Research Journal of Soil and Water Management 1 (3-4): 76-84, 2010
ISSN: 2075-1095

Evaluation of Soil Water Percolation in Response to Different Rainfall Conditions using HYDRUS-1D Model in the Low Hill Red Soil Region of Jiangxi, China

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Abstract: Soil water plays an important role in the process of formation, transformation and consumption of water resources and its quantity and existing form is closely related to the growth and development of crops. As for plants, soil water use efficiency is to a large extent constrained by soil water content and storage which are affected by many factors in different degree. Among them, soil water percolation is one of the main reasons to cause soil water loss. Previous research indicated that percolation loss is one of the most important ways of water and nutrients loss from agricultural soil. In most cases, natural rainfall and unrational irrigation easily lead to soil water percolation loss. In order to understand the response of soil water percolation to different rainfall conditions for subsequent assessment of associated nitrogen loss, a numerical model has been used to simulate the soil water percolation rates under different rainfall scenarios in this study. Results indicated that soil water percolation rate was highly correlated to the rainfall intensity. For the same total amount of rainfall in a certain time period, the total amount of soil water percolation for rainfall events of low frequency and high intensity was greater than that for rainfall events of high frequency and low intensity. On the other hand, the percolation rate was relevant to the preceding rainfall events. Multiple rainfall events in a relatively short period will result in a peak percolation rate.

Key words: Soil water percolation, rainfall conditions, numerical investigation, HYDRUS-1D, intensity, China

INTRODUCTION

Soil water plays an important role in the process of formation, transformation and consumption of water resources and it has very close links with agricultural production, forestry production, hydrology and climate change, etc. It is known that soil water is the uppermost water source that maintain the growth and development of crops and the virtuous circle of ecological environment. All the water required for the growth and development of crops cannot be absorbed by crops untill they are transformated into soil water. So soil water quantity and quality have a direct impact on the growth and development of crops. As for agricultural crops, most of the water for the growth needing by root absorption derived from farmland soil water especially root zone soil water. Furthermore how much surface soil water content and its effectiveness are affected by many factors in different degree such as soil structure, soil water percolation, soil evaporation, natural rainfall, crop transpiration, irrigation and groundwater level, etc. Among them, soil water percolation is one of the main ways of soil water leaching loss. Moreover, soil water percolation is closely related to the leaching losses of soil salt, nutriments and pollutants, etc. Because of unreasonable agricultural water management in some areas, percolation intensity of soil water is quite higher which further lead to many other environmental problems

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such as soil secondary salinization, shallow groundwater eutrophication, excessive heavy metal and pesticide accumulation in groundwater etc. (Johns and McConchie, 1994; Ryan, 1998; Mitra *et al*., 2007). In order to make good use of soil water resources, it is important to clearly explain the percolation mechanism of the soil water from the surface soil layer to the deep soil layer. In the past times, many researches were carried out to reveal the percolation mechanism of the soil water by using the isotope tracer method, weighing lysimeter, water balance method and numerical modeling, etc. Chapman and Malone, 2002; Green *et al*., 2005; Meißner *et al*., 2010; Benson *et al*., 2001; Ochoa *et al*., 2007; Song and Yanful, 2010). Many studies have shown that the percolation intensity of the soil water is affected by lots of factors such as soil texture, soil structure, soil density, water table conditions and hydraulic loading etc. (Fravolini *et al*., 2005; Ghodrati and Jury, 1992; Sophocleous, 2002; Edwards *et al*., 1992). However, previous research has been insufficient to the deep understanding of the percolation mechanism of the soil water under different rainfall conditions and further studies are still necessary to clarify the effect of different factors on soil water percolation. So there was decided to develop field position location monitoring and provide more data to study water leaching loss through the surface soil to the deeper soil and even the groundwater reservoir in the red soil regions of China. Unlike previous studies, the research emphatically studied the influence of rainfall frequency and intensity on soil water percolation rate and accumulated volume, in order to reveal the close relation between soil water percolation and different rainfall conditions. This study has important significance to further understand the influence mechanism of soil water percolation which will be beneficial to reduce soil water loss, improve agricultural water use efficiency, reduce contamination risk of groundwater and peripheral ecological environment from agricultural production, etc.

