Back calculation of soil hydraulic parameters based on HYDRUS-1D

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Abstract: Soil hydraulic parameters are the basis for simulating and calculating the progress of soil water movement and salt transport, and the parameters back-calculation method is simple and effective to determine those parameters. HYDRUS-1D software can simulate the movement of water, salt and heat of soil, as well as realize the inverse calculation of the soil hydraulic parameters through utilizing measured data. Based on the soil moisture content and negative-pressure data monitored in the Erdaoqiao test field of HangjinRear Banner ofInner MongoliaAutonomous Region, soil hydraulic parameters were inversely calculated, and the parameters were verified by utilizing the monitored data of soil with the same lithology under different conditions. The results show that soil moisture content and negative-pressure profile calculated by the soil hydraulic parameters through this method coincide comparably well with the measured results. This indicated that the soil hydraulic parameters obtained through this method were suitable for the moisture movement calculation of soil with the same lithology in field scale.

Keywords: HYDRUS-1D; Simulation; Soil hydraulic parameters

Introduction

Soil hydraulic parameter is an important embodiment of soil properties. Presently, many scholars here and abroad have taken a lot of studies on measuring method of soil hydrodynamic parameters, and they also proposed multiple measuring methods. Bruse and Klute (1956) put forward an infiltration method of semi-infinite horizontal column to measure the diffusivity D(θ) of unsaturated soil moisture; Gardner (1962) put forward an outflow method to measure the diffusivity D(θ) of soil water moisture content, through solving definite solution questions of outflow of transiently-variable pressure and gradually-variable pressure; SHAO Ming-An *et al*. (2000) put forward a simple infiltration method to calculate the parameters of soil moisture movement; WANG Quan-Jiu *et al*. (2002) analysed hydraulic parameters of soil by utilizing infiltration characters of horizontal column and Brooks-Corey model parameters. In recent years, inversely calculating the model parameter of soil hydraulic-characteristics by utilizing soil water movement progress has been focused and improved by some scholars. Shao M and Horton R (1998) were the first to propose to use integral method to definite Van Genuchten model parameter. ZOU Chao-wang (2006) and CHENG Qin-Bo (2010) *et al*. calculated the parameters of Brooks-Corey model according to different head infiltration data. The approximate solution usually used the simple primary functions to indicate the spatial and temporal distribution of flux, wetting front and soil moisture, fitting to obtain corresponding model parameters of soil hydraulic-characteristics. The methods above mostly provided soil hydraulic parameters for laboratory tests. However, as for the limitations of hydraulic parameters obtained in laboratory tests, these methods would cause relatively obvious errors when used for calculating soil moisture movement and salt transport in field scale. As numerical model of computer had been widely applied to the model of soil moisture movement, back calculating

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the parameters of soil moisture movement by utilizing numerical model had gradually become an important method for people to solve problems of soil moisture movement characteristics. WEI Yi-Chang (2004) and WANG Wei (2008) *et al*. utilized RETC software to derive and verify soil hydrodynamic-parameters, but the data obtained was imprecise. LIU Jian-Jun *et al*. carried out an analysis through back calculating soil hydraulic parameters with HYDRUS-1D. His analysis was based on cumulative infiltration-volume data of the test of one-dimensional water infiltration, and calculated inversely the parameters of soil hydraulic characteristics by utilizing HYDRUS-1D software. The result showed that the measured data of cumulative infiltration-volume, infiltration rate, wetting front and moisture content distribution of soil had some differences with the simulated data, and the relative average errors were all between 2% and 15% (LIU Jian-jun, WANG Quan-jiu, *et al*. 2010). On the basis of summarizing existing studies, this article calculated soil hydraulic parameters by utilizing the moisture content data of negative-pressure and profile of long-time sequence soil in the field tests, as well as the HYDRUS-1D model, and to verify the accuracy of the parameters through monitoring data in the field.

Developed by US Salinity Laboratory, HYDRUS-1D was used as an ideal platform to simulate the movement of moisture, solute and heat in one-dimensional variably-saturated vadose zone. After years of improvement, this software could well simulate vertical distribution, temporal and spatial variation and migration rule of moisture, solute, as well as energy in soil, being widely approved and applied (Simunek J, M Sejna, *et al*. 1998).

Relied on the monitoring data of field-test-site tests in the study area, this article calculated soil hydraulic parameters by utilizing HYDRUS-1D software, and carried out studies on soil hydraulic parameters in field scale. It had great significance to simplify the hydraulic parameters calculation, as well as to improve the calculated simulation accuracy of soil water.

1 Testing materials and methods

This test took two backfilling quadrats of clayey sand in situ as objects of study. In the test, the groundwater levels of 06 test quadrat and 01 test quadrat were 2.0 m and 1.2 m respectively. The dynamic monitoring system of soil water was utilized in the quadrats to obtain the data of soil water potential and soil moisture content.

