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Evaluation of water flow and infiltration using HYDRUS model in sprinkler irrigation system

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Abstract. HYDRUS model is one of the advanced models, which is applied in soil & water system for simulation of water flow, moisture distribution, and solutes transport. In the present research, water movement in soil in the sprinkler irrigation system is studied. With regard to primary information of water & soil, soil physical and empirical parameters are estimated based on constituent particles. Cumulative value of input flow in upstream, cumulative value of root absorption and cumulative value of output flow in downstream are of other results. Variations in absorption, moisture, hydraulic conductivity and flow in relation to depth are determined in different period of simulation. Also, moisture characteristic curve of the studied soil and the relation between absorption and Hydraulic conductivity are specified.

Keywords: Simulation, Sprinkler Irrigation, HYDRUS Model

1. Introduction

The relations between water, soil and plant could be considered as a complex system, in which all the elements of the system influence one another and their performance. None of the processes in this complex could be considered simple, independence and separate. Hence, with regard to the complexity of this porous medium, their elements and behaviors should be simulated. HYDRUS model is one of the models that could simulate movement of water, heat and solute in saturated and unsaturated conditions. This software has been made in California University (4 & 5). Considering its complexity, sometimes we could analyze the process of this chain separately, in order to make the problem and its expression easy. In a water, soil & plant system, rainfall, irrigation and capillarity rise, are inputs of unsaturated area. Deep permeation and drainage are output of the unsaturated area. Also, evapotranspiration from soil & plant are considered as outputs. HYDRUS software has the ability to simulate the movement of water, solute, heat, carbon dioxide, and the water absorption by root, in both saturated & unsaturated areas. HYDRUS model and its capabilities have been shown in figure (1). As it is shown in the figure, water flow, solute & heat transport are the main parts of this model, in calculation of each some factors are involved, that the most important of them are soil hydraulic parameters in water movement calculation and the governing equitation in each calculation.

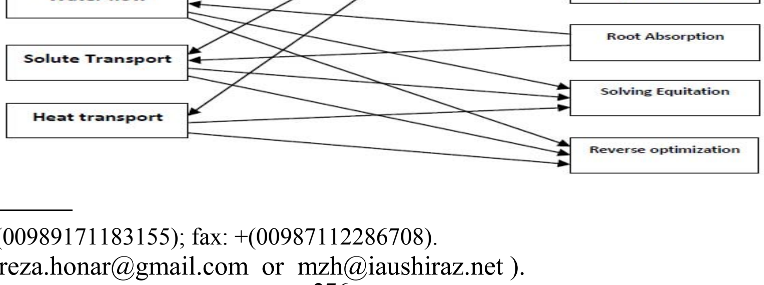

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Fig. 1: HUDRUS model and its constituents

1.1. Model theory:

Governing Equitation

Richards equitation is the governing equitation, which is applied in unsteady conditions. Richards equitation is shown in one-dimensional mode (equitation 1) and two-dimensional mode (equitation 2), (1,4,5).

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left[K(\theta)(\frac{\partial h}{\partial x} + \cos\alpha)\right] - S \quad [1]$$

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i}\left[K(K_{ij}^{A}\frac{\partial}{\partial x_j} + K_{iZ}^{A})\right] - S \quad [2]$$

Ɵ: Volumetric moisture

K (Ɵ): Unsaturated hydraulic conductivity

H: Matrix potential

α: Angle between flow path and vertical axis

S: Water intake by root

x: Distance

t: Time

HYDRUS model solves Richards equitation using linear finite elements pattern, for simulation of water movement in soil (2).

Software process & model implementation

This software acts in three stages of pre-processing, calculation, and post-processing.

Inputs in pre-processing:

- The main processing menu: At this part, considered simulation should be selected.
- Geometric Data
- Time Data
- Information about Results Print
- Numerical Solution Conditions
- Soil Hydraulic Properties

Calculation Steps are as follows:

1- Solving governing equitation (Richards equitation) using finite element method (Equitation 1 for one-dimensional mode and equitation 2 for two-dimensional mode)
2- Calculation of absorption & moisture values in successive iteration based on specified time steps.
3- Comparison of absorption & moisture values between two successful iteration as compared with solving accuracy (tolerance) given to the model
4- Provided that, Δh or Δθ is larger than the given accuracy, the continuation of calculations goes to the next iteration and if Δh or Δθ is smaller than the given accuracy, calculations is done at the next time step.