MATERIALS AND METHODS

Site description: In this study, the Farmland Ecological Experiment Station of Nanchang is selected as research site. The station (28°33'N, 115°57'N, 31.9 m.a.s.l) is located in Nanchang County, Jiangxi Province, Southeastern China (Fig. 1). Nanchang county lies in the southwest lakeside zone of the Poyang lake plain which is a fluvial-lacustrine plain with a groundwater depth being <5.0 m. The site is represented by a humid sub-tropical climate with hot humid summers and cold dry winters. The actual mean annual precipitation is 1624.4 mm, nearly 50% of which occurred in the summer season. Statistical data show that the annual average actual evaporation is 1385.5 mm, the annual average sunlight is 1574.1 h and the

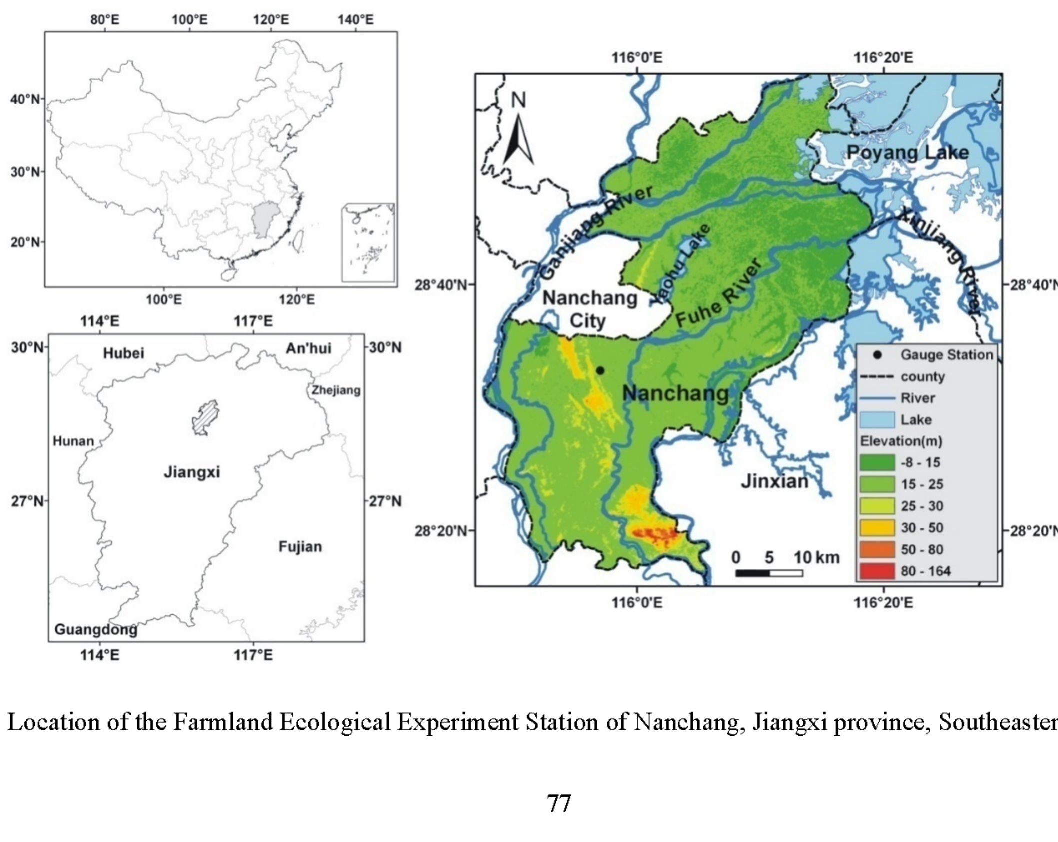

Fig. 1: Location of the Farmland Ecological Experiment Station of Nanchang, Jiangxi province, Southeastern China

annual mean temperature is 17.8°C at Nanchang station. The soil texture was investigated according to the international soil texture class standard. Soil samples (0-100 cm) were taken by digging to the corresponding depth. These soil samples were brought to the laboratory for analysis. Two soil layers in the profile were observed when taking soil samples. The upper soil layer with red-brown colour (0-40 cm) is clay loam and the lower soil layer with brown red colour (40-100 cm) is loamy clay, indicating a heterogeneous soil structure. The parent material of the soil originated from the silt loam of the quaternary.