Soil water potential: This test dynamically monitored the soil water potential of the test area by utilizing WM-1 mercury-type negative-pressure-meter system, which was developed by Institute of Hydrogeology and Environmental Geology, CAGS (WU Qing-hua, WANG Gui-ling, *et al*. 2012). The system was buried and inserted in shallow and oblique way. According to the reading of the mercury manometer, negative-pressure of soil could be calculated, and the calculation formula is as follows:

$$\psi_m = -12.6H_1 + 13.6H_0 - H_a + Z \quad (1)$$

Where, H_a was the distance from zero mark of the observation plate to the earth surface; H_0 was the height of mercury level of the mercury - record; H_1 was the height of the mercury level of negative-pressure-meter; and Z was the vertical distance from the middle of pot clay end to the earth surface.

Soil moisture content: The British IH-II neutron moisture gauge was utilized to measure soil with different depth, and by calibrating the neutron gauge, the calculation formula of soil moisture content was obtained as:

$$\theta = 48.508\, R/Rs + 13.337 \quad (2)$$

Where, θ indicated the soil moisture content; R was the neutron count of each measured layer; and R_s was measuring standard count, which was also called STD value.

Monitoring frequency: Water potential and moisture content of soil should be monitored every three days conventionally, but on the condition of rainfall or irrigation, intensive observations were essential: At preliminary stage, the data should be monitored once an hour, then monitoring time would be prolonged to 2 to 4 hours, and then 6 to 12 hours, extending time interval gradually. The

solution conductivity of soil should be monitored every three days.

Rain capacity and irrigation volume: The real-time data of rain capacity was obtained from micro weather station located in the testing field, and the distribution of rainfall and irrigation volume was as Fig. 1.

In the test area, the monitoring points of negative-pressure-meter and neutron gauge were distributed in the depth of 10cm, 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 70 cm,80 cm,100 cm,120 cm, 140 cm, 160 cm, and 180 cm. The test was carried out from June 14, 2010 to October 13, 2010, taking 214 days. Water potential, moisture content and solute conductivity of soil were monitored every three days, and additional measure was needed before and after the rainfall.

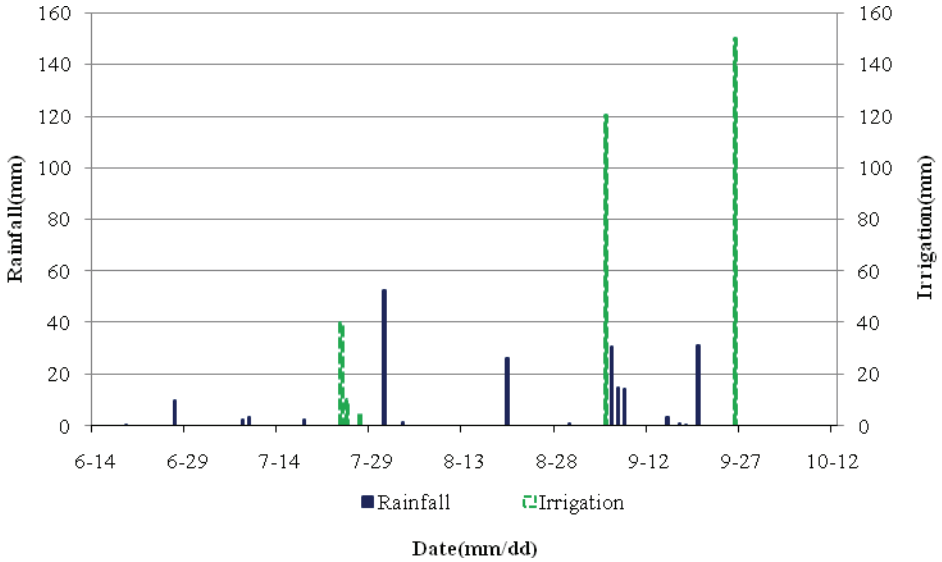

Fig.1 Distribution of precipitation and irrigation of No.6 test quadrat

2 Flow model

The simulated profile of flow model could be generalized to be saturated-unsaturated one-dimensional steady flow of homogeneous and isotropy clayey sand. Take earth surface as the base level, coordinate axis Z was perpendicular to it, and the downward was negative. Atmospheric boundary was chosen as the upper boundary, and the known water-head boundary as the lower boundary. The simulated depth was L: 0≤l≤L, and L=-200 cm. The simulation was carried out from June14, 2010 to October 13, 2010, totally taking 121 days. This could also expressed as 0≤t≤T，T=121 d. The governing equation and boundary conditions were as follows:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[\mathrm{K}(h)(\frac{\partial h}{\partial z} + 1)\right] - s \qquad (3)$$

Where, θ: Volumetric water content [L^3L^{-3}]; h: Pressure head [L]; K: Hydraulic conductivity [LT^{-1}]; z: Coordinate axis; t: Time [T]; s: Rate of water uptake by roots per unit depth.

