Numerical Simulation of Soil Water and Salt Transport in Desert Soil under Saline Water Irrigation in the Lower Reaches of the Tarim River

Wang Shiming, Fan Jinglong

2021-08-02
ChinaRxiv

Abstract

During shelterbelt construction in the desert regions of the lower Tarim River, soil profile water-salt variations are pronounced under saline groundwater irrigation conditions and exhibit certain regularities. To characterize vertical soil water-salt dynamics, the development of a numerical model represents a highly efficient methodology. Through reconstructing the dynamic processes of water-salt movement within the soil profile, the underlying principles governing soil water-salt transport in high-salinity environments can be elucidated, thereby facilitating shelterbelt ecological engineering construction and subsequent sustainable irrigation management. This study employs HYDRUS-1D to simulate the spatiotemporal distribution characteristics of soil water-salt under varying groundwater salinity levels during the initial phase of shelterbelt establishment, with soil hydraulic parameters optimized based on measured soil water-salt data to assess model applicability. Results demonstrate that the surface layer (0–30 cm) exhibits substantial irrigation-induced fluctuations in soil water content and salinity, accompanied by pronounced salt surface accumulation; conversely, the deep layer (50–150 cm) shows minimal irrigation influence and minor fluctuations. Numerical model simulations show good agreement with observed data, effectively capturing soil water-salt transport processes. The developed model can be applied to simulate soil water-salt transport dynamics under various irrigation salinity conditions in the mobile desert regions of the lower Tarim River, providing both theoretical foundation and technical support for ecological shelterbelt construction in this area.

Full Text

Numerical Simulation of Soil Water and Salt Transport in Desert Soil under Saline Water Irrigation in the Lower Reaches of the Tarim River

Wang Shiming1,2,3,4, Fan Jinglong1,2,3,4, Zhao Ying5, Zhang Tao1,2,3,4, Li Shengyu1,2,3,4

(1. State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China; 2. Cele National Station of Observation and Research for Desert-Grassland Ecosystem, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Cele 832000, Xinjiang, China; 3. Taklimakan Desert Research Station, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Korla 841000, Xinjiang, China; 4. University of Chinese Academy of Sciences, Beijing 100049, China; 5. Ludong University, Yantai 264039, Shandong, China)

Abstract: During the construction of shelterbelts in desert areas in the lower reaches of the Tarim River, changes in water and salt in soil profiles under groundwater saline-water irrigation are pronounced and exhibit certain regularity. To understand the vertical dynamics of soil water and salt, establishing a numerical model is a highly efficient approach. By reconstructing the dynamic process of water and salt in soil profiles, the laws of soil water and salt transport under high-salinity environments can be revealed, serving ecological engineering construction of shelterbelts and subsequent sustainable irrigation management. HYDRUS-1D was used to simulate the distribution characteristics and temporal changes of soil water and salt under groundwater irrigation conditions with different mineralization degrees during the initial stage of shelterbelt construction. Based on measured soil water and salt data, soil hydraulic characteristic parameters were optimized and the applicability of the model was evaluated. The results show that water content and salt content in the surface layer (0–30 cm) are strongly affected by irrigation, with large numerical fluctuations and strong salt accumulation; the deep layer (50–150 cm) is less affected by irrigation and shows smaller numerical fluctuations. The numerical model simulations agree with measured values and can well reflect soil water and salt transport. The established model can be used to simulate soil water and salt transport in mobile desert areas of the lower reaches of the Tarim River under irrigation conditions with different mineralization degrees, providing a theoretical basis and technical support for ecological shelterbelt construction in the region.

Keywords: saline-water irrigation; soil water and salt transport; HYDRUS-1D model; lower reaches of the Tarim River

Article number:

The Golmud-Korla railway is an overland transport corridor from China to West Asia, the Mediterranean, and the Black Sea regions, and is of great significance for national economic development and the consolidation of national defense. The railway passes through ecologically fragile areas in the lower reaches of the Tarim River[1-2], where wind-sand activity is intense; ecological shelterbelts need to be established to ensure the safe operation of the railway. However, because water resources in this region—especially surface water—are preferentially used for agricultural production, groundwater is affected by evaporation and drainage processes, has very high mineralization, and can hardly be used directly for conventional plant irrigation. Using such poor-quality groundwater to irrigate highly salt-tolerant trees and shrubs is an important technical pathway for shelterbelt construction in the region. Studies have shown that saline-water irrigation has a significant inhibitory effect on the growth of most desert plants[3–4], and high-salinity irrigation can even lead to plant death[5]. At present, scholars in China and abroad have carried out extensive research on saline-water irrigation, covering soil physics, chemistry, and biology[6–8], and also including analyses of soil water and salt transport and salt distribution[9–11]. However, previous studies have mainly focused on saline water with mineralization less than 5 $g \cdot L^{-1}$, with a maximum not exceeding 30 $g \cdot L^{-1}$. Research involving saline-water irrigation above 30 g・L−1 is almost absent. Under high-salinity irrigation environments, the viscosity coefficient and dispersivity of soil increase to a certain extent, and the laws of soil water and salt transport also differ from those under low-salinity conditions. According to measurements, the groundwater TDS (total dissolved solids) in the proposed shelterbelt area commonly exceeds 30 g・L−1, and may reach 50–70 g・L−1 or more at its highest. Therefore, from the perspective of groundwater utilization, investigating the distribution characteristics of water and salt in soil profiles is of profound significance for the efficient use of saline groundwater resources in desert areas and for the cultivation and management of salt- and alkali-tolerant desert plants.

Establishing a water and salt transport model is one of the important means of analyzing soil water and salt transport. Compared with traditional field measurements, using models to simulate water and salt patterns can save large amounts of manpower and material resources. At present, several soil water and salt transport models widely applied in China and abroad include HYDRUS, PROFLOW, WAV-ES, 2DFATMIC, SHAW, and others. Among them, the HYDRUS-1D model is a freely available model developed by the U.S. Salinity Laboratory

---

Received: 2020-04-01; **Revised:** 2020-06-11

Funding: Supported by the Science and Technology Research and Development Program of China Railway Corporation (2017G004-E-02); Major Science and Technology Special Subprojects of Xinjiang Uygur Autonomous Region (2016A03008-3-2, 2016 A03008-2-3); Regional Key Project of the Science and Technology Service Network Initiative (STS) of the Chinese Academy of Sciences (KFJ-STS-QYZD-062); and the National Natural Science Foundation of China (31971731).