Available data: The soil water content was measured by ThetaProbe ML2x soil moisture probes at two depths (25, 50 cm) in this study. Precipitation and evaporation were measured by means of a digital automatic ombrometer and a high precision weighing lysimeter. Hourly data were recorded automatically with 24 h cycle of each day from 8 August to 16 September 2007 at Nanchang station. These data were used to calibrate soil hydraulic parameters and validate the model.

Modelling approach

Water flow model: The modeling of water flow movement was conducted using an adapted version of the computer simulation model, HYDRUS-1D (Simunek *et al*., 2005). This software package is a one-dimensional finite element model for simulating the transient movement of water, heat and multiple solutes in variably saturated media with extensive capabilities such as options to simulate crop root water uptake, hysteresis in the characteristic curve and hydraulic conductivity. It is easy to set flexible boundary conditions, time step, convergence conditions and output format in HYDRUS-1D which greatly improves computational efficiency and simulation precision of the model. The Marquardt-Levenberg algorithm being embedding in the inverse solution module of the model can reversely resolve soil water and solute transport parameters, kinetic parameters. Currently, HYDRUS-1D has been widely used in the research of soil water, salt and nitrogen transport (Bah *et al*., 2009; Boudreau *et al*., 2009; Cao and Gong, 2003; De Vos *et al*., 2000; Endo *et al*., 2009; Garg *et al*., 2009; Gribb *et al*., 2009; Hao *et al*., 2008a, b; Heatwole and McCray, 2007; Liu and Xie, 1998; Meng *et al*., 2004; Ndiaye *et al*., 2007; Simunek *et al*., 2005; Wang *et al*., 2005; Xu *et al*., 2005). The following contents are main theory of the model.

In HYDRUS-1D, revised Richards equation is used to simulate water movement in one-dimensional variably saturated media. In the model the equations for soil water movement are expressed by the following equations:

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

Where:

θ = The volumetric soil water content (cm^3 cm^{-3})
t = Represents time (T)
h = The pressure head (cm)
K = Unsaturated hydraulic conductivity (cm day^{-1})
S = Root water uptake term (cm^3 cm^{-3} T^{-1})

The soil hydraulic properties are described by the modified MVG model (Vogel *et al*., 2000):

$$\theta(h) = \begin{cases} \theta_r + \dfrac{1}{\left[1+|\alpha h|^n\right]^m} & h < h_s \\ 1 & h \geq h_s \end{cases} \qquad (2)$$

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

where, $S_e = (\theta-\theta_r)/(\theta_s-\theta_r)$ is the effective water content; θ_r is residual soil water content (cm^3 cm^{-3}), θ_s is saturated soil water content (cm^3 cm^{-3}), α (cm^{-1}) and n (unitless) are parameters that define the shape of the water retention function (Van Genuchten, 1980), K_s is saturated hydraulic conductivity (cm day $^{-1}$), l is the pore-connectivity parameter of Mualem (1976) and h_s<0 is the maximum pressure head allowed at the soil surface i.e., the non-zero minimum capillary height (Vogel *et al*., 2000). In this study there is assume that m = 1-1/n and n>1. Applications of the model assume unique, single-valued (non-hysteretic) functions in characterizing the hydraulic properties at a certain point in the soil profile so it is acceptable that hysteresis effects were neglected in the model.

Domain geometry: The domain geometry of the soil water flow in the model is a simplification of the soil description observed in the field. The depth of the simulation range is 0-100 cm including two soil layers. The soil hydrology and the soil texture are mainly considered when the vertical soil profile are discretized vertically into a number of nodes. Based on the similarities in soil characteristics between the upper soil layer (0-40 cm) and the lower soil layer (40-100 cm), the soil profile (0-100 cm) was divided into 100 units with 1 cm equal interval namely being discretised uniformly in the vertical direction into 101 nodes for the one-dimensional simulation in the model. The soil profile at Nanchang station is unaffected by wheel tracks and does not exhibit any lateral variations.

