة، امتصاص ماء الجذر.

1. INTRODUCTION

Surface drip irrigation system is increasingly used in arid regions with limited water resources to irrigate crops, so the water content of the plant root zone can reach an optimum level. **(Vrugt, et al., 2001a),** developed a two-dimensional root water absorption model that can be merged into the numerical multidimensional flow models. The two-dimensional uptake model is based on the Raats model (1974) but extended with a radial component. The residual between simulated and measured water data on contents, eliminating the pattern of root water absorption, was integrated for a two dimensional model of flow, and parameters for root water uptake advanced. Water content was measured for 16 days at 25 locations. Simulated and measured water contents were in good agreement, with R^2 value of 0.94 and 0.99 and a root mean squared error (RMSE) of 0.015 $m^3 \, m^{-3}$. The standard error in measuring the water content was 0.01 $m^3 \, m^{-3}$ and 0.02 $m^3 \, m^{-3}$. **(Vrugt, et al., 2001b),** tested a three-dimensional root water uptake for the simultaneous, dynamic simulation model of transient soil water flow and uptake root water (around an almond tree). Soil absorption of hydraulic and root water, optimized parameters by eliminating residual between the estimated and the calculated simulated water content data. Water content was measured in a three-dimensional for 16 days after irrigation. The obtained results showed that water content values during the 16 day period were better, with an overall time-averaged root mean squared error (RMSE) of 0.018 $m^3 \, m^{-3}$. These results are in good agreement, keeping in mind that the standard error of the water content calculating was between 0.01 and 0.02 $m^3 \, m^{-3}$. **(Shankar, V., et al., 2012),** developed root water uptake for the nonlinear parameter in the (O-R a nonlinear root water uptake model-referred to hereafter as the O-R model), moisture absorption model from easily calculated plant physiological parameters, such as maximum daily transpiration (Tjmax), maximum root depth (Zrmax), and time to attain the maximum transpiration (t). Data to assess the relationship were obtained by reducing the moisture differences found between the field literature recorded depletions of 28 crops and Richards equation based numerically simulated depletion of soil moisture is combined with the moisture uptake configuration of root water uptake. Also, field experiments on three Indian crops (maize, Indian mustard, and wheat) are conducted to further confirmation of the proposed empirical relationship. Comparisons of model predictions with field soil observations and moisture depletion in different layers of the root region show good agreement during different stages of plant growth. The obtained results were highlighting the utility of the developed equation for modeling root water uptake over a wide range of crops. **(El-Nesr, et al., 2013),** evaluated three technologies for water movement and the soluting transport in the root zone. The three technologies are a physical barrier, a dual-drip system with concurrent irrigation, and a double drip system sequential irrigation. The results show that the physical barrier was more efficient from double drip irrigation to strengthen the distribution of water and solute concentration transport in soils in the root region.

Additionally, the double drip irrigation with sequential irrigation, and thus the double drip irrigation with concurrent irrigation was the most efficient way to reduce downward leaching of solutes transport in the root region. **(Abid, M. B., 2018)** developed a describing spatial

distribution of the soil water content in unsaturated soil obtained from the Richards equation numerical simulation.

(Khalil, L. A., 2018), studied the wetted zone (wetted radius and depth) under surface trickle point source with crops, and developed an equation to estimate the radius and depth of the wetted soil taking to calculate evaporation and extraction water by plants roots with different soil types in Iraq. The experimental fieldwork was in six different sites in Iraq having three different soil textures; (sandy loam, clay loam, and silty clay loam) classified according to USDA, different saturated hydraulic conductivity, and cultivated with different plants; (eggplant, corn, cauliflower, potato, and tomato) and measure the radius of wetted to compare the measurement values with the simulated by the software HYDRUS- 2D/3D. The simulation selected five emitter discharges of 0.5, 1, 2, 3, and 5*l*/hr. For each discharge, five initial volumetric soil moisture contents ranged between field capacity and the wilting point was selected. The wetting patterns for the soils were predicted at every thirty minutes for a total time of irrigation equals 3hr. The results showed that the crops have a very simple effect on the wetted zone and effect on the soil moisture content. The equations obtained from STATISTICA software Version 12 showed that the maximum error between the values obtained from HYDRUS-2D/3D and the values obtained from the equations which were estimated for all types of soil in this research did not exceed 23%, modeling efficiency (EF) was not less than 0.98. Root mean square error (RMSE) did not exceed 1.17cm. In general, a good agreement was found between the predicted results compared with those obtained from experimental fieldwork. (**Khalil and Abid, 2019),** simulated soil wetting pattern around a drip surface irrigation of water application depending primarily on hydraulic soil properties, discharge of drip, time of durations, and root water uptake. (**Abid, H.N., and Abid, M.B., 2019**) predicted soil wetting pattern from one subsurface drip irrigation was analyzed to calculate the roots of different plants (pepper, cucumber, and tomato). There were three soil types loamy sand, loam, and sandy loam soil by utilizing the HYDRUS (2D/3D) software.

This research aims to simulate the infiltration of water and to calculate wetted area depths and widths using the numerical HYDRUS (2D/3D) model for the soil of specified texture. Also, to study the effect of different models of root uptake on the wetted area from a surface emitter.