This software starts calculations by performing a model with an initial time step, and then compares the obtained values in iteration to the given accuracy, eventually, arrange and modified values according to maximum & minimum time steps specified in software.

The output data of the model includes: simulation time, number of iterations in each time step, total cumulative of the number of iterations, flow variations in upstream border, total cumulative input flow in upstream, total cumulative water absorption by root, total cumulative output flow in downstream, Matrix potential in upstream, downstream and by root.

HYDRUS model is used in field and laboratory works, to simulate water flow, soil hydraulic properties, solute and co2 transport. In using this model, several studies have been done, some of them are mentioned at follows. In a research, HYDRUS software was studied for transferring main ions (calcium, magnesium, sodium, potassium, sulfate and chloride) in different temperature and its relation with ion chemical equilibrium. The results have indicated that this software could be a powerful tool in irrigation management for estimating the effect of irrigation water quality on soil and underground waters; also it could be effective in the completion of irrigation & fertilization in planning & irrigation projects. Moreover, this software was successful in simulation of irrigation and could study well the effect of different waters and soil chemistry (3). In another study, this software was used to simulate of farm's water & soil conditions using real data and for corn cultivation in France. With regard to two-dimensional simulation power, this software could be applied for better management & design of Faroe irrigation. It also has the ability to analyze and estimate the ability of Faroe irrigation system (7). In another research, which is the simulation of soil moisture distribution in drip irrigation system using HYDRUS2D software, moisture distribution was done vertically and horizontally in radish plant root area. Also, deep leaching was done through modeling root area medium. In this research, results from field and laboratory analysis were given to the model. Results indicated that with which irrigation and rate of flow, moisture could be kept at farming capacity (1). Therefore, the purpose of the present research is to use HYDRUSID model for simulation of water movement in soil, analysis & evaluating of soil hydraulic parameters variation with regard to depth during irrigation.

2. Methodology

In the present research, in order to simulate water movement in soil, HYDRUS model is used. Initial data to be entered to the model are: Components of the studied soil in percent dissociation: sand: 22%, silt: 43%, clay: 35%. The depth of the studied soil is 1 meter and single layer. Initial soil moisture was measured 15%, the used sprinkler intensity is 6.6mm/hour and the irrigation period is 12 hours. As it was mentioned before, one of the properties of this model is to consider mass balance in time steps. In the present research, providing balance in the whole soil profile is intended. Starting time of calculations were considered as zero, and its termination time was considered 720 minute based on irrigation time period. As mentioned before, model performs simulation based on variable time steps. Therefore, we considered a primary Δt, is equal to one for the model. Then, data are checked once in the output, considering that the flow is constant in the whole period of simulation. Also, the number of outputs has been considered to be 8, for more accurate analysis of simulation to modify outputs every 90 minutes, which includes; flow, moisture and absorption value. Considering the fact that the governing equitation is Richards equitation and it should be solved with iteration method, therefore, solving accuracy is given to the model. The number of iterations is considered 20; and generally, the model reaches the answer with 4 to 6 iteration. In time step stage, optimal range of iteration is considered in both upper and lower limit of 3 & 7. Also, in order to give accuracy to the model and selecting the most appropriate value of Δt, in time step control section, some values and coefficients should be given to the model for minimum and maximum optimal iterations. In this way, if obtained value of Δt is small, the model can large Δt by applying coefficient with the amount of 1.3, and if obtained amounts of Δt is large, the model can small Δt by applying coefficient with the amount of 0.7.

Then based on soil constituent percentage, residual moisture parameter, saturated moisture, saturated hydraulic conductivity and empirical values of equitation, are identified, using neural network estimation in the existent model. The amount of these values is shown in table (1). Model boundary condition in upstream is considered as constant flow intensity and in downstream is considered as free drainage. Input flow intensity rate is defined -0.011 cm/minute to the model as upstream boundary condition.

3. Results

The values of soil estimated by the model based on percentage of constituent particles are shown in table1.