Boundary and initial conditions: An atmospheric boundary condition was imposed at the soil surface accounting for time-dependent data of precipitation (mm h^{-1}) and potential evaporation rate (mm h^{-1}). The potential evaporation (Ep; mm day^{-1}) was estimated from Penman Monteith equation (Monteith, 1965, 1981). Transpiration effect of vegetation was not considered during the simulation period because the surface was bare soil at the test site. A free drainage condition was used at the bottom boundary z = -100 cm (depth of the model is 100 cm) in the flow domain. As initial condition we applied the volumetric soil water contents θ ($cm^3\ cm^{-3}$) obtained by linear interpolation of pressures at 25, 50 cm depths measured on 8 August 2007 at Nanchang station. The initial condition and boundary conditions of basic equations describing soil water movement can be written as:

$$h(z,t) = h_i(z) \quad \text{at} \quad t = 0 \tag{4}$$

$$h(z,t) = h_L(t) \quad \text{at} \quad z = L \tag{5}$$

And:

$$-K\left(\frac{\partial h}{\partial z} + 1\right) = q_0(t) - \frac{\partial h}{\partial t} \text{ at } z = 0 \text{ for } h_A \le h \le h_s$$

$$\begin{aligned} h(0,t) &= h_A \quad \text{for} \quad h<h_A \\ h(0,t) &= h_s \quad \text{for} \quad h>h_s \end{aligned} \tag{6}$$

Where:

Z = The spatial coordinate (cm), the origin is in surface, positive upward

h_i (z) = The initial water pressure head derived from linear interpolation of observed data at the 25, 50 cm depths

h_L (t) = Denotes the prescribed (observed) pressure head at the bottom boundary

L = -100 cm (depth of the model is 100 cm)

q_0 (t) = The net infiltration rate (i.e., precipitation minus evaporation)

h_A, h_s = Signifies the minimum and maximum pressure head allowed at the soil surface

The initial conditions are described by Eq. 4 and 5. Equation 6 describes the atmospheric boundary condition at the soil-air interface (Simunek and van Genuchten, 1996). Infiltration-excess overland flow is neglected and the limits h_A = -100 cm and h_s = -0.01 cm is used. The model set-up is shown in Fig. 2 where the upper boundary was subject to precipitation infiltration namely the second boundary condition. The lower boundary was assigned as

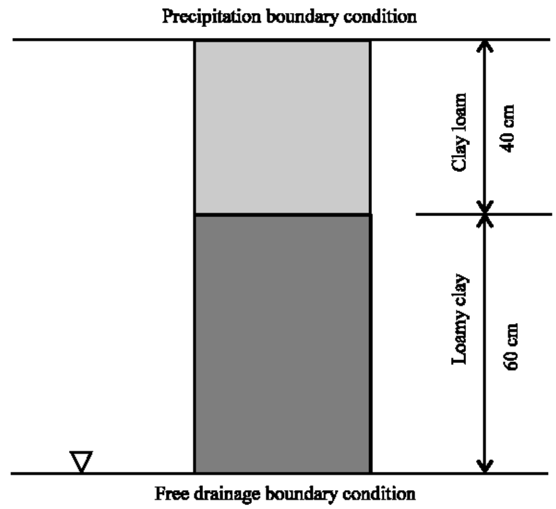

Fig. 2: Schematic diagram of soil profile in the model

free drainage boundary to simulate a freely draining soil profile because the water table lay far below the simulation domain.