2. OVERNING EQUATION

The water movement in the soil was simulated by the numerical HYDRUS (2D/3D) model. The Richard's equation for the flow of water from a point source through variably saturated, porous media can be written in axisymmetric coordinates (**Vrugt and Hopmans, 2001; El-Nesr, 2013; and Khalil, L.A., 2018**) :

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

where:

θ = Volumetric soil moisture content (cm^3/cm^3), t = Time (hr), h = Soil water pressure head, (cm), r = Radial (horizontal) coordinate, (cm), z = Vertical coordinate (upward direction is positive), (cm), K (h) = Unsaturated hydraulic conductivity, (cm/hr), and S (h) = A sink term that explain the root water uptake expressed as a water volume that removed from a unit volume of soil per unit time, $(cm^3/cm^{-3}/hr)$.

3.YDRAULIC SOIL MODELS

HYDRUS comprises the subsequent analytical types to evaluate soil hydraulic properties (**Brooks and Corey 1964; Van Genuchten, 1980; Vogel and Císlerová, 1988; Kosugi, 1996).** The soil water retention was modeled as:

3.1 Brooks and Corey (1964)

$$S_e = \begin{cases} |\alpha h|^{-n} & h < -\frac{1}{\alpha} \\ 1 & h \geq -\frac{1}{\alpha} \end{cases} \tag{2}$$

$$K = K_s \, S_e^{\,2/n+l+2} \tag{3}$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{4}$$

where: Se = Effective soil moisture content, dimensionless, θr = Residual soil moisture content, (cm^3/cm^3), θs = Saturated soil moisture content, (cm^3/cm^3), K_s = Saturated hydraulic conductivity (cm/hr), α = Inverse of the air-entry value, (1/cm), n = Pore size distribution index, dimensionless, and l = A pore-connectivity parameter assumed to be 2.0 in the original study of (**Brooks and Corey 1964).**

3.2 Van Genuchten, 1980; and Mualem, 1976:

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{[1+|\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \tag{5}$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \frac{1}{(1+|\alpha h|^n)^m} \ , \ m = 1 - \frac{1}{n}, n > 1 \tag{6}$$

The hydraulic conductivity was believed to be described using the closed-form equation of van Genuchten, 1980, which combines the analytical expression of Eq. (5) with the pore size distribution model of Mualem, 1976:

$$K(h) = K_s \, S_e^{\,l} \left[1 - \left(1 - S_e^{\frac{1}{m}} \right)^m \right]^2 \tag{7}$$

l =The pore connectivity parameter l in the hydraulic conductivity function was estimated (**Mualem, 1976**) to be about 0.5 as an average for many soils.

3.3 Vogel and Císlerová (1988):

$$\theta(h)= \begin{cases} \theta_r + \frac{\theta_s - \theta_r}{[1+|\alpha h|^n]^{\wedge}m} & h < h_s \\ \theta_s & h \geq h_s \end{cases} \tag{8}$$

$$K(h) = \begin{cases} k_s\, k_r & h \leq h_s \\ k_s + \frac{(h-h_s)(k_s-k_s)}{h_s - h_k} & h_k < h < h_s \\ k_s & h \geq h_s \end{cases} \tag{9}$$

$$K_r = \frac{K_s}{K_s}\left(\frac{S_e}{S_{ek}}\right)^{\frac{1}{2}} \left[\frac{F(\theta_r) - F(\theta)}{F(\theta_r) - F(\theta_k)}\right]^2 \tag{10}$$

$$F(\theta) = \left[1 - \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{\frac{1}{m}}\right]^m \tag{11}$$

$$S_{ek} = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{12}$$

3.4 Kosugi (1996):

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \begin{cases} \frac{1}{2}\ \mathrm{erfc}\left\{\frac{\ln(\frac{h}{\alpha})}{\sqrt{2}n}\right\} & (h < 0) \\ 1 & (h \geq 0) \end{cases} \tag{13}$$

Application of Mualems model of distribution by pore size (**Mualem, 1976**) now leads to the following hydraulic conductivity function:

$$K = \begin{cases} K_s S_e^{\frac{1}{2}}\left\{\frac{1}{2}\ \mathrm{erfc}\left[\frac{\ln(\frac{h}{\alpha})}{\sqrt{2}n} + \frac{n}{\sqrt{2}}\right]\right\}^2 & (h < 0) \\ K_s & (h \geq 0) \end{cases}$$

Modeling of water movement from a drip irrigation surface of axisymmetric, the domain is half of was HYDRUS (2D/3D) simulation. The single drip surface was a location at the left top corner of the domain near to the crop. However, the dimension horizontal simulated of the wetting design represents of the wetted radius. In this paper, the domain is to be 60 cm in width and 80 cm in depth. The top surface area, the flow boundary, was assumed to be zero along the boundary of the drip irrigation, where a constant flow was considered to the drip. The sides (right and left) were assumed to be zero, and the bottom to be free drainage boundary, **Fig. 1.** The radius of the constant flow boundary had been calculated by taking unit flow rate area equal to the hydraulic conductivity of the saturated soil when the pressure head was assumed

