Numerical Simulations of Soil Water Dynamics under Surface Drip Irrigation Using HYDRUS-2D

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Abstract. Irrigated agriculture plays a crucially important role in food production worldwide. Micro-irrigation has proved an effective approach to optimise and potentially save water use in agriculture. In this study, numerical simulations using HYDRUS-2D were performed to investigate soil water dynamics after surface drip irrigation on a clay loam soil. Two emitter radii of 5 cm and 10 cm for drip irrigation were assumed. The initial soil water content was set at the point that trigged irrigation, and the soil at the water discharge surface remained saturated during irrigation. Results showed that the irrigated amount of water for the emitter radius of 10 cm was 1.07, 1.97 and 2.86 L for the irrigation durations of 1, 2 and 3 h, respectively, about 1.55, 1.66 and 1.48 times higher than those for the emitter radius of 5 cm. Correspondingly, the soil wetting depth for the emitter radius of 10 cm was 13.5, 18.4 and 21.0 cm, respectively, about 20.1%, 35.8% and 22.5% higher than those for the emitter radius of 5 cm.

1. Introduction

Irrigated agriculture plays an important role in food production worldwide. A huge amount of water is wasted due to over application of irrigation or inefficient irrigation methods. As a result, water resources are increasingly becoming scarce.

It is well accepted that micro irrigation is an effective method to use water in agriculture efficiently. Nowadays, drip irrigation has widely been applied and shown its great potential in saving agricultural water [1-3]. Numerous studies have also been carried out to use numerical models to optimize irrigation scheduling and amount. Amongst all the simulation tools, HYDRUS software package [4, 5] has been widely and successfully used, and achieved a large body of practically useful results [6-9].

In this study, HYDRUS-2D was employed to investigate soil water movement during and after surface drip irrigation on a clay loam soil with the emitter radii of 5 cm and 10 cm. The simulated results, including water infiltration amount and soil wetting depth, could potentially be useful for managing agricultural water use.

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2. The theory

2.1. Governing equations for soil water movement

The Richards' equation, describing soil water movement under axis-symmetric conditions for drip irrigation, can be expressed as:

$$\frac{\partial \theta}{\partial \mathrm{t}} = \frac{1}{r}\frac{\partial}{\partial r}\left[rK(\theta)\frac{\partial \mathrm{h}}{\partial \mathrm{r}} \right] + \frac{\partial}{\partial z}\left[K(\theta)\frac{\partial \mathrm{h}}{\partial z} \right] + \frac{\partial K(\theta)}{\partial \mathrm{z}} \tag{1}$$

$$\Theta = \frac{\theta - \theta_{\mathrm{r}}}{\theta_{\mathrm{s}} - \theta_{\mathrm{r}}} = \left[\frac{1}{1 + |\alpha \mathrm{h}|^{\mathrm{n}}} \right]^{\mathrm{m}} \tag{2}$$

$$K(h) = K_s \Theta^{0.5}[1 - (1 - \Theta^{1/\mathrm{m}})^{\mathrm{m}}]^2 \tag{3}$$

Where θ is the volumetric soil water content, h is the soil pressure head, z is the vertical coordinate, r is the radial coordinate, t is the time, K is the soil hydraulic conductivity, θ_s and θ_r are the saturated and residual soil water content, respectively, α and n are the shape parameters, respectively, $\mathrm{m} = 1 - 1/\mathrm{n}$, K_s is the saturated soil hydraulic conductivity, Θ is the relative saturation.

2.2. Model parameter values and initial conditions

The simulated soil was a clay loam type with the hydraulic properties shown in Table 1 [10]. The initial soil water content was set to be at the mid-point between the field capacity and the permanent wilting point, below which crop transpiration was limited for most crops and thus irrigation was required [11].

Table 1. The soil hydraulic parameters used in the simulations [10]

θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n (-)	K_s (cm/d)
0.410	0.095	0.019	1.31	6.24

The computed domain was 30 cm in the vertical direction and 25 cm in the radial direction. Two emitter radii of 5 cm and 10 cm were used. The soil was assumed to be saturated within the emitter radius during irrigation, and the irrigated amount was simulated.