Model calibration and validation: In this model simulation period included 960 h from 2007-08-08 to 2007-09-16. Because there was high-pressure gradients from the top to the bottom of the soil profile at the initial time of the simulation period so 1 h interval, a relatively smaller time unit was selected as time step to provide more accurate simulation calculation. Model output consisted of soil water balance and soil water variation of the observed node. The HYDRUS-1D code includes a Levenberg-Marquardt parameter optimization algorithm for inverse estimation of transport parameters. Researchers used this algorithm to estimate field scale hydraulic parameters using measured soil water content data. The algorithm expresses the error between observed and modeled data:

$$\Phi(b) \pounds \tfrac{1}{2} \sum_{i=1}^{N} \left[E_i^*(z,t) - E_i(z,t;b) \right]^2 \tag{7}$$

The Eq. 7 represents the sum of squared deviations between the measured and calculated space-time variables e.g., soil water contents. Here, N is the number of measurements, E_i (z, t)* represents specific measurements at time t and depth z, E_i (z, t; b) are the corresponding values simulated with a set of parameters, b. Saturated hydraulic conductivity (Ks) and saturated soil water content (θs) were two important and calibrated parameters according to parameter sensitivity analysis. Researchers used measured soil water content data from 8 August to 16 September 2007 and the inverse parameter optimization routines in HYDRUS-1D to test and adjust the calibration of the soil hydraulic property model. Several possible parameterizations were considered which differed according to the number of soil layers (1-2) and the number of hydraulic parameters that were fitted for each layer. The overall parameterization was determined based on the diagnostic information provided by the HYDRUS-1D routines about model fit and algorithm convergence, visual inspection of the model fit to the data and the principle of parsimony. It was determined that the best parameterization involved two soil layers with two parameters, α and n, fitted for each layer. Fitting more than two parameters per layer tended to cause the inverse algorithm to fail to converge, possibly due to the lack of a unique solution. Therefore, the chosen solution with two layers and α and n fitted for each layer provided the best correlation between simulated and measured soil water contents (R^2 = 0.885/0.768). The final soil hydraulic parameters were shown in Table 1 where α, n and l were empirical constants in van Genuchten Equation.

Simulated values and measured soil water contents on two observation nodes were compared and these were shown in Fig. 3 and 4. In order to obtain a quantitative assessment of simulation results, Root Mean Square Error (RMSE), Relative Mean Absolute Error (RMAE) and Correlation Coefficient (r) were adopted to evaluate numerical simulation precision:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(E_i - M_i)^2\right]^{1/2} \quad (8)$$

$$RMAE = \frac{\frac{1}{N}\sum_{i=1}^{N}|M_i - E_i|}{\frac{1}{N}\sum_{i=1}^{N}M_i} \times 100\% \quad (9)$$

$$r = \frac{\sum_{i=1}^{N}(M_i - \overline{M})(E_i - \overline{E})}{\sqrt{\sum_{i=1}^{N}(M_i - \overline{M})^2 (E_i - \overline{E})^2}} \quad (10)$$

where, M_i and E_i are respectively the ith measured values and simulated values; N is the observation frequency. RMSE, RMAE and r are chosen as the yardstick of assessing advantage and disadvantage of simulation results. These are as follows: as for Root Mean Square Error (RMSE), the smaller its value is the closer simulation results are to the measured value as for Relative Mean

Table 1: Hydraulic parameters of each soil layer used in the model

Depth (cm)	Soil texture	θ_r (cm^3 cm^{-3})	θ_s (cm^3 cm^{-3})	α (Fit) (cm^{-1})	n (Fit)	Ks (cm day^{-1})	l
0-40	Clay loam	0.0889	0.3917	0.0084	1.432	9.944	0.5
60-100	Loamy clay	0.0617	0.4508	0.0056	1.571	8.608	0.5

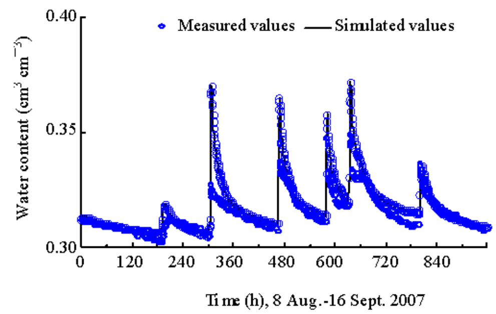

Fig. 3: Comparison between simulated and measured soil water contents at 25 cm depth