to be zero **(Naglič, et al., 2014):**

$$q_f = \frac{Q}{A} = K_s \tag{15}$$

where Q= Flow rate of the emitter, (*l/*hr), A= Saturated surface area $=\pi r^2$, (cm^2) and qf = Flux per unit area, (cm/hr).
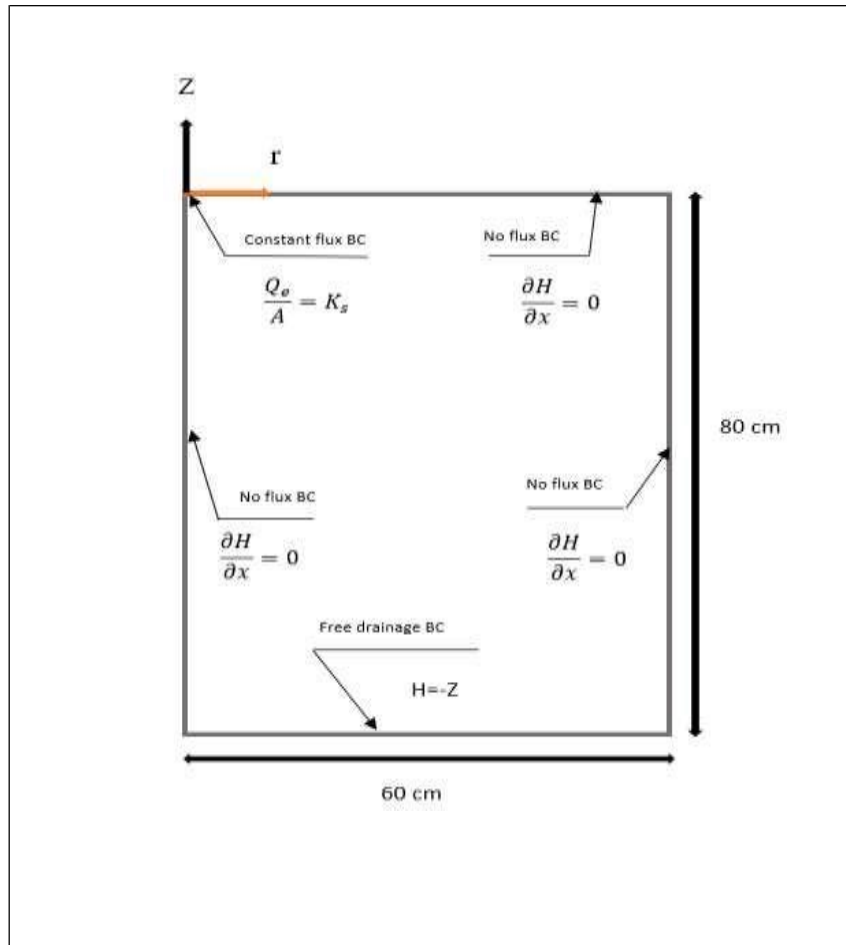
Figure 1. Schematic of the boundary condition utilized in all simulations.

Table 1. shows the soil physical characteristics for different hydraulic soil model. The wetting patterns for the soil were predicted every three hours for a total irrigation time equal to 12 hours. Drip discharges of 0.5 and 1 *l*/hr. Wetting patterns were used to predict. Three initial soil moisture contents were used ranged between field capacity =0.29 (cm^3/cm^3), and wilting point = 0.10 (cm^3/cm^3) for a different hydraulic model, as shown in **Table 2.**

Table 1. Hydraulic parameters for different models for sandy loam soil textured.

Hydraulic soil model	Ks (cm/hr.)	Θ_r (cm³/cm³)	Θ_S (cm³/cm³)	$\propto$ 1/cm	n
Brooks and Corey, 1964	2.59	0.041	0.453	0.068	0.322
Van Genuchten, 1980	1.933	0.039	0.387	0.034	1.416
Vogel and Císlerová, 1988	4.421	0.065	0.41	0.075	1.89
Kosugi, 1996	4.421	0.065	0.41	27.423	1.26

Table 2. Values of the initial soil water content for sandy loam soil textured.

Hydraulic soil model	Initial soil water content (cm³/cm³)		
Brooks and Corey, 1964	0.15	0.18	0.22
Van Genuchten, 1980	0.15	0.18	0.22
Vogel and Císlerová, 1988	0.15	0.17	0.18
Kosugi ,1996	0.15	0.17	0.18

4.THE SINK TERM

The sink term S(h) was calculated using the Feddes model (**Feddes, et al., 1978**) modified to a radially symmetric problem (**Vrugt, et al., 2001; El-Nesr, 2013; and Khalil, L. A., 2018**):

$$S(h) = \alpha(h) \, S_p \tag{16}$$

$$S_p = \beta(z)T_P \, A_t \tag{17}$$

$$\beta(z) = \left(1 - \frac{z}{z_m}\right)e^{-(\frac{p_z}{z_m}|z^* - z|)} \tag{18}$$

where S = Actual root water uptake rate, during no stress period, ($cm^3 cm^{-3}$/hr), S(h)=A sink term that explains the root water uptake expressed as a water volume that removed from a unit volume of soil per unit time, ($cm^3 cm^{-3}$/hr), S_p = Potential root water uptake rate, ($cm^3 cm^{-3}$/hr), α (h) = A dimensionless water stress response function of the soil water pressure head varies between 0 and 1, Feddes, et al. 1978, as shown in Fig. 3, β (z) = A function

for describing the spatial root distribution, Vrugt, et al., 2001, (-), z_m = The maximum rooting lengths in the z-direction, (cm), z = Distances from the origin of the plant in the z-direction, (cm), p_z = Empirical parameters, (-), z* = Empirical parameters, (cm), T_p = The potential transpiration rate, (cm/hr), and A_t = The surface area associated with the transpiration process, (cm²).

$$A_T = \pi \left(r^* \% \, wetting \right)^2 \tag{19}$$

where r = radius of infiltration surface area, (cm), and the percentage of wetting was considered to be equal to 40%.