Table1: Estimated physical and empirical parameters based on soil constituent particles

$(\frac{cm^3}{cm^3})\ \theta_r$	$(\frac{cm^3}{cm^3})\ \theta_s$	$(\frac{cm}{d})\ K_s$	α	n	l
0.0874	0.4594	12.09	0.0103	1.4401	0.5

Cumulative values of input flow in upstream is cumulative values of root absorption and cumulative values of output flow from downstream boundary. In the present research, with regard to the absence of root absorption, its value is zero, and the cumulative value of output flow from downstream is 0.22×10^{-5} cm, which is approximately equal to zero. Because, the upstream boundary is in direct contact with water and is approximately saturated, absorption in upstream is minimal and close to zero after 720 minute. Matrix potential in downstream is equal to -5554.3 cm and is constant during simulation period (figure 2 & 3). Variations of matrix, moisture, hydraulic conductivity and flow with regard to depth in different periods of simulation are shown in figures (4 to 7). In mentioned figures, with regard to 720 minute and 8 period of simulation, results are shown, once every 90 minutes. The studied soil moisture characteristic curve and the relation of matrix with hydraulic conductivity are shown in figures (8 & 9).

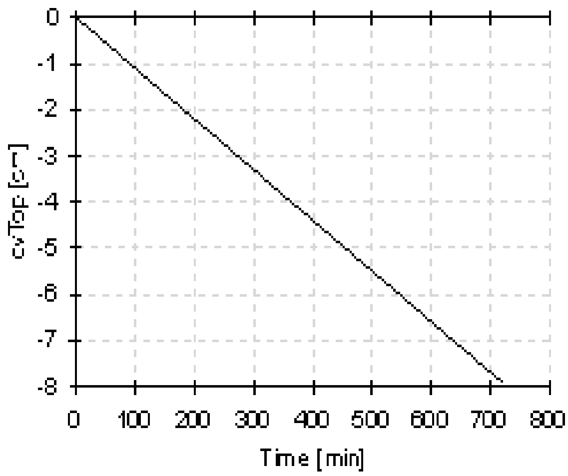

Fig. 2: Cumulative values of input flow in downstream

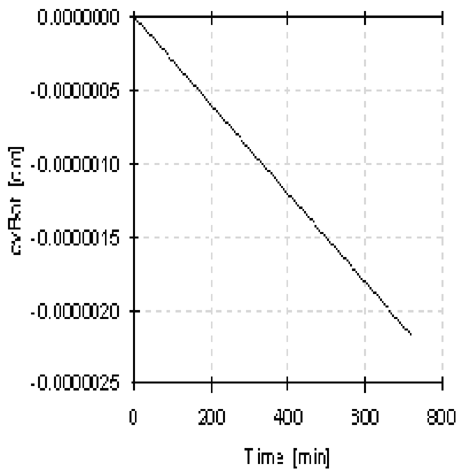

Fig. 3: Cumulative values of input flow in upstream

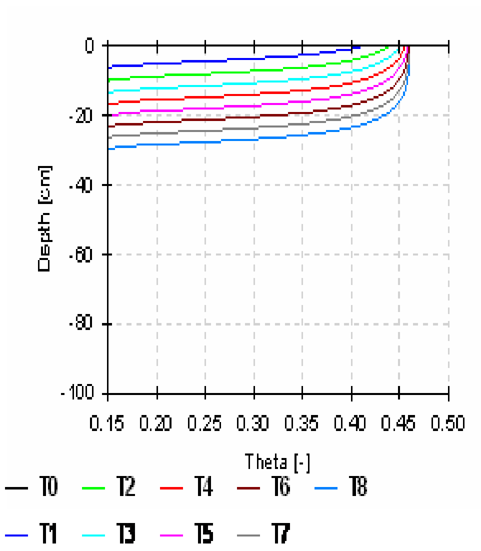

Fig. 4: Variations of moisture to depth in different periods

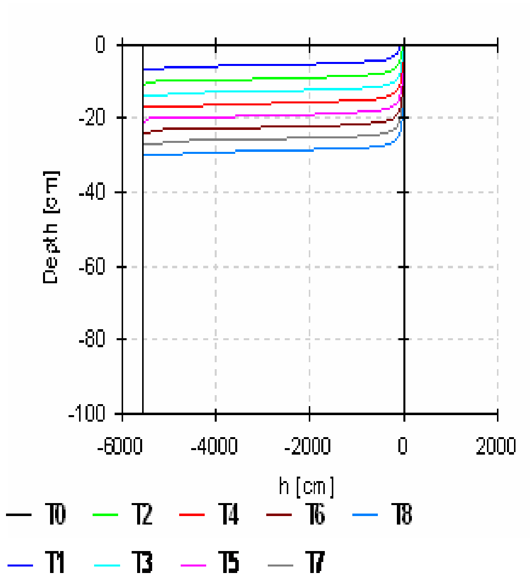

Fig. 5: Variations of matrix to depth in different periods

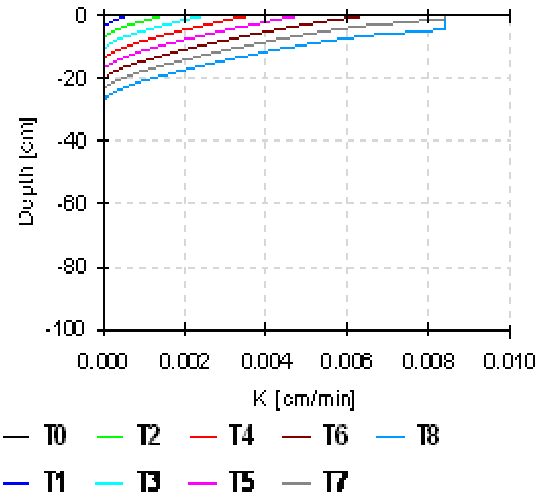

Fig. 6: Variations of flow in different periods

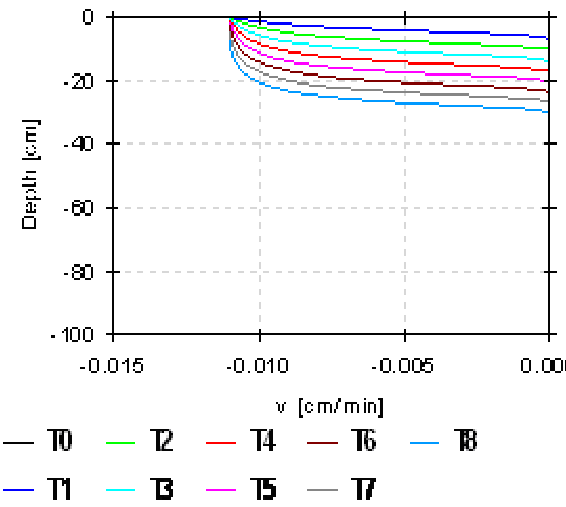

Fig. 7: Variations of hydraulic conductivity to depth in different periods

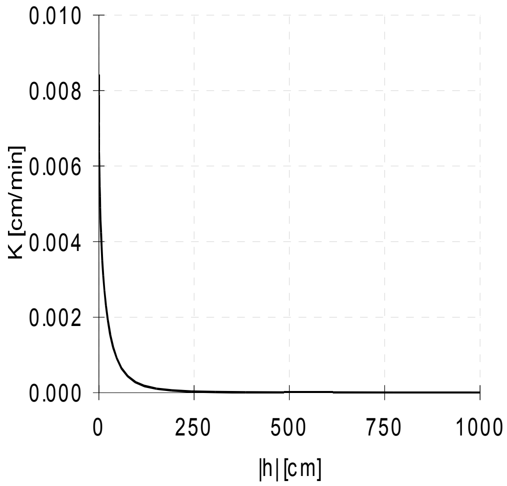

Fig. 8: Relative between hydraulic conductivity & matrix

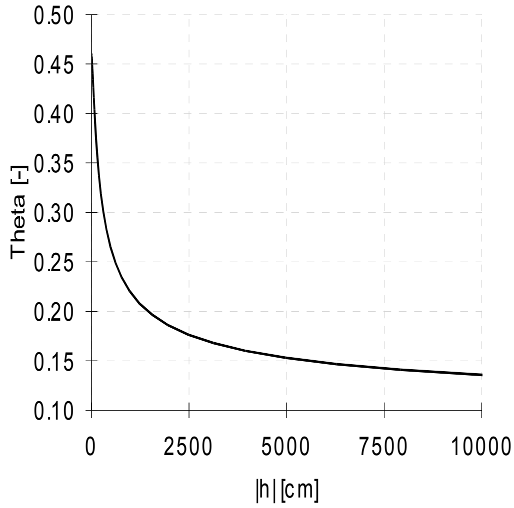

Fig. 9: Soil moisture characteristic curve

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