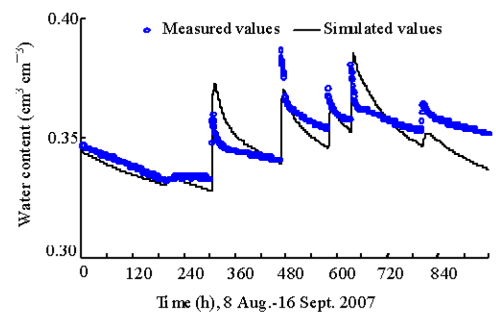

Fig. 4: Comparison between simulated and measured soil water contents at 50 cm depth

Absolute Error (RMAE), its value range is [0, 1] which respectively represented fitting precision ranging from high to low and for correlation coefficient (r), its value range is [-1, +1] with a correlation coefficient of +1 indicating that the two variables have a perfect, upward-sloping (+) linear relationship and a correlation coefficient of -1 showing that the two variables have a perfect, downward-sloping (+) linear relationship. A correlation coefficient of 0 stands for no linear relationship between the variables.

The calculation of RMSE, RMAE and r had been accomplished according to the above formula. The results showed that the value of RMSE and RMAE between measured values and simulated values of 25 cm soil water contents were respectively 0.0067 and 1.21% and the value of RMSE and RMAE between measured values and simulated values of 50 cm soil water contents were respectively 0.0085 and 1.77%. Furthermore, correlation analysis showed that there was a remarkable correlation between simulated values and measured values and correlation coefficient (r) of two observed points were up

Table 2: Scenarios design for different rainfall conditions

Scenario scheme	Time interval of adjacent rainfall events (h)	Intensity single rainfall event (mmh^{-1})
1	2	0.386
2	4	0.772
3	8	1.544
4	16	3.088
5	24	4.633
6	32	6.177
7	64	12.353
8	96	18.530
9	Unequal distance	12.353

to 0.885 and 0.768. Based on the above analysis, it can be seen that simulation results agreed well with observation results especially for the simulation at 25 cm soil depth.

Scenarios simulation design: Based on the measured rainfall data being used in the process of model calibration, on the premise of the same total precipitation during the same simulation period (960 h), there were designed nine kinds of scenarios simulation scheme in Table 2. Design principle of scenarios 1-9 highly embodied gradual transition from high frequency and low intensity to low frequency and high intensity. In order to verify the effects of the preceding rainfall events on the percolation rate, the rainfall intensity of scenario 9 was assigned to the same as that of scenario 7 but time interval of adjacent rainfall events of scenario 9 was unequal distance. Moreover, the time distribution design of rainfall events of scenario 9 was consistent with the natural rainfall process and the duration of every rainfall event for scenario 9 was 1 h. Evaporation intensity of all scenarios simulation schemes was kept constant and potential evaporation intensity was assigned as 0.4 mm h^{-1} in the model.

RESULTS AND DISCUSSION

The influence of different rainfall conditions on the volume of soil water percolation: According to different rainfall scenarios, simulation calculations were completed by using hydrus-1d model. Water balance components under different simulation scenarios were shown in Table 3 (as for variation of soil water storage in Table 3, positive values and negative values, respectively represented soil water storage capacity surplus-deficit status). Table 3 also showed that mass balance errors under different simulation scenarios were <1% which further indicated that simulation accuracy and efficiency was higher. Water balance analysis showed that the total amount of soil evaporation decreased gradually from scenarios 1-8 but the total amount of soil water storage and percolation volume increased gradually. There were reasons as follow: as time interval between adjacent rainfall events in scenarios 1-8 increased gradually, the time of the surface soil being in the wettable state was

Table 3: Terms of the water mass balance under different rainfall scenarios

Scenario simulation scheme	Rainfall (mm)	Surface runoff (mm)	Soil evaporation (mm)	Variation soil water storage (mm)	Percolation volume (mm)	Mass balance error (%)
Nature rainfall	185.3	0.001	152.3	4.9	28.1	0.000
Scenario 1	185.3	0.000	209.0	-30.4	6.7	0.000
Scenario 2	185.3	0.000	208.1	-29.5	6.8	0.000
Scenario 3	185.3	0.000	204.6	-26.3	7.0	-0.001
Scenario 4	185.3	0.000	197.3	-19.9	7.9	0.000
Scenario 5	185.3	0.000	190.7	-14.3	8.9	0.000
Scenario 6	185.3	0.000	184.8	-9.6	10.1	0.000
Scenario 7	185.3	0.000	164.8	4.7	15.8	0.000
Scenario 8	185.3	0.018	147.5	15.5	22.4	0.000
Scenario 9	185.3	0.000	164.3	-8.2	29.2	0.000