Author biography: Wang Shiming (1994–), male, master's student, mainly engaged in research on soil water and salt transport. E-mail: 1443661410@qq.com

Corresponding author: Fan Jinglong (1978–), male, senior engineer, mainly engaged in research on soil and water conservation and desertification control. E-mail: fanjl@ms.xjb.ac.cn

The model program for simulating variably saturated and porous-medium water, heat, and solute transport[^12] can couple atmospheric processes (evaporation, rainfall, irrigation), soil water and solute transport, heat, plant root water uptake, and other processes for integrated simulation. In recent years, HYDRUS software has been widely used to simulate soil water movement[^13–15] and solute transport[^16–17] under different land-use patterns, and has been proven to have good applicability and effectiveness.

Based on measured soil water data for one complete irrigation cycle in each of the summer and autumn seasons under drip irrigation with groundwater of different salinities, as well as soil-profile salinity data at the end of the irrigation cycles in

Fig. 1 Geographic location of the study area

Figure 1: Fig. 1 Geographic location of the study area

summer and autumn, this study combined local meteorological, irrigation, and vegetation conditions and used the HYDRUS-1D model to simulate soil water-salt transport processes within the drip-irrigated belt of *Tamarix chinensis* Lour. By comparing and analyzing simulated and measured values, the reliability and accuracy of the model were verified. The results can provide a theoretical basis and effective technical support for the construction of shelterbelt projects in this region.

1 Data and Methods

1.1 Overview of the study area

The study area is located in the desert along the Gewu Railway in the 33rd Regiment of the Second Agricultural Division, on the northeastern margin of the Tarim Basin, at 40°45′N, 87°18′E (Fig. 1). The mean annual air temperature in this region is 12 °C; the extreme maximum air temperature can reach 44.3 °C, and the extreme minimum air temperature exceeds −30.9 °C. Mean annual precipitation is 24.7-54.1 mm, and annual potential evaporation is 2000–3000 mm. The windy season occurs from April to July each year; the prevailing wind directions are mainly easterly and northeasterly winds. The mean annual wind speed is 1.6–3.2 $m \cdot s^{-1}$, and the maximum wind speed is 13.3–20.5 $m \cdot s^{-1}$. The soil texture in the experimental area is sandy soil. During the experiment, groundwater depth fluctuated between 4.25 and 4.65 m.

1.2 Experimental methods

This study adopted a field-controlled experiment conducted in the *Tamarix* planting experimental shelterbelt. The experimental area was equipped with water-supply wells for groundwater-level monitoring and pumping irrigation. To study the effects of saline-water irrigation at different salinities on plants and soil, local groundwater was desalinated and used for drip-irrigation afforestation. The irrigation-water salinity gradient was divided into four levels (10 $g \cdot L^{-1}$, 25 $g \cdot L^{-1}$, 40 $g \cdot L^{-1}$, and raw water), where raw water refers to untreated groundwater. The salinity stability of the irrigation water is shown in Fig. 2. Except that the raw water varied over a relatively large range (33.32–54.14 $g \cdot L^{-1}$), the desalination equipment was generally able to maintain irrigation-water salinity at the salinity levels shown in Fig. 2.

图 1 研究区示意图

Fig. 1 Geographic location of the study area

图 2 试验期间灌溉水矿化度监测

Fig. 2 Monitoring of irrigation water salinity during the experiment

Figure 2: Fig. 2 Monitoring of irrigation water salinity during the experiment

Fig. 2 Monitoring of irrigation water salinity during the experiment

Field monitoring was conducted from May 30, 2019 to September 20, 2019. Monitoring indicators included *Tamarix* root distribution, plant height, leaf area index, soil water content, soil electrical conductivity ($EC_{1:5}$), groundwater level, groundwater electrical conductivity, and meteorological data.

The spatial distribution of root density was determined by excavating the entire root system at the end of the growing season, washing and oven-drying the roots, and weighing them by layer, with three replicates. Soil water content was measured using a neutron soil moisture meter. The measurement points of the neutron probe were placed beneath the emitters, and the monitoring depth range was 0–100 cm (in this paper, soil water contents at soil-layer depths of 15 cm, 30 cm, 50 cm, and 90 cm were selected as validation data for the model). Soil electrical conductivity was measured by layered sampling with a soil auger (measurement depth 0–160 cm, one layer every 20 cm) and a 1:5 soil-water ratio ($EC_{1:5}$). An Excel fitted equation was used to convert electrical conductivity values to salt content. August 1 and September 20 (the ends of the two irrigation cycles) were the sampling dates; soils were sampled by layer with three replicates. The spacing between emitters in the drip-irrigation belt was 60 cm, the emitter discharge was 3.8 $L \cdot h^{-1}$, the spacing between drip lines was 2.5 m, the drip-line length could reach 100 m, each continuous irrigation event lasted 8 h, and the wetted width of the drip-irrigation belt could reach 65 cm.

1.3 Numerical simulation

HYDRUS-1D software was used to simulate soil water and salt in 2019.

transport conditions; the simulated soil-depth range was 0–160 cm. The simulation period was from May 30 to September 30, 2019, totaling 124 d. Measured soil water-content data from the two irrigation periods of July 22–August 1 and September 10–September 20, and measured soil-profile salinity data from August 1 and September 20, were used to validate the model. The initial time step was set to 0.001 d, the maximum time step to 0.5 d, and the maximum number of iterations to 10, allowing the program to automatically adjust the time step within the prescribed time-step range.

The Van Genuchten–Mualem model was adopted as the soil-water characteristic curve model. The soil water content and electrical conductivity measured before the irrigation period were input into the model as the initial conditions. According to the local climate and irrigation conditions, the upper boundary of the simulated soil body was determined to be an open atmospheric boundary, receiving irrigation replenishment, soil-surface evaporation, precipitation, etc.; the potential evapotranspiration ET_0 was calculated from meteorological data and leaf-area index using the FAO-recommended Penman–Monteith equation. The groundwater table in the study area fluctuated between 4.25 and 4.65 m. According to the studies of Zhou Hong, Zheng Bowen, et al.[18–19], the capillary rise height of sandy soil above the phreatic layer is 120 cm; therefore, groundwater had almost no influence on the simulated soil body (0–160 cm), and the lower boundary condition was set as free drainage.