Table 3. shows the parameters describing a spatial root distribution for the HYDRUS model (**Vrugt, 2001**).
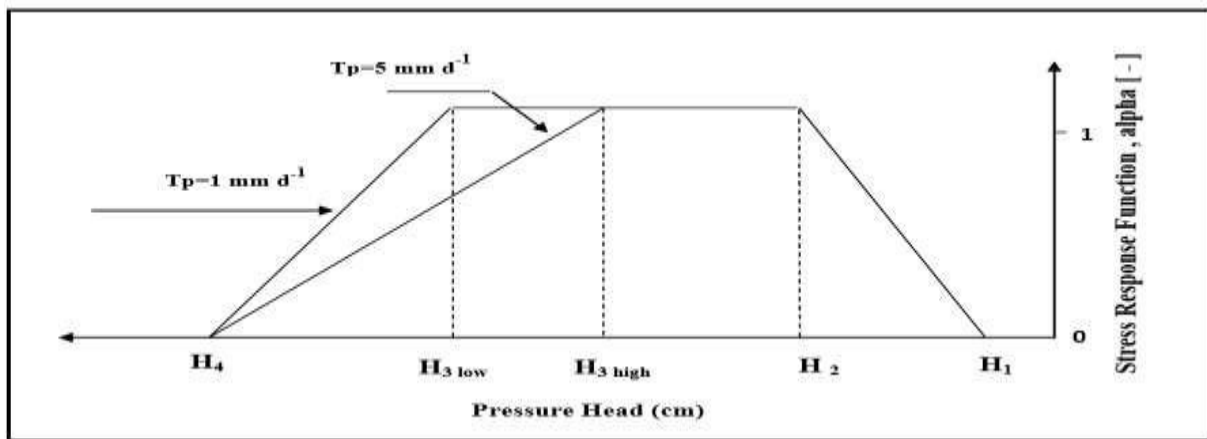
Figure 2. Schematic of the sink-term variable alpha as a function of the soil water pressure head.

Table 3. Parameter definition a spatial root distribution for the HYDRUS model.

Crop type	Z_m (cm)	z^* (-)	Z (cm)	P_z (-)	$\beta(z)$ (-)
Corn	30	1	20	1	0.18
Tomato	25	1	10	1	0.42
Sweet sorghum	65	10	20	1	0.59

The HYDRUS-2D requires separating the evapotranspiration rate into evaporation and transpiration rate. The transpiration rate for the two crops was considered to be invariable with time for all runs and equal 4 mm/day.

5. STATISTICAL INDICES

The obtained results predicted from HYDRUS (2D/3D) software were compared with the experimental data. These parameters include modeling efficiency (EF), which has a maximum value of 1 when the predicted value is of an excellent match with the observed ones (**Naglic, 2014).** A model with a value EF near 0 would not typically be assumed as a better model. Additionally, the root mean square error (RMSE) was applied. The optimal value is zero. Also, the relative error was used to test and comparison between the measured values from experimental data and with simulated values from HYDRUS (2D/3D) of the wetted area, as suggested by Legates and (**Mccabe, 1999):**

$$EF = 1 - \frac{\sum_{i=1}^{n}(p_i - o_i)^2}{\sum_{i=1}^{n}(o_i - o)^2}$$

(20)

$$RMSE = \sqrt{\sum_{i=1}^{n}\frac{(p_i - o_i)^2}{N}}$$

(21)

$$Error \% = 100(\frac{M - S}{M})$$

(22)

where: P_i= the data simulated by the HYDRUS, O_i= the observed data, obtained in the experimental test, N= the number of the observations, M= measured wetted, (cm), and S= simulated wetted, (cm).

6. SIMULATION WETTING PATTERN

In this simulation process, three initial water content for different hydraulic soil models is shown in **Table 2** for the two types of plants corn and tomato. The water flow from a surface drip was two dimensional axisymmetric; the domain of half requires to be predicted in HYDRUS (2D/3D). The soil wetting patterns were simulation at every 3 hr. for a total irrigation time equal 12 hr. Drip discharges to simulate the wetting patterns were 0.5 and 1 *l*/hr. For sandy loam soil. **Figs. 3,** to **Fig. 6**, show samples of wetting patterns for sandy loam soil and corn plant at discharge 1 *l*/hr for different hydraulic soil models. **Figs 3,** for (**Brooks and Corey, 1964)** with initial water content, is 0.22 (cm^3/cm^3). Additionally, to **Figs 4,** for the (**Van Genuchten, 1980)** with initial water moisture content is 0.22 (cm^3/cm^3), but **Fig. 5 and Fig. 6** for (**Vogel and Císlerová, 1988),** and (**Kosugi, 1996),** with an initial water content of 0.18 (cm^3/cm^3)**.**

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7.COMPARISON OF THE OBTAINED RESULTS

The obtained results that simulated by HYDRUS (2D/3D), a field data was recorded from the experiment of tomato for five times with sandy loam soil, but corn plant recorded for one time also, in sandy loam soil and then compared. **Tables 4, 5, 6, and 7** show the result of such comparison for drip discharge equaled to 1.45 *l*/hr, for tomato and 1.3 *l*/hr for corn, and initial water content 0.21 $cm^3\ cm^{-3}$ for tomato and 0.19 $cm^3\ cm^{-3}$ for corn. The information about their plants was taken it from **Khalil, 2018.** The comparison of measured and simulated wetted radius HYDRUS for different hydraulic soil models this data taken it from research **Khalil, 2018** shows in **Tables 4, 5, 6, and 7**.The predicted of the wetted radius and depth were compared with **Selim, 2013** for sandy loam soil with plant tomato at drip discharge 1.01 *l*/hr, and initial water content 0.15 $cm^3\ cm^{-3}$. The values of relative error were shown in **Tables 8, 9, 10, and 11** for different hydraulic soil models**.**