Initial condition:

$$\mathrm{h}(z,0) = \mathrm{h}_0(z) \qquad Z \le z \le 0 \qquad (4)$$

Upper boundary:

$$-\mathrm{K}(h)(\frac{\partial h}{\partial z} + 1) = q \qquad z=0 \qquad (5)$$

Lower boundary:

$$\mathrm{h}(Z, t) = \mathrm{h}_b(t) \qquad (6)$$

Where, $h_0(z)$: Negative-pressure of initial soil water of the profile.q: for surface moisture flux [L/T], positive value was taken when evapo-transpiration, while negative value was taken when infiltration of rainfall and irrigation, and it was the boundary of upper variable flow. $h_0(t)$: Pressure head of lower boundary [L].

3 Parameter identification

Obtain experimental data and characteristic curve of soil moisture from laboratory, and analyze the data of characteristic curve of soil by utilizing RETC software. Meanwhile, discreet value of soil hydraulic parameters of clayed sand was obtained by fitting. Based on the discreet value of parameters, establish the model of soil moisture movement, and develop identification and correction of the parameters by soil moisture content and measured value of negative-pressure.

The equation of soil moisture characteristic curves showed that the negative-pressure value h was relatively larger, *a* was between 0.01 and 0.2, and the variation of moisture content was insensitive to a. The variation of moisture content was the most sensitive to n, which was the exponential order power. And the difference between residual moisture content and saturated moisture content was not obvious. Therefore, in parameter identification, *n* was mainly identified. According to the monitoring data of 06 clayed sand test site, when the groundwater was 2.0 m in buried depth, soil moisture content dynamic distribution curve in different periods showed that soil moisture content variation was mainly concentrated in the depth of 0 to 90 cm. So, the depth of 20 cm, 50 cm, 90 cm and 150 cm were regarded as simulated monitoring points. Then the fitting curves of soil moisture content, simulated negative-pressure value and measured value were observed by adjusting the parameters. (Fig. 2, Fig. 3)

The fitting chart of the measured value and simulated value through utilizing parameter identification obtained better fitting effect. The hydraulic parameters of clayed sand ware as Table 2.

Table 1 Productivity of soil hydraulic parameters

Lithology	θ_r	θ_s	α	n	K_s
Cay sand（0-60 cm）	0.11340	0.37260	0.52573	1.11880	150
Clay sand (60-120 cm)	0.10247	0.36061	0.54012	1.12130	150

Θr: residuewater content [L^3L^{-3}]; θs: Saturated water content [L^3L^{-3}]; α :the constant lapse rate saturated air; n:Exponential distribution of the porous volume; Ks :Saturated hydraulic conductivity; (cm · min^{-1})

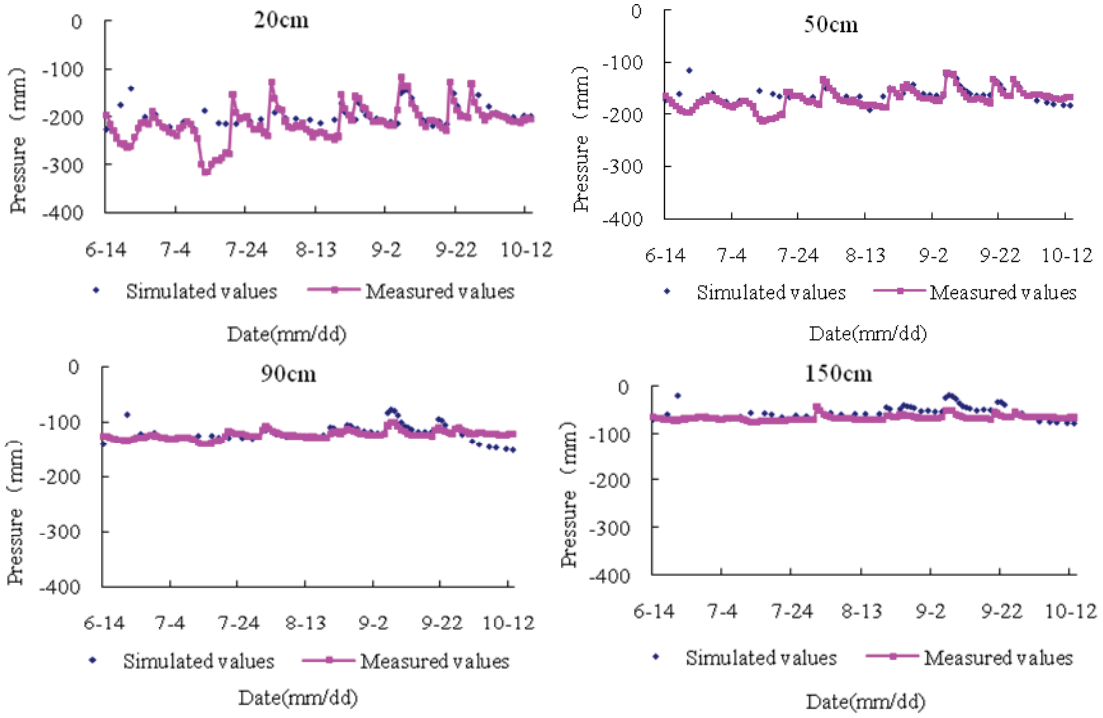

Fig. 2 Simulation values and measuring values of the soil negative pressure