1.3.1 Water-movement model

In this simulation, the Richards equation was used to describe one-dimensional vertical soil-water movement in the vadose zone:

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

where: θ is the volumetric water content ($\mathrm{cm}^3 \cdot \mathrm{cm}^{-3}$); t is time (d); z is the vertical soil-depth coordinate (cm), with the ground surface taken as the origin and downward defined as positive; $K(h)$ is hydraulic conductivity ($\mathrm{cm} \cdot \mathrm{d}^{-1}$); h is negative pressure head (cm); and S is the source–sink term, mainly used to describe root water uptake ($\mathrm{cm}^3 \cdot \mathrm{cm}^{-3} \cdot \mathrm{d}^{-1}$).

The hydraulic parameters of unsaturated soil water are described as follows:

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{\left(1 + |\alpha h|^n\right)^m}, & h < 0 \\ \theta_s, & h > 0 \end{cases} \qquad (2)$$

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

where: θ_s and θ_r refer respectively to saturated water content and residual water content ($\mathrm{cm}^3 \cdot \mathrm{cm}^{-3}$); α, m, and n are empirical parameters, of which $m = 1 - 1/n$; K_s is saturated hydraulic conductivity ($\mathrm{cm} \cdot \mathrm{d}^{-1}$); S_e is the dimensionless relative water content; and l is the pore-connectivity parameter, usually taken as 0.5.

1.3.2 Salt-transport model

Without considering solid-phase adsorption, the equilibrium convection–dispersion equation was selected to describe solute transport in the root zone:

$$\frac{\partial \theta C}{\partial t} = \frac{\partial}{\partial z}\left(\theta D \frac{\partial C}{\partial z}\right) - \frac{\partial v \theta C}{\partial z} \qquad (4)$$

where: C represents solute concentration ($\text{mol}\cdot\text{cm}^{-3}$); D represents the hydrodynamic dispersion coefficient ($\text{cm}^2\cdot\text{d}^{-1}$); and v represents the average pore-water velocity ($\text{cm}\cdot\text{d}^{-1}$).

1.3.3 Root water-uptake model

Because the distribution of potential transpiration (i.e., potential root water uptake) in the root zone is consistent with the spatial distribution of root density, this study, based on the results of field-layered excavation of roots, input the dry weight of roots in each layer into the model, and the model transformed them to generate the root distribution function. The model converts the root water-uptake parameters into a water-stress response function to represent root water uptake. In this study, the Feddes trapezoidal function was used to describe the water-uptake process of *Tamarix* roots. According to the research results of Moayyad and Grinevskii[20], the water-uptake parameter values are shown in Table 1. Root water uptake in HYDRUS-1D uses the modified Feddes model, as shown in Eq. 5:

$$S(h, h_\varphi, x, z) = \alpha(h, h_\varphi, x, z) b(x, z) S_t T_p \qquad (5)$$

where: $\alpha(h, h_\varphi, x, z)$ is the soil-water stress response function; h_φ is osmotic pressure (cm); $b(x, z)$ is the root distribution function (cm^{-2}); S_t is the surface length related to transpiration (cm); and T_p is the potential transpiration rate ($\text{cm}\cdot\text{d}^{-1}$).

Table 1 Root water-uptake parameters

Tab. 1 Water absorption parameters of roots

h_1/cm	h_2/cm	h_{3-1}/cm	h_{3-2}/cm	h_4/cm	r_{2H}/cm·d^{-1}	r_{2L}/cm·d^{-1}
−0.1	−2.0	−80.0	−250.0	−15000.0	0.5	0.1

Note: h_1 is the soil matric potential at the wilting point for root water uptake; h_2 is the soil matric potential at the beginning of the optimum range for root water uptake; h_3 is the soil matric potential at the end of the optimum range for root water uptake (h_{3-1} is −80 soil matric potential, and h_{3-2} is −250 soil matric potential); h_4 is the soil matric potential at the wilting point of root water uptake; r_{2H} and r_{2L} are two assumed potential crop transpiration rates, respectively.

1.3.4 Calculation of potential evapotranspiration

When meteorological data are input into the model as the upper boundary condition, the Penman–Monteith equation is used to calculate potential evapotranspiration. The applicability of this equation in arid environments has been verified by many scholars[21-22]. Its main form is:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (6)$$

where: ET_0 is evapotranspiration ($mm \cdot h^{-1}$); R_n is net radiation at the crop surface [$MJ \cdot (m^2 \cdot d)^{-1}$]; G is soil heat flux [$MJ \cdot (m^2 \cdot d)^{-1}$]; γ is the psychrometric constant; T is the daily mean air temperature at 2 m height (℃); u_2 is the daily mean wind speed at 2 m height ($m \cdot s^{-1}$); e_s is saturated vapor pressure (kPa); e_a is actual vapor pressure (kPa); and Δ is the slope of the saturation vapor pressure curve with temperature.

1.4 Model calibration and evaluation

According to the vertical distribution characteristics of the measured soil texture, soil profiles at different depths were divided into 5 layers (the specific soil-layer depth division is shown in Table 2). The water-characteristic parameters of each layer were obtained by using the Rosetta module of the HYDRUS-1D model: measured soil particle size and bulk density for each layer were input to obtain the initial parameters for each layer. Parameter calibration was performed using the measured soil water-content data during the summer irrigation period; the soil longitudinal dispersivity was 60 cm. To improve the accuracy of the numerical simulation, it was necessary to adjust the soil-water characteristic parameters.