0.219 0.239 0.259 0.279 0.299 0.319 0.339 0.359 0.379 0.399 0.419 0.439

Water Content - th[-], Min=0.219, Max=0.439

After time3 hr. of irrigation

0.219 0.239 0.259 0.279 0.300 0.320 0.340 0.360 0.380 0.400 0.421 0.441

Water Content - th[-], Min=0.219, Max=0.441

After time 6 hr. of irrigation

0.219 0.239 0.259 0.279 0.300 0.320 0.340 0.360 0.380 0.401 0.421 0.441

Water Content - th[-], Min=0.219, Max=0.441

After time 9 hr. of irrigation

0.218 0.239 0.259 0.279 0.300 0.320 0.340 0.360 0.381 0.401 0.421 0.441

Water Content - th[-], Min=0.218, Max=0.441

After time 12 hr. of irrigation

Figure 3. (Brooks and Corey, 1964) Simulation of wetting pattern a surface emitter for the sandy loam soil texture, with uptake by corn plant, with 60x80 cm domain, $\theta i=0.22$ (cm^3/cm^3), by volume and discharge 1 l/hr. After the time (3hr, 6hr, 9hr, and 12 hr.).
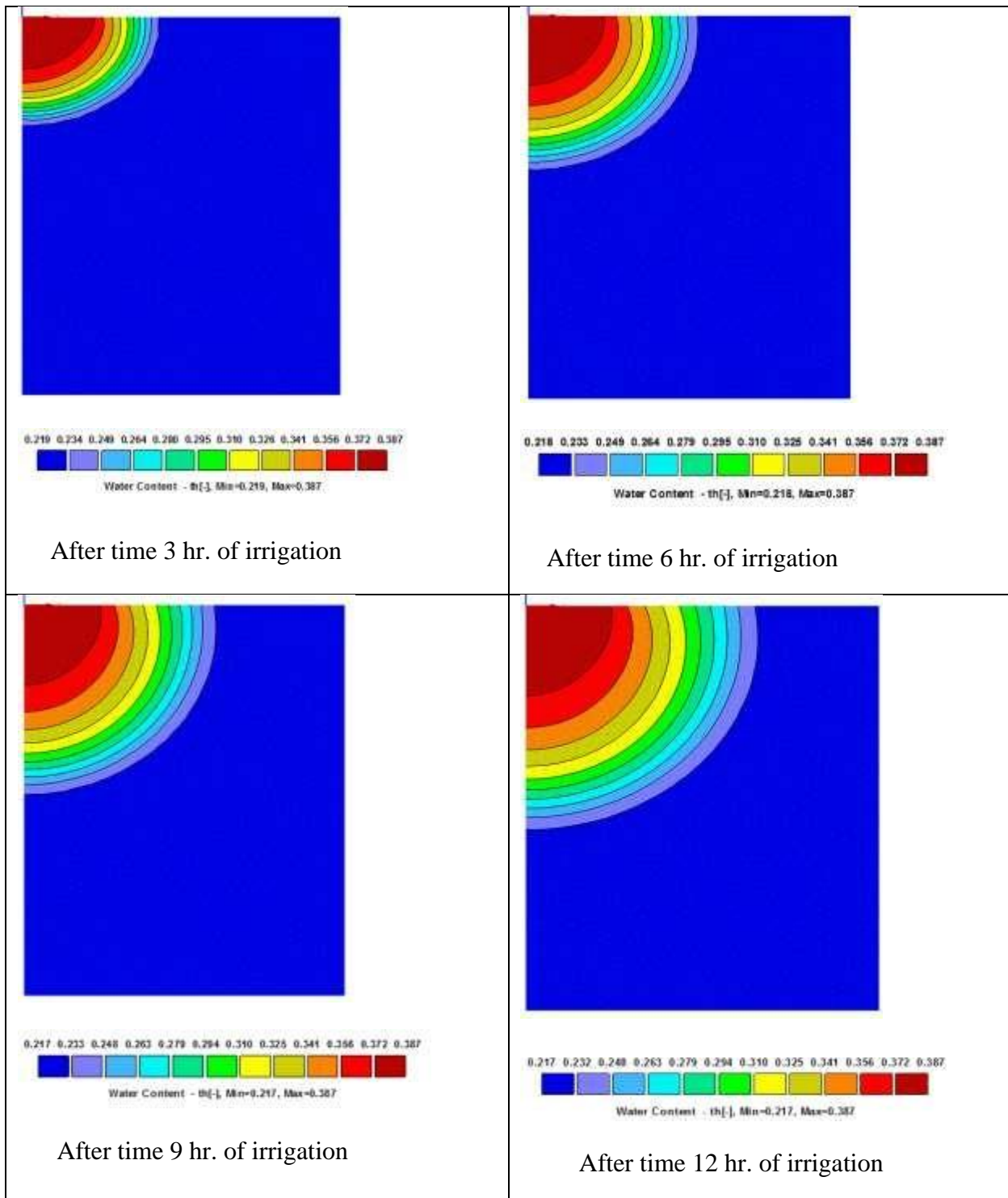
Figure 4. (Van Genuchten, 1980) Simulation of wetting pattern a surface emitter for the sandy loam soil texture, with uptake by corn plant, with 60x80 cm domain, $\theta i= 0.22$ (cm^3/cm^3), by volume and discharge 1 *l*/hr. After the time of (3 hr, 6 hr, 9 hr, and 12 hr).