3. Results and discussion

3.1. Water infiltration

The simulated cumulative water infiltration under irrigation radius of 5 cm and 10 cm is shown in Figure 1. Basically the relationship between the cumulative infiltration and time was in a linear manner. In terms of the infiltrated depth of water, it is about 61.2% greater under the radius of 5 cm than that under the radius of 10 cm. This may be attributed to the fact that under the radius of 5 cm the irrigated water has a larger volume of soil to permeate, resulting in a faster infiltration rate. However, in terms of the total irrigated amount, the opposite was found to be the case. The total irrigated amount of water for the irrigation radius of 10 cm was 1.07, 1.97 and 2.86 L after 1, 2 and 3 h irrigation, respectively, about 1.55, 1.66 and 1.48 times higher than those for the irrigation radius of 5 cm.

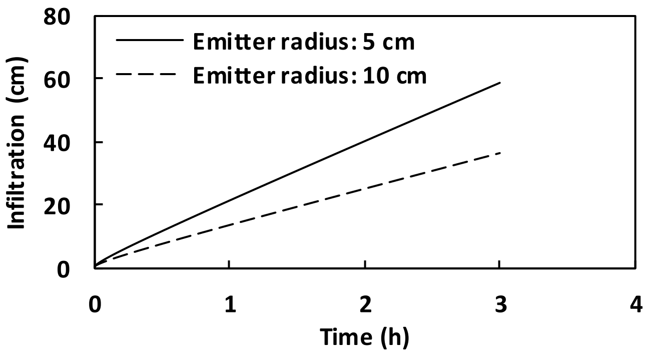
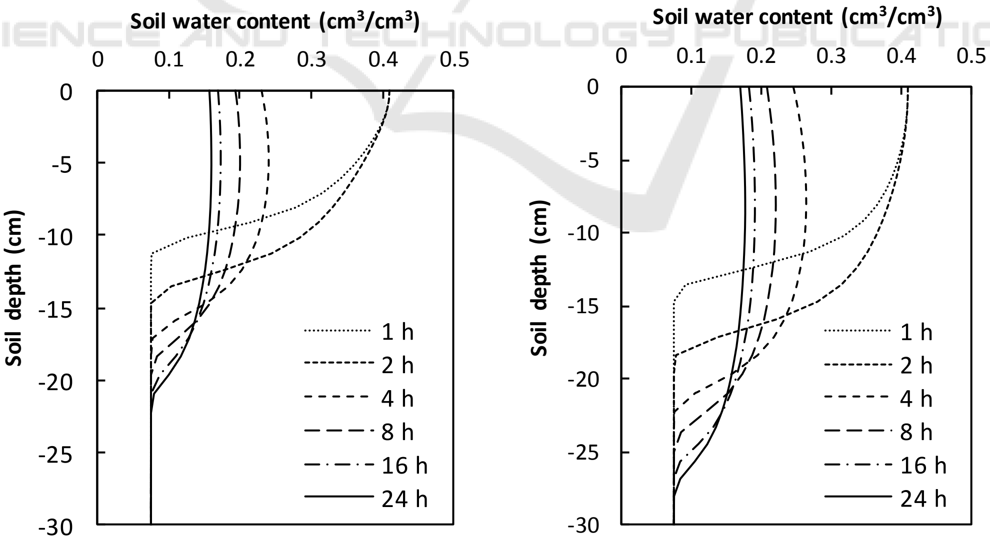


Figure 1. The simulated cumulative infiltration under different emitter radii.

3.2. Vertical soil water content distribution

Figure 2 shows the vertical soil water distribution at different time intervals for the irrigation duration of 2 h. Generally speaking, the patterns of soil water content distribution were similar with each other in both cases. In the upper region, soil water content was close to be saturated during irrigation, and then decreased with time due to re-distribution. Compared with those of the emitter radius of 5 cm, the wetting depth and the wetted soil volume were both greater for the emitter radius of 10 cm. For example, the wetted soil volume was about 10.0 and 52.4 L at the time intervals of 1 h and 8 h for the irrigation radius of 5 cm, while the corresponding values were about 5.0 and 22.8 L for the irrigation radius of 10 cm.



(a) Emitter radius: 5 cm. (b) Emitter radius: 10 cm.