Table 2 Soil particle size and soil water characteristic parameters in the study area

Soil depth / cm	Sand	Silt	Clay	Soil bulk density / $g \cdot cm^{-3}$	θ_r / $cm^3 \cdot cm^{-3}$	θ_s / $cm^3 \cdot cm^{-3}$	K_s / $cm \cdot d^{-1}$	α / cm^{-1}	n	l
0–20	79.6	19.6	0.8	1.46	0.015	0.382	100	0.047	2.82	0.5
20–60	98.9	1.1	0.0	1.52	0.013	0.377	56	0.031	2.59	0.5
60–80	97.5	2.5	0.0	1.55	0.011	0.368	86	0.032	3.26	0.5
80–100	94.1	5.9	0.0	1.58	0.017	0.370	56	0.035	3.13	0.5
100–150	97.5	2.5	0.0	1.54	0.013	0.372	100	0.032	4.04	0.5

Fig. 3 Simulated and measured values of soil moisture content

Figure 3: Fig. 3 Simulated and measured values of soil moisture content

Note: θ_r is residual water content; θ_s is saturated water content; K_s is saturated hydraulic conductivity; α is the air-entry value; n is an empirical parameter related to pore-size distribution; l is the pore-connectivity coefficient.

The parameters were adjusted. According to sensitivity analysis, optimization was mainly performed for the saturated hydraulic conductivity K_s and the empirical parameter n; the optimized results are shown in Table 2. The water-salt observation data were divided into two periods: 22 July 2019 to 1 August 2019 was used for model calibration, and the other period was used for model validation. Three methods—the root mean square error (RMSE), the coefficient of determination (R^2), and the Nash-Sutcliffe model efficiency coefficient (NSE)—were used to evaluate the performance of the numerical simulation in this study.

2 Results and Analysis

2.1 Simulation of soil moisture

It can be seen from Fig. 3 that the simulated values of soil moisture were relatively consistent with the measured values. After irrigation, the water content of the surface soil layer (0-30 cm) first increased rapidly, reaching 15%-20%, and then quickly decreased to below 10%. The water content of the 50-90 cm soil layers changed little and generally fluctuated between 5% and 10%; among them, the response at the 90 cm soil layer to irrigation showed an obvious lag, and the numerical changes were not very sharp. During the stage of water redistribution, the water content of the surface soil was lower than that of the lower layers, indicating that the surface soil was strongly affected by irrigation infiltration and evaporation. The model was able to simulate well the changes in soil moisture from infiltration to redistribution. The above results indicate that the HYDRUS-1D model has strong applicability for simulating soil water movement in the study area.

Fig. 3 Simulated and measured values of soil moisture content

The overall simulated effect for soil water content was evaluated. The results show that the calibrated HYDRUS-1D model can simulate the dynamic changes in soil moisture with relatively high accuracy (Fig. 3). This is mainly reflected in the small RMSE and the high R^2 and NSE. Generally, RMSE indicates the deviation between simulated and measured values, but it cannot reflect the goodness of fit between simulation and observation, whereas R^2 and NSE can provide a good explanation of model fit. Under the four irrigation treatments with different mineralization levels, the RMSE of soil moisture ranged from 0.014 to 0.020, R^2 ranged from 0.71 to 0.88, and NSE ranged from 0.67 to 0.85.

Under the four irrigation treatments with different mineralization levels, the evaluation results for different soil layers are shown in Table 3. The RMSE values for soil moisture at different depths during the calibration and validation periods were all between 0.005 and 0.032. From the numerical perspective, the model simulation results were relatively satisfactory and had a certain degree of reliability. However, from the feedback of the two evaluation indices R^2 and NSE, the simulation performance for different soil layers followed the order: 30 cm > 15 cm > 50 cm > 90 cm. The simulation accuracy for the 50 cm and 90 cm soil layers was low; in particular, the model efficiency coefficient for the 90 cm soil layer was shown to be unreliable (NSE < 0). The simulation performance for the surface soil layer (0–30 cm) was better than that for the lower layer (50–90 cm).

2.2 Soil salinity simulation

Figure 4 compares the simulated and measured values of soil profile salinity on August 1, 2019 and September 20, 2019. The simulated values and measured values basically agreed. As can be seen from Fig. 4, under irrigation treatments with different water mineralization levels, the soil salt content first decreased rapidly from the surface layer to the deep layer, and then maintained a stable distribution pattern. A relatively obvious salt-accumulation zone existed in the surface soil layer. With the increase in irrigation water mineralization, the salt content in each soil layer increased correspondingly, and surface accumulation of salt became more pronounced.

As shown in Table 4, under the four irrigation treatments with different mineralization levels, the RMSE values between simulated and measured soil salinity were 0.13, 0.23, 0.33, and 0.59, respectively; R^2 values were 0.92, 0.85, 0.86, and 0.74, respectively; and NSE values were 0.92, 0.78, 0.89, and 0.65, respectively. The smaller RMSE and higher R^2 and NSE indicate that, under irrigation with different mineralization levels, the spatial distribution patterns of simulated and measured soil salinity were relatively consistent, with little difference.

2.3 Scenario simulation

To better reflect the future trends in the transport processes of water and salt in forest soil after irrigation with saline water, this study set a simulation period of approximately 4 months from the irrigation start date in the following year to the end of the plant growing season (May 30–September 22).

For the soil hydraulic characteristic parameters, the summer irrigation parameters after parameter calibration were used. The plant growth module in HYDRUS-1D was selected, and the monitored data of *Tamarix* plant height, leaf area index, and root depth during the growing period were input into the model.

Table 3 Statistical analysis of simulated soil moisture results

Tab. 3 RMSE, R^2 and NSE of simulated value and measured value of soil moisture content

Irrigation water mineralization / $g \cdot L^{-1}$	Soil layer / cm	RMSE Calibration	RMSE Validation	R^2 Calibration	R^2 Validation	NSE Calibration	NSE Validation
10	15	0.027	0.021	0.83	0.83	0.75	0.79
10	30	0.020	0.013	0.83	0.91	0.50	0.85
10	50	0.026	0.021	0.54	0.58	0.29	0.07
10	90	0.025	0.012	0.36	0.58	−5.20	−0.04
10	Overall effect	0.020		0.75		0.67	
25	15	0.021	0.026	0.79	0.69	0.66	0.72
25	30	0.023	0.030	0.81	0.72	0.75	0.64
25	50	0.024	0.023	0.83	0.88	0.75	0.83
25	90	0.017	0.016	0.62	0.79	0.47	0.71
25	Overall effect	0.020		0.77		0.72	
40	15	0.015	0.011	0.91	0.91	0.82	0.81
40	30	0.021	0.008	0.82	0.93	0.59	0.91
40	50	0.032	0.013	0.81	0.71	0.67	0.79
40	90	0.019	0.012	0.58	0.53	−0.60	−0.13
40	Overall effect	0.014		0.88		0.85	
Raw water	15	0.022	0.007	0.75	0.93	0.68	0.89
Raw water	30	0.012	0.007	0.83	0.85	0.77	0.76
Raw water	50	0.022	0.009	0.69	0.67	0.63	0.69
Raw water	90	0.019	0.005	0.40	0.52	−3.48	−3.82
Raw water	Overall effect	0.015		0.71		0.68	

Note: RMSE is the root mean square error; R^2 is the coefficient of determination; NSE is the model efficiency coefficient. The same below.