0.174 0.195 0.216 0.238 0.259 0.280 0.301 0.323 0.344 0.365 0.386 0.407

Water Content - th[-], Min=0.174, Max=0.407

After time 3hr. of irrigation

0.174 0.195 0.216 0.238 0.259 0.280 0.301 0.323 0.344 0.365 0.386 0.407

Water Content - th[-], Min=0.174, Max=0.407

After time 6 hr. of irrigation

0.174 0.195 0.216 0.238 0.259 0.280 0.301 0.323 0.344 0.365 0.386 0.407

Water Content - th[-], Min=0.174, Max=0.407

After time 9hr. of irrigation

0.174 0.195 0.216 0.238 0.259 0.280 0.301 0.323 0.344 0.365 0.386 0.407

Water Content - th[-], Min=0.174, Max=0.407
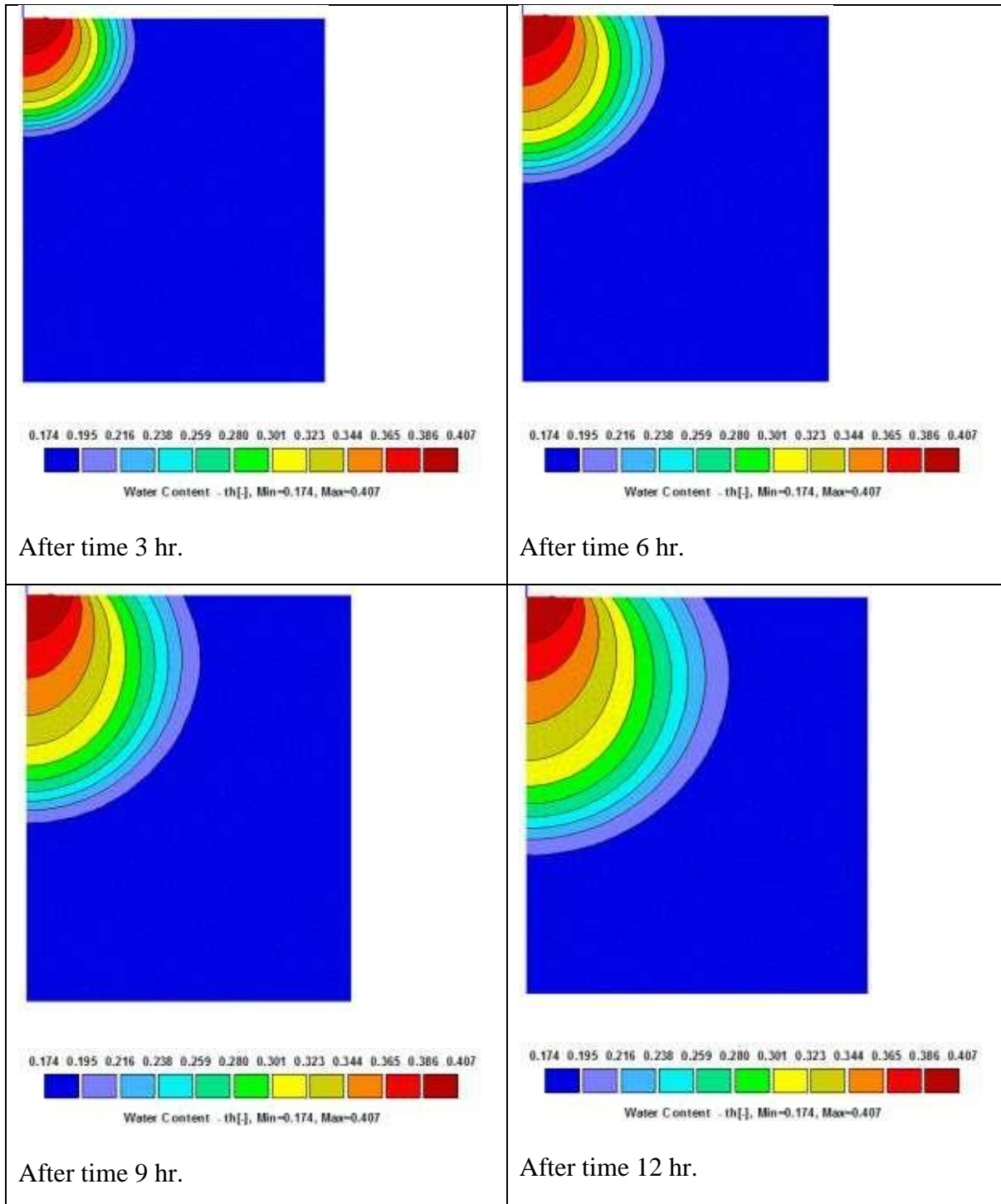
After time 12 hr. of irrigation
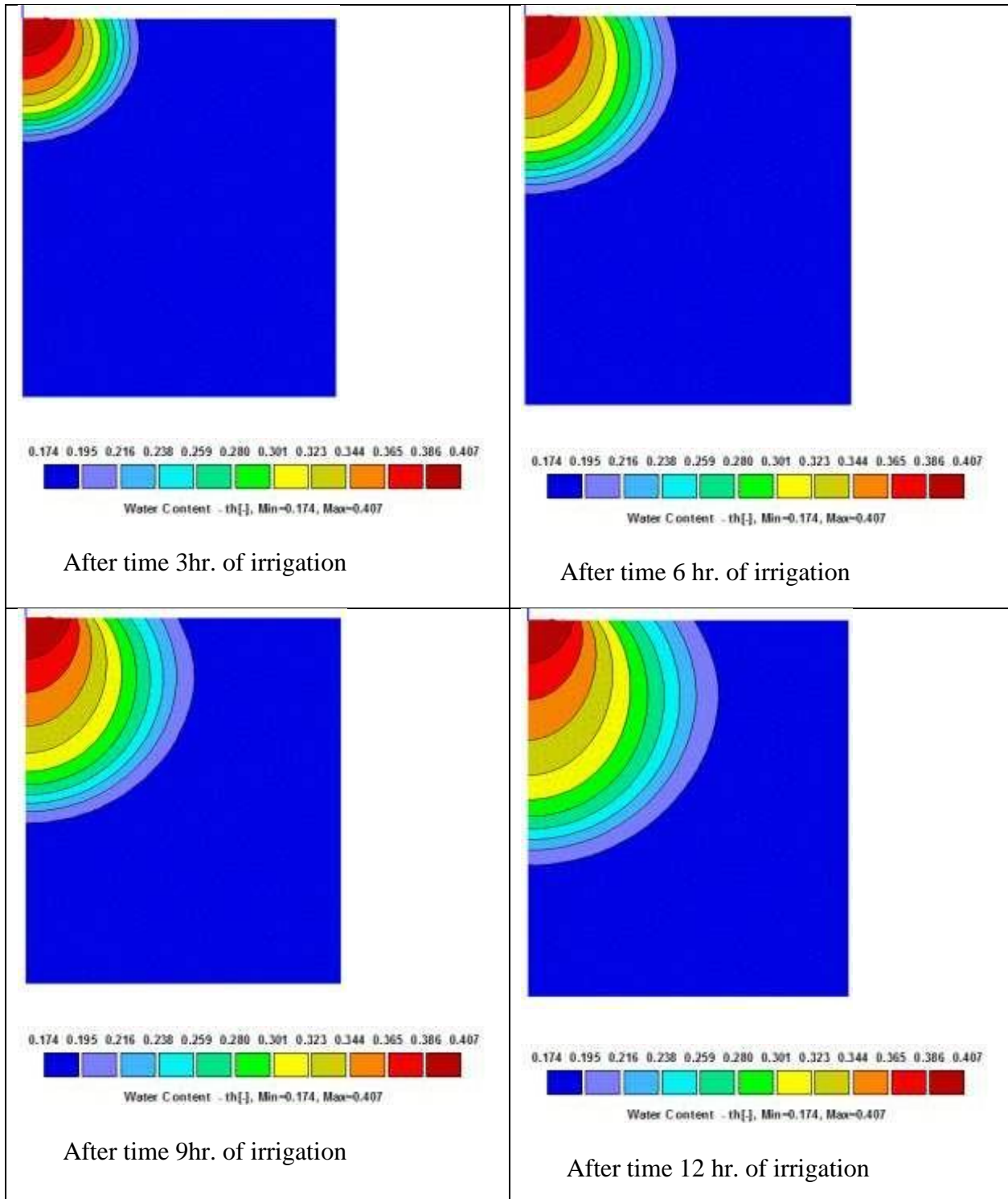
Figure 5. (Vogel and Císlerová, 1988) Simulation of wetting pattern a surface emitter for the sandy loam soil texture, with uptake by corn plant, with 60x80 cm domain, θ_i= 0.18 (cm^3/cm^3), by volume and discharge 1 l/hr. After the time of (3 hr, 6 hr, 9 hr, and 12 hr).