Figure 2. The variation of soil water content distribution in the vertical direction with time (irrigation duration: 2 h).

3.3. Soil water content contour

The simulated soil water content contour at time intervals for the emitter radius of 5 cm and irrigation duration of 2 h is shown in Figure 3. It can be seen that the wetted distance in the vertical and radial directions was approximately identical. The irrigated water was stored in the volume of about 10.2 L after 2 h irrigation, and the volume increased to about 29.8 L after 24 h. The final water content in the wetted region was relatively uniform, ranging from 0.1 to 0.15 cm^3/cm^3. This indicates that water flow in the soil was relatively easy due to the good capacity of water drainage.

3.4. Wetting depth

The effects of irrigation radius and time on soil wetting depth are given in Figure 4. Clearly, the wetting depth increased more rapidly with time during irrigation and shortly after irrigation. The increase rate of the wetting depth was much smaller after 5 h for all the simulated cases. The emitter radius was positively related to the soil wetting depth. For example, the final wetting depth was 29.1 cm for the emitter radius of 10 cm and irrigation duration of 3 h, while the value was reduced to 21.7 cm for the emitter radius of 5 cm. For the same emitter radius, a longer irrigation duration resulted in a bigger soil wetting depth, but they were not proportionately correlated.

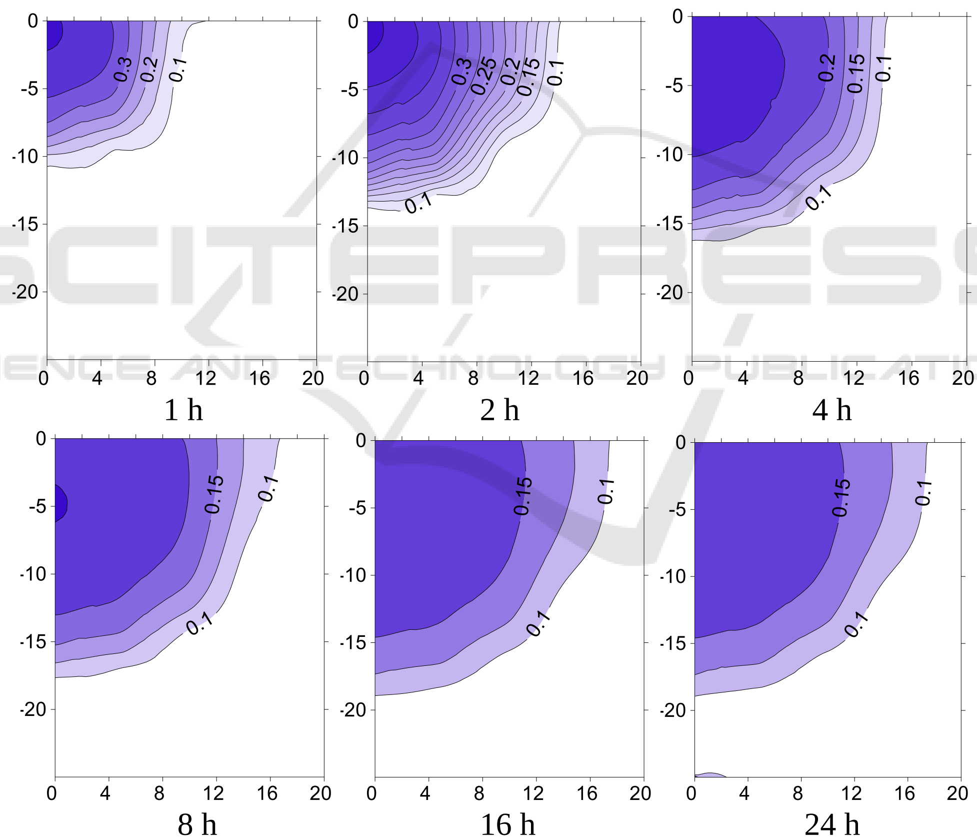
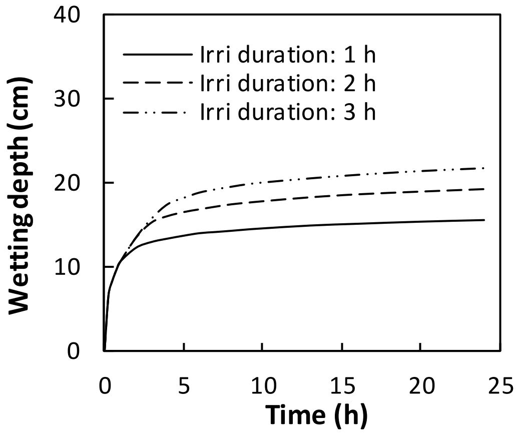
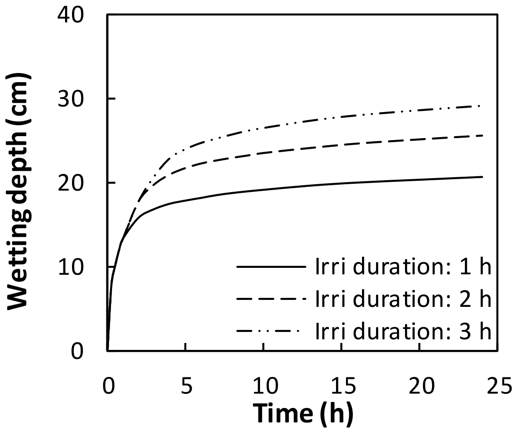


Figure 3. Soil water content contour at different time intervals after the beginning of irrigation (emitter radius: 5 cm, irrigation duration: 2 h).



(a) Emitter radius: 5 cm.



(b) Emitter radius: 10 cm.

Figure 4. Effects of the emitter radius and irrigation duration on the soil wetting depth.

4. Conclusions

Based on the results presented the above, the following conclusions could be drawn: (1) The cumulative infiltration amount was approximately linearly correlated with time in the studied cases. (2) The soil wetting distance in both the vertical and radial directions was close to each other. (3) The soil wetting depth was positively correlated with irrigation radius and irrigation time, but they were not proportionately related.

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References

[1] Sezen S, Yazar A and Eker S 2006 Effect of drip irrigation regimes on yield and quality of field grown bell pepper *Agric Water Manage* **81** 115
[2] Trout T, Imunek J, Shouse P and Skaggs T 2004 Comparison of hydrus-2d simulations of drip irrigation with experimental observations *J. Irrig. Drain. Eng.* **130** 304
[3] Ayars J, Phene C, Hutmacher R, Davis K and Schoneman R 1999 Subsurface drip irrigation of row crops: a review of 15 years of research at the water management research laboratory *Agric Water Manage* **42** 1
[4] Šimůnek J, Genuchten M T V and Šejna M 2008 Development and applications of the hydrus and stanmod software packages and related codes *Vadose Zone J.* **72** 587
[5] Nakhaei M and Šimůnek J 2014 Parameter estimation of soil hydraulic and thermal property functions for unsaturated porous media using the hydrus-2d code *J. Hydro. Hydromech.* **62** 7
[6] Wu Z and Huang M 2011 Analysis of influential factors for maize root water uptake based on Hydrus-1D mode *Transact Chinese Soc. Agric. Eng.* **27** 66
[7] Ma H, Yang D, Lei H, Cai J and Kusuda T 2011 Application and improvement of Hydrus-1D model for analyzing water cycle in an agricultural field *Transact. Chinese Soc. Agric. Eng.* **27** 6
[8] El-Nesr M, Alazba A and Šimůnek J 2014 HYDRUS simulations of the effects of dual-drip subsurface irrigation and a physical barrier on water movement and solute transport in soils *Irri. Sci.* **32** 111

[9] Pinho R and Miranda J 2014 Evaluation of HYDRUS-1D to simulate water and potassium transport in two laboratory tropical soil columns *Engenharia Agrícola* **34** 899

[10] Šimůnek J, van Genuchten M Th and Kodešová R 2013 *Proceedings of the 4 th International Conference "HYDRUS Software Applications to Subsurface Flow and Contaminant Transport Problems"* (Czech University of Life Sciences, Prague, Czech Republic) p 404

[11] Allan R, Pereira L, Raes D and Smith M 2005 Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements *FAO Irrigation and Drainage Paper 56*