(a1) 10 $g \cdot L^{-1}$ irrigation water (2019-08-01) (a2) 10 $g \cdot L^{-1}$ irrigation water (2019-09-20)

Soil salt content / $g \cdot kg^{-1}$
Soil depth / cm

Measured value —Simulated value

(b1) 25 g · L^{-1} irrigation water (2019-08-01) (b2) 25 g · L^{-1} irrigation water (2019-09-20)

Soil salt content / g · kg^{-1}
Soil depth / cm
Measured value —Simulated value

(c1) 40 g · L^{-1} irrigation water (2019-08-01) (c2) 40 g · L^{-1} irrigation water (2019-09-20)

Soil salt content / g · kg^{-1}
Soil depth / cm
Measured value —Simulated value

(d1) Raw water (2019-08-01) (d2) Raw water (2019-09-20)

Soil salt content / g · kg^{-1}
Soil depth / cm
Measured value —Simulated value

Fig. 4 Comparison of simulated and measured values of soil salinity

Table 4 RMSE, R^2 and NSE of simulated and measured soil salinity values

Tab. 4 RMSE, R^2 and NSE of simulated and measured soil salinity values

Indicator	10 g · L^{-1} irrigation water	25 g · L^{-1} irrigation water	40 g · L^{-1} irrigation water	Raw water
RMSE	0.13	0.23	0.33	0.59
R^2	0.92	0.85	0.86	0.74
NSE	0.92	0.78	0.89	0.65

and the model defaulted to uniform root growth from the irrigation starting point to the end of the growing season. Combining the actual irrigation data and daily meteorological data, soil water and salt were simulated. Because the roots of the plants in the experimental plot were mainly distributed within the 0–40 cm range, and because the simulation accuracy for soil water in this interval was relatively high, the 15 cm and 30 cm soil layers were mainly simulated. The simulation results are shown in Fig. 5.

After irrigation, soil salinity and water are closely related, especially with the most pronounced response in the surface soil. Figures 5a and 5b show the process of change in soil water content, in which each increase in water content indicates that irrigation was carried out on that day (precipitation was relatively small and can be ignored). As shown in Fig. 5c and Fig. 5d, after irrigation began, the salts in the soil dissolved in the water, and the water moved downward under the action of gravity; salts leached with the water to deeper soil layers. This process is called salt leaching, during which soil salinity decreases rapidly. After the irrigation process ended, because evaporation is intense in desert areas, surface water evaporated rapidly, and water in the lower soil layers carried salts upward and accumulated in the surface layer, causing salt accumulation in the surface soil. Moreover, as time progressed, after soil water had undergone upward and downward movement, water content decreased, and the rate of increase in salinity in the surface soil also gradually slowed. In analyzing the change processes of surface soil water content and salt content within a given period, the dynamic relationship between the two was close. With multiple irrigations in the experimental area, except under raw-water irrigation, where the change in mineralization was relatively large, salt accumulation and increases appeared in the surface soil under the other salinity levels of irrigation.

3 Discussion

The desert area in the lower reaches of the Tarim River has an arid climate with little rainfall and a harsh natural environment. The application of sandy-land saline-water drip irrigation technology to establish shelterbelts can provide a strong guarantee for the safe operation of the Golmud–Korla Railway. In this paper, the effects of four salinity levels of irrigation water—10 $g \cdot L^{-1}$, 25 $g \cdot L^{-1}$, 40 $g \cdot L^{-1}$, and raw water (untreated groundwater)—on soil water and salt transport were studied. It was found that after irrigation ended, the water content of the surface soil rapidly decreased to below 10%. This is consistent with the phenomenon reported by Ding Xinyuan et al. [23]. Water is a key factor ensuring normal plant growth, and the poor water-retention capacity of sandy soil in shelterbelts makes how to slow the rapid loss of water from shallow soil after irrigation a focus of future work.

Soil salinization is a problem frequently encountered during the later construction and maintenance of shelterbelts. Based on the results of two salt observations in summer and autumn, this study found that the higher the salinity of the irrigation water, the more obvious the salt accumulation in the soil surface layer; this also confirms from another perspective the conclusion of Gong Kaige et al. [10]. Through observation of water–salt movement patterns over four years, Zhou Zhishan et al. [24] concluded that under the dominance of irrigation and evaporation, the overall soil salt content can maintain a relatively balanced state in the short term and presents periodic fluctuations. In this study, the model was used to simulate and reconstruct the fluctuation of salinity in the root-zone soil throughout the growing season, also showing that soil salinity has periodic fluctuation characteristics. However, from a long-term perspective, under continuous high-salinity irrigation, salt is continuously supplied to the soil; it tends to accumulate slowly at all depths. As seedlings gradually grow, the salt-accumulation effect of the root system [23] also begins to become evident, as

Fig. 5 Simulation of soil water and salt migration at depths of 15 cm and 30

Fig. 5 Simulation of soil water and salt migration at depths of 15 cm and 30 cm

Figure 4: Fig. 5 Simulation of soil water and salt migration at depths of 15 cm and 30 cm

cm

(a) Soil water content at 15 cm

(b) Soil water content at 30 cm

(c) Soil salt content at 15 cm

(d) Soil salt content at 30 cm

Legends: 10 $g \cdot L^{-1}$ irrigation water; 25 $g \cdot L^{-1}$ irrigation water; 40 $g \cdot L^{-1}$ irrigation water; raw water.
Axis labels: soil water content / $cm^3 \cdot cm^{-3}$; soil salt content / $g \cdot kg^{-1}$; date / month–day.

how to balance and regulate the spatial distribution of salts, and to seek effective desalination pathways, is the direction of further research.