0.174 0.195 0.216 0.238 0.259 0.280 0.301 0.323 0.344 0.365 0.386 0.407

Water Content - th[-], Min=0.174, Max=0.407

After time 3 hr.

0.174 0.195 0.216 0.238 0.259 0.280 0.301 0.323 0.344 0.365 0.386 0.407

Water Content - th[-], Min=0.174, Max=0.407

After time 6 hr.

0.174 0.195 0.216 0.238 0.259 0.280 0.301 0.323 0.344 0.365 0.386 0.407

Water Content - th[-], Min=0.174, Max=0.407

After time 9 hr.

0.174 0.195 0.216 0.238 0.259 0.280 0.301 0.323 0.344 0.365 0.386 0.407

Water Content - th[-], Min=0.174, Max=0.407

After time 12 hr.

Figure 6. (Kosugi, 1996) Simulation of wetting pattern a surface emitter for the sandy loam soil texture, with uptake by corn plant, with 60x80 cm domain, $\theta i = 0.18$ (cm^3/cm^3), by volume and discharge 1 l/hr. After the time of (3 hr, 6 hr, 9 hr, and 12 hr).

Table 4. Comparison of the measured and simulated wetted radius by HYDRUS using **Brook and Corey, 1964** model for sandy loam soil texture.

Plant type	Q l/hr.	Time hr.	*Measured from Khalil,2018	**HYDRUS	Relative error%	EF	RMSE
Tomato	1.45	0.5	23	18.22	20.78	1	9.48
		1	25	20.59	17.64		
		1.5	26	22.51	13.42		
		2	28	24.13	13.82		
		2.5	30	25.34	15.53		
Corn	1.30	3	24	25.20	-5	1	1.2

*By using **Khalil (2018)**.
By using **HYDRUS model.

Table 5. Comparison of the measured and simulated wetted radius by using **Van Genuchten, 1980,** model for sandy loam soil texture.