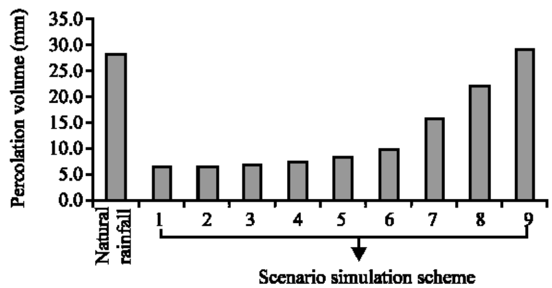

Fig. 5: Comparison of the total amount of soil water percolation under different scenarios

shortened continuously which led to the actual soil evaporation decreasing gradually. At the same time, downward movement of water through the soil profile (i.e., soil water percolation) intensified which resulted in the total amount of soil water percolation increasing gradually (Fig. 5). As for scenarios 1-7, rainfall was completely consumed by soil infiltration and evaporation so there was no surface runoff. Only in scenario 8 was there surface runoff because rainfall intensity of scenario 8 was higher than the infiltration capacity of the soil. Furthermore, it could be shown from Fig. 5 that the total amount of soil water percolation in scenario 9 was more close to that of natural rainfall. There were reasons as follow: rainfall process in scenario 9 was designed to be consistent with natural rainfall process and multiple rainfall events in a relatively short period in scenario 9 further intensified the increase of soil infiltration capacity which led to the notable increase of soil water percolation volume and the peak percolation rate of 0.10 mm h^{-1}. Conclusively, under the precondition of the same total rainfall, actual soil evaporation decreased gradually and the total amount of soil water percolation increased gradually with the increase of rainfall intensity and the decrease of rainfall frequency.

The influence of different rainfall conditions on soil water percolation rate: Comparing the percolation rate of natural rainfall and scenarios 1-9, it was found that soil

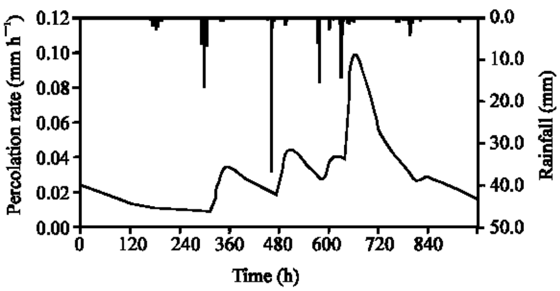

Fig. 6: Variation curves of soil water percolation rate for 0-100 cm soil layer under natural rainfall conditions

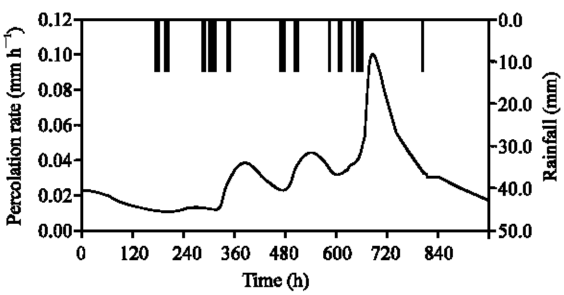

Fig. 7: Variation curves of soil water percolation rate for 0-100 cm soil layer under scenario 9

water percolation rate fluctuations under these ten kinds of simulation conditions was consistent with rainfall process which also further suggested that soil water recharge by rainfall infiltration significantly increased soil water percolation rate. By comparison of Fig. 6 with Fig. 7, it can be seen that variation process of soil water percolation rate under natural rainfall and scenario 9 showed similar characteristics to a great extent and the total amount of soil water percolation under these simulation conditions were very close to each other, respectively reached to 29.2 and 28.1 mm. The maximum soil water percolation rate occurred during the period of high intensity rain events which further verified that it was high intensity rainfall process that induced soil water percolation aggravation. By comparative analysis of Fig. 7 and 8, there is found that although, total rainfall and rainfall intensity of scenario 9 and scenario 7 were same, their percolation rate and total percolation were greatly different because the time distribution design of rainfall events of scenario 7 was very different from that of scenario 9. Figure 8 showed the variation process of soil water percolation rate for 0-100 cm soil depth under scenario 7. It could clearly be shown in Fig. 8 that the dynamic change of of soil water percolation rate over time varied accordingly to the rainfall intensity. Rain events in