In recent years, the use of software to simulate water–salt dynamics as a means of participating in water–salt management and regulation has become an increasingly popular approach. Yu Genjian

15

and Li Liang et al.

25

used the HYDRUS model to simulate and study the laws of water and salt transport in the Hetao irrigation district of Inner Mongolia, providing new ideas for regional water-saving, salt control, and the long-term development of irrigation districts. Li Kaiming

16

and Shi Peijun et al.

26

applied the HYDRUS model to simulate the laws of soil water and salt transport under open-ditch and subsurface-pipe drainage conditions, proving that under these conditions the HYDRUS model can be effectively applied. Li Huijie

27

and Wang Zaimin et al.

28

used the HYDRUS model to simulate, respectively, the water dynamics in the maize root zone and the water–salt transport patterns during cotton growth, showing that the model can be used to monitor soil water and salt conditions during crop irrigation. According to the above research results, the HYDRUS model can be applied flexibly under a variety of conditions and has been shown to have considerable reliability and stability. The use of HYDRUS numerical simulation methods can, while effectively reducing research costs, provide relatively accurate predictions of future changes in the soil water–salt environment, and can also play an effective auxiliary role in studies of other soil processes.

Under the severe conditions of continuous irrigation with highly mineralized saline water, especially when the irrigation-water salinity exceeds 30 $g \cdot L^{-1}$, the movement of water in the pore medium is affected by soil adsorption forces and changes in the pore structure of the soil body, and the solute-transport parameters of the soil change accordingly. Plants under irrigation with highly mineralized saline water are subjected to the dual stress of water and salt, and significant changes occur in physiological and ecological aspects; these issues all require further research. The actual movement of water after drip irrigation is three-dimensional, whereas this paper mainly considers the vertical movement of water beneath the dripper. Although the main water–salt movement process within the soil body is described, the lack of consideration of lateral movement and anisotropy results in some loss of spatial information. Preferential flow during infiltration generally cannot be ignored; however, considering that the surface of the experimental area was flat and the upper sandy soil was relatively homogeneous, and that no pores or fissures caused by plant-root growth or animal factors were observed, the possibility of preferential flow was relatively small. Therefore, this experiment assumed that preferential flow did not exist. In addition, in the model predictions, the influence of climate change on future model input parameters was not considered; subsequent research will focus on this issue.

4 Conclusions

(1) After irrigation, the water content of the surface soil layer (0–30 cm) increased rapidly and could quickly reach 15%–20%. After irrigation ceased, it again declined rapidly to below 10%. The change in water content in soil layers below 50 cm was relatively small, generally fluctuating between 5% and 10%.

(2) For the numerical simulation of soil moisture, the depth above 30 cm was better than the lower soil layer; for the numerical simulation of soil salinity, the simulated values and measured values showed relatively consistent spatial distribution patterns, with little discrepancy. The salinity simulation results under irrigation with relatively low-mineralization water had higher reliability.

(3) The HYDRUS-1D model was used to simulate the vertical variation trends

of soil water content and salt content under high-mineralization water drip-irrigation conditions. The simulated values had a high degree of fit with the measured values, indicating strong applicability in the study area and an ability to provide technical support for the construction of desert shelter forests.

References

[1] Fan Zili, Xu Hailiang, Fu Jinyi, et al. Ecological protection objectives and restoration measures in the lower reaches of the Tarim River[J]. Journal of Desert Research, 2013, 33(4): 1191-1197. [Fan Zili, Xu Hailiang, Fu Jinyi, et al. Ecological protection objects and restoration measures in the lower reaches of Tarim River[J]. Journal of Desert Research, 2013, 33(4): 1191-1197.]

[2] Chen Yaning, Li Weihong, Xu Changchun, et al. Desert riparian vegetation and groundwater in the lower reaches of the Tarim River Basin[J]. Environmental Earth Sciences, 2015, 73(2): 547-558.

[3] Ma Xuexi, Li Shengyu, Xu Xinwen, et al. Effects of saline-water irrigation with different mineralization levels on the survival and growth of seedlings of three *Tamarix* species[J]. Journal of Arid Land Resources and Environment, 2016, 30(1): 185-190. [Ma Xuexi, Li Shengyu, Xu Xinwen, et al. Effects of different mineralized irrigation water on seedling survival and growth of three species of *Tamarix* in Taklimakan Desert[J]. Journal of Arid Land Resources and Environment, 2016, 30(1): 185-190.]

[4] Zhu Jinfang, Xia Jiangbao, Lu Zhaohua, et al. Effects of salt-drought cross stress on the growth and physiological-biochemical characteristics of *Tamarix chinensis* seedlings[J]. Acta Botanica Boreali-Occidentalia Sinica, 2012, 32(1): 124-130. [Zhu Jinfang, Xia Jiangbao, Lu Zhaohua, et al. Growth physiological and biochemical characteristics of *Tamarix chinensis* seedlings under salt-drought intercross stress[J]. Acta Botanica Boreal-Occidentalia Sinica, 2012, 32(1): 124-130.]

[5] Liao Yan, Peng Yougui, Chen Guizhu. Research progress on mechanisms of plant salt tolerance[J]. Acta Ecologica Sinica, 2007, 27(5): 2077-2089. [Liao Yan, Peng Yougui, Chen Guizhu. Research advances in plant salt-tolerance mechanism[J]. Acta Ecologica Sinica, 2007, 27(5): 2077-2089.]

[6] Moreno F, Cabrera F, Fernandez-boy E, et al. Irrigation with saline water in the reclaimed marsh soils of south-west Spain: Impact on soil properties and cotton and sugar beet crops[J]. Agricultural Water Management, 2001, 48(2): 133-150.

[7] Li Fayong, Wang Xingpeng, Lin Jie, et al. Effect of brackish-water drip irrigation with different mineralization levels on soil alkali-hydrolyzable nitrogen in the root zone of jujube[J]. Arid Zone Research, 2013, 30(3): 424-429. [Li Fayong, Wang Xingpeng, Lin Jie, et al. Effect of drip irrigation with brackish water with different salinities on soil alkali-hydrolyzable nitrogen content in

rhizosphere of *Ziziphus jujuba* trees[J]. Arid Zone Research, 2013, 30(3): 424-429.]

[8] Wang Lijie, Zhou Zhibin, Chang Qing, et al. Effects of salt-drought cross stress on the growth and physiological-biochemical characteristics of *Populus pruinosa* seedlings[J]. Acta Ecologica Sinica, 2018, 38(19): 7026-7033. [Wang Lijie, Zhou Zhibin, Chang Qing, et al. Growth, physiological and biochemical characteristics of *Populus pruinosa* seedlings under salt-drought stress[J]. Acta Ecologica Sinica, 2018, 38(19): 7026-7033.]

[9] Xue Xinwei, Yang Hengshan, Zhang Ruifu, et al. Research progress on the effects of drip irrigation on soil water and salt movement and secondary salinization in semi-arid areas[J]. Chinese Agricultural Science Bulletin, 2019, 35(32): 89-94. [Xue Xinwei, Yang Hengshan, Zhang Ruifu, et al. Effects of drip irrigation on soil water and salt movement and secondary salinization in semi-arid areas: Research progress[J]. Chinese Agricultural Science Bulletin, 2019, 35(32): 89-94.]

[10] Dou Kaige, Wang Yongdong, Lei Jiaqiang, et al. Analysis of soil salinity distribution characteristics in the Tarim Desert Highway shelterbelt under saline-water drip irrigation[J]. Arid Land Geography, 2015, 38(3): 576-584. [Dou Kaige, Wang Yongdong, Lei Jiaqiang, et al. Salt distribution characteristics of Taklimakan Desert highway shelterbelt under saline water drip-irrigation[J]. Arid Land Geography, 2015, 38(3): 576-584.]

[11] Li Bingwen. Study on the mechanism of water-salt regulation in desert highway shelterbelts irrigated with saline water[D]. Beijing: Beijing Forestry University, 2010. [Li Bingwen. Mechnism of water-salt regulation for the shelterbelts with saline water irrigation along the Tarim Desert Highway[D]. Beijing: Beijing Forestry University, 2010.]

[12] Simunek J, Van Genuchten M T, Sejna M. The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media[J]. University of California-Riverside Research Reports, 2005(3): 1-240.

[13] Li Bingbing, Wang Yunqiang, Li Zhi. Applicability of the HYDRUS-1D model in simulating soil moisture in deep profiles of the rainfed highlands of the Weibei Plateau[J]. Chinese Journal of Applied Ecology, 2019, 30(2): 398-404. [Li Bingbing, Wang Yunqiang, Li Zhi. Applicability of HYDRUS-1D model in simulating the soil moisture in deep profiles on the Weibei rainfed highland[J]. Chinese Journal of Applied Ecology, 2019, 30(2): 398-404.]

[14] He Kangkang, Yang Yanmin, Yang Yonghui. HYDRUS-1D model simulation of soil water and salt movement under different brackish-water utilization modes in the low plains of North China[J]. Chinese Journal of Eco-Agriculture, 2016, 24(8): 1059-1070. [He Kangkang, Yang Yanmin, Yang Yonghui. HYDRUS-1D model simulation of soil water and salt movement under various brackish water use schemes in the North China Lowplain[J]. Chinese

Journal of Eco-Agriculture, 2016, 24(8): 1059-1070.]

[15] Yu Genjian, Huang Jiesheng, Gao Zhanyi. Simulation of soil water and salt transport under different irrigation modes based on the HYDRUS model[J]. Journal of Hydraulic Engineering, 2013, 44(7): 826-834. [Yu Genjian, Huang Jiesheng, Gao Zhanyi. Study on water and salt transportation of different irrigation modes by the simulation of HYDRUS model[J]. Journal of Hydraulic Engineering, 2013, 44(7): 826-834.]

[16] Li Kaiming, Liu Hongguang, Shi Peijun, et al. Simulation of soil water and salt transport under open-ditch drainage conditions[J]. Arid Zone Research, 2018, 35(6): 1299-1307. [Li Kaiming, Liu Hongguang, Shi Peijun, et al. Simulation of soil water and salt mi-

gration under open-ditch drainage[J]. *Arid Zone Research*, 2018, 35(6): 1299-1307.]

[17] Cao Qiaohong, Gong Yuanshi. Simulation and analysis of water balance and nitrogen leaching in winter wheat farmland using the Hydrus-1D model[J]. *Plant Nutrition and Fertilizer Science*, 2003(2): 139-145.
[Cao Qiaohong, Gong Yuanshi. Simulation and analysis of water balance and nitrogen leaching using Hydrus-1D under winter wheat crop[J]. *Plant Nutrition and Fertilizer Science*, 2003(2): 139-145.]

[18] Zhou Hong, Zhao Wenzhi. Soil physical characteristics of the shallow vadose zone in a desert region and simulation of their effects on the capillary rise of groundwater[J]. *Chinese Journal of Applied Ecology*, 2019, 30(9): 2999-3009.
[Zhou Hong, Zhao Wenzhi. Soil physical characteristics of shallow vadose zone and modeling its effects on upward capillary rise of groundwater in an arid-desert area[J]. *Chinese Journal of Applied Ecology*, 2019, 30(9): 2999-3009.]

[19] Zheng Bowen, Hu Shunjun, Zhou Zhibin, et al. Characteristics of soil moisture and the maximum capillary rise height of soil water at the southern edge of the Gurbantunggut Desert[J]. *Arid Land Geography*, 2020, 43(4): 1059-1066.
[Zheng Bowen, Hu Shunjun, Zhou Zhibin, et al. Maximum height of capillary rising water and characteristic of soil moisture in the southern edge of Gurbantunggut Desert[J]. *Arid Land Geography*, 2020, 43(4): 1059-1066.]

[20] Grinevskii S O. Modeling root water uptake when calculating unsaturated flow in the vadose zone and groundwater recharge[J]. *Moscow University Geology Bulletin*, 2011, 66(3): 189-201.

[21] Hou Yusheng, Wang Zhenhua, Li Wenhao, et al. Effects of water-fertilizer coupling on water consumption patterns and crop coefficients of drip-irrigated grapes in an extremely arid region[J]. *Journal of Soil and Water Conservation*, 2019, 33(2): 279-286, 330.
[Hou Yusheng, Wang Zhenhua, Li Wenhao, et al. Effects of water and fertilizer coupling on water consumption and crop coefficient of drip irrigated grape in extreme arid area[J]. *Journal of Soil and Water Conservation*, 2019, 33(2): 279-286, 330.]

[22] Chen Shengnan, Kong Zhe, Chen Lixin, et al. Stand transpiration characteristics of *Pinus tabulaeformis* and their influencing factors in a semi-arid urban environment[J]. *Acta Ecologica Sinica*, 2020, 40(4): 1269-1280.
[Chen Shengnan, Kong Zhe, Chen Lixin, et al. The stand transpiration characteristics of *Pinus tabulaeformis* and its influential factors in a semi-arid urban environment[J]. *Acta Ecologica Sinica*, 2020, 40(4): 1269-1280.]

[23] Ding Xinyuan, Zhou Zhibin, Xu Xinwen, et al. Dynamics of soil water and salt in an artificial shelterbelt under drip irrigation with saline water in the hinterland of the Taklimakan Desert[J]. *Acta Pedologica Sinica*, 2016, 53(1): 103-116.
[Ding Xinyuan, Zhou Zhibin, Xu Xinwen, et al. Dynamics of soil water and salt in soil under artificial plantation shelterbelt drip-irrigated with saline water in the center of the Taklimakan Desert[J]. *Acta Pedologica Sinica*, 2016, 53(1): 103-116.]

[24] Zhou Zhibin, Li Peijun, Xu Xinwen, et al. Effect of an artificial green belt in the hinterland of the Taklimakan Desert on the spatiotemporal distribution of salt in sandy land[J]. *Journal of Soil and Water Conservation*, 2002, 16(2): 16-19.
[Zhou Zhibin, Li Peijun, Xu Xinwen, et al. Effect of artificial green belt on salt distribution in sand land in hinterland of Taklimakan Desert[J]. *Journal of Soil and Water Conservation*, 2002, 16(2): 16-19.]

[25] Li Liang, Shi Haibin, Jia Jinfeng, et al. Simulation of water and salt transport patterns in uncultivated land in the Hetao Irrigation District of Inner Mongolia[J]. *Transactions of the CSAE*, 2010, 26(1): 31-35.
[Li Liang, Shi Haibin, Jia Jinfeng, et al. Simulation of water and salt transport of uncultivated land in Hetao Irrigation District in Inner Mongolia[J]. *Transactions of the CSAE*, 2010, 26(1): 31-35.]

[26] Shi Peijun, Liu Hongguang, He Xinlin, et al. Simulation of water and salt transport under subsurface drainage based on the HYDRUS model[J]. *Agricultural Research in the Arid Areas*, 2019, 37(3): 224-231.
[Shi Peijun, Liu Hongguang, He Xinlin, et al. The simulation of water and salt transportation under subsurface drainage by HYDRUS model[J]. *Agricultural Research in the Arid Areas*, 2019, 37(3): 224-231.]

[27] Li Huijie, Yi Jun, Zhao Ying, et al. Numerical simulation of the effects of shallow groundwater on moisture in the maize root zone and root water uptake[J]. *Journal of Irrigation and Drainage*, 2015, 34(11): 35-38, 46.
[Li Huijie, Yi Jun, Zhao Ying, et al. Effects of shallow groundwater table on root zone and root water uptake of maize using numerical model[J]. *Journal of Irrigation and Drainage*, 2015, 34(11): 35-38, 46.]

[28] Wang Zaimin, He Yujiang, Jin Menggui, et al. Optimization of a mulched drip-irrigation regime with brackish water for cotton using a soil water-salt transport model[J]. *Transactions of the Chinese Society of Agricultural Engineering*, 2012, 28(17): 63-70.

[Wang Zaimin, He Yujiang, Jin Menggui, et al. Optimization of mulched drip-irrigation with brackish water for cotton using soil-water-salt numerical simulation[J]. *Transactions of the Chinese Society of Agricultural Engineering*, 2012, 28(17): 63–70.]

Numerical simulation of water and salt migration in desert soil in the lower reaches of Tarim River under salt-water irrigation

WANG Shiming1,2,3,4, FAN Jinlong1,2,3,4, ZHAO Ying5, ZHANG Taotao1,2,3,4, LI Shengyu1,2,3,4

(1. State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China; 2. Mosuowan Desert Research Station, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Shihezi 832000, Xinjiang, China; 3. Taklimakan Desert Research Station, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Korla 841000, Xinjiang, China; 4. University of Chinese Academy of Sciences, Beijing 100049, China; 5. Ludong University, Yantai 264039, Shandong, China)

Abstract: During shelterbelt construction in the lower reaches of Tarim River, Xinjiang, China, the water and salt balance of the soil profile clearly changed because of underground saltwater irrigation. Establishing a numerical model is a very efficient means of understanding the vertical water and salt dynamics of soil. By reconstructing the dynamic process of water and salt in the soil profile, the regularity of soil water and salt migration in a high-salt environment can be revealed, which would be useful for the construction of shelterbelts in ecological engineering projects and sustainable management of the subsequent irrigation. In this study, the distribution characteristics and temporal changes of the soil water and salt under different salinity conditions for groundwater irrigation in the early construction stages of the HYDRUS-1D shelter forest were simulated. Soil water and salt data were collected for optimization of the soil water characteristic parameters, and the applicability of the established numerical model was evaluated. The results showed that the water and salt contents of the surface soil (0–30 cm depth) were greatly affected by irrigation with large fluctuations. Additionally, the salt content was highly concentrated at the soil surface. In the deep layer (50–150 cm), irrigation had a small influence with small fluctuations in values. The simulated values of the numerical model were in good agreement with the measured values, which demonstrated that the model could reflect the soil water and salt migration at the test site. The established model can be used to simulate the soil water and salt migration in the desert area downstream of Tarim River under different salinity conditions for irrigation and provides a theoretical basis and technical support for the construction of an ecological shelterbelt in this area. Using the HYDRUS numerical simulation method effectively reduces the research costs of accurately predicting future changes in the soil water and salt environment, and it can also play an effective auxiliary role in research on other soil processes. This experiment was conducted in a desert environment, and few experimental studies have been performed in similar environments. Hence, this study is innovative and can provide new ideas and methods for experimental studies in relevant desert environments.

Key words: salt water irrigation; soil water and salt migration; HYDRUS-1D model; lower Tarim River