Plant type	Q l/hr.	Time hr.	*Measured from Khalil,2018	**HYDRUS	Relative error%	EF	RMSE
Tomato	1.45	0.5	23	19.96	13.22	1	5.26
		1	25	22.46	10.16		
		1.5	26	24.43	6.04		
		2	28	26.03	7.04		
		2.5	30	27.35	8.83		
Corn	1.30	3	24	26.33	-9.71	1	2.33

*By using **Khalil (2018)**.
By using **HYDRUS model.

Table 6. Comparison of the measured and simulated wetted radius by using **Vogel and Císlerová (1988)** model for sandy loam soil texture.

Plant type	Q l/hr.	Time hr.	*Measured from Khalil,2018	**HYDRUS	Relative error%	EF	RMSE
Tomato	1.45	0.5	23	16.60	27.83	1	13.08
		1	25	19.21	23.16		
		1.5	26	20.99	19.27		
		2	28	22.23	20.61		
		2.5	30	23.52	21.60		
Corn	1.30	3	24	23.37	2.63	1	0.63

 *By using **Khalil (2018)**.
 By using **HYDRUS model.

Table 7. Comparison of the measured and simulated wetted radius by using **Kosugi (1996),** model for sandy loam soil texture.

Plant type	Q l/hr	Time hr	*Measured from Khalil,2018	**HYDRUS	Relative error%	EF	RMSE
Tomato	1.45	0.5	23	16.50	28.26	1	13.11
		1	25	19.17	23.32		
		1.5	26	21.00	19.23		
		2	28	22.37	20.11		
		2.5	30	23.65	21.17		
Corn	1.30	3	24	23.48	2.17	1	0.52

 *By using **Khalil (2018)**
 By using **HYDRUS model.

Table 8. Comparison of wetted radius and wetted depth simulated by HYDRUS -2 D with those simulated by various techniques for **Brook and Corey, 1964.**

Emitter discharge l/hr.	Time hr.	Wetted radius r, cm		Relative error %	EF	RMSE
		HYDRUS	Selim, 2013			
1.01	3.67	23.23	23	-1	1	0.23
		Wetted depth z, (cm)				
		21.01	22	4.5	1	0.99

Table 9. Comparison of wetted radius and wetted depth simulated by HYDRUS -2 D with those simulated by various techniques for **Van Genuchten, 1980.**

Emitter discharge l/hr.	Time hr.	Wetted radius r, cm		Relative error %	EF	RMSE
		HYDRUS	Selim, 2013			
1.01	3.67	24.62	23	-7.04	1	1.62
		Wetted depth z, (cm)				
		21.11	22	4.05	1	0.89

Table 10. Comparison of wetted radius and wetted depth simulated by HYDRUS -2 D with those simulated by various techniques for **Vogel and Císlerová (1988).**

Emitter discharge l/hr.	Time hr.	Wetted radius r, cm		Relative error %	EF	RMSE
		HYDRUS	Selim, 2013			
1.01	3.67	22.02	23	4.26	1	0.98
		Wetted depth z, (cm)				
		25.90	22	-17.73	1	3.9

Table 11. Comparison of wetted radius and wetted depth simulated by HYDRUS -2 D with those simulated by various techniques for **Kosugi, (1996).**

Emitter discharge l/hr.	Time hr.	Wetted radius r, cm		Relative error %	EF	RMSE
		HYDRUS	Selim,2013			
1.01	3.67	22.03	23	4.22	1	0.97
		Wetted depth z, (cm)				
		25.58	22	-16.27	1	3.60

8. CONCLUSIONS

1-Soil wetting pattern from a single surface drip irrigation was dependent on the drip of discharge, time of duration, hydraulic soil properties, and root water uptake.

2-The HYDRUS program solves Richards's problems numerically convection-dispersion equation for saturated-unsaturated water flow and heat and solution conveyance equation.

3-The flow equation features a sink term to calculate for plant roots taking up of water.

4-Comparison of the simulated wetted radius and wetted depth obtained by HYDRUS with experiment data of (**Selim, 2013**) for sandy loam soil with crop tomato at drip discharge 1.01 l/hr and initial water content 0.15 cm^3/cm^3.

5-The estimated wetted radius and depth simulated by HYDRUS (2D/3D) software model were in good agreement with the measured values data of (**Selim, 2013**).

6-The relative error used to the different hydraulic soil models, by the model of **Brook and Corey, 1964,** is in good agreement compared with different models.

7-The RMSE was 0.23cm, while the relative error -1% and 1% for EF for wetted radius. For wetted depth the RMSE was 0.99 cm and relative error 4.5% and 1% for EF for the model of **Brook and Corey, 1964**.

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10.NOMENCLATURE

θ= Volumetric soil moisture, (cm^3/cm^3)
θi= Initial water content, (cm^3/cm^3)
θr= Residual water content, (cm^3/cm^3)
θs= Saturated water content, (cm^3/cm^3)
r = Radial (horizontal) coordinate, (cm),
K(h)= Unsaturated hydraulic conductivity, (cm/hr),
Ks= Saturated hydraulic conductivity, (cm/hr),
S(h)= A sink term that explain the root water uptake expressed as a water volume that removed from a unit volume of soil per unittime , ($cm^3 cm^{-3}/hr$),
h= Soil water pressure head,(cm),
α = Inverse of the air-entry value, 1/cm.
n = Pore size distribution index, dimensionless.
Z= Drip depth, (cm),
t = Time, (hr),
Q= Trip discharge, (*l*/hr).