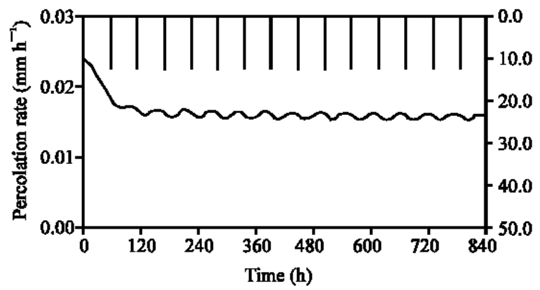

Fig. 8: Variation curves of soil water percolation rate for 0-100 cm soil layer under scenario 7

scenario 7 were designed in equal intervals and therefore, variation process of soil water percolation rate changed slightly. Soil water percolation rate was about 0.015 mm h^{-1} and the total amount of percolation was only 15.8 mm in scenario 7. However for scenario 9, rain events were designed in unequal intervals, antecedent rainfall and soil water content significantly affected soil water infiltration (Wangemann *et al*., 2000; Reynolds *et al*., 2004) and multiple rainfall events in a relatively short period resulted in a peak percolation rate of 0.100 mm h^{-1}. The total amount of soil water percolation in scenario 9 was up to 29.2 mm much higher than that of scenario 7 and this outcomes further showed that relatively intense rainfall processes significantly increased soil water percolation intensity. In addition, Wanke *et al*. (2008) also found that the development of groundwater recharge was influenced not only by the sum of annual precipitation to a great extent but was also influenced by a large amount of precipitation in a relatively short period. This result was consistent with research conclusions of this study. Based on the above analysis, there is found that high rainfall intensity events increased the total amount of soil water percolation especially for multiple rainfall events in a relatively short period.

CONCLUSION

Different rainfall intensity and distribution strongly influenced soil water percolation and nutrient leaching loss. In this study, a numerical model was employed to investigate the response of soil water percolation rate and accumulated percolation amount to rainfall frequency and rainfall intensity. The conclusions are as follows:

Soil water percolation is closely related to rainfall intensity. Multiple rainfall events in a relatively short period result in a peak percolation rate. For the same total rainfall, the total amount of soil water percolation under rainfall events of low frequency and high intensity is greater than that of soil water percolation under rainfall events of high frequency and low intensity. From the perspective of reducing soil water loss and improving water use efficiency with the same amount of irrigation, high frequency and low intensity irrigation could reduce the total amount of soil water percolation. This is more beneficial to long residence times of soil water with surface application in crop root and by this increasing the chance of nutrient uptake and utilization. Furthermore, this improves the efficient use of farmland irrigation. Conversely, low frequency and high intensity irrigation would cause the total amount of soil water percolation increasing greatly thus increasing the risk of soil water leaching loss from soil and reducing the use efficiency of irrigation; meanwhile, it also caused soil nutrient leaching loss to different degrees.

Under the background of global warming being increasingly intensified, the frequency occurrence of extreme weather and climate events has been greatly changed. Latest evaluation report being published by the Intergovernmental Panel on Climate Change (IPCC, 2007) showed that extreme weather and climate events especially for short duration and high intensity rainfall events presented a continuously increasing trend. According to the research, the increase of these extreme rainfall events would result in the total amount of soil water percolation loss increasing thus causing an aggravation of environmental pollution.

ACKNOWLEDGEMENTS

This research is jointly supported by Special Fund for Forestry Scientific Research in the Public Interest (201004021), One Hundred Talents Program of the Chinese Academy of Sciences, the National Natural Science Foundation of China (40871026, 40701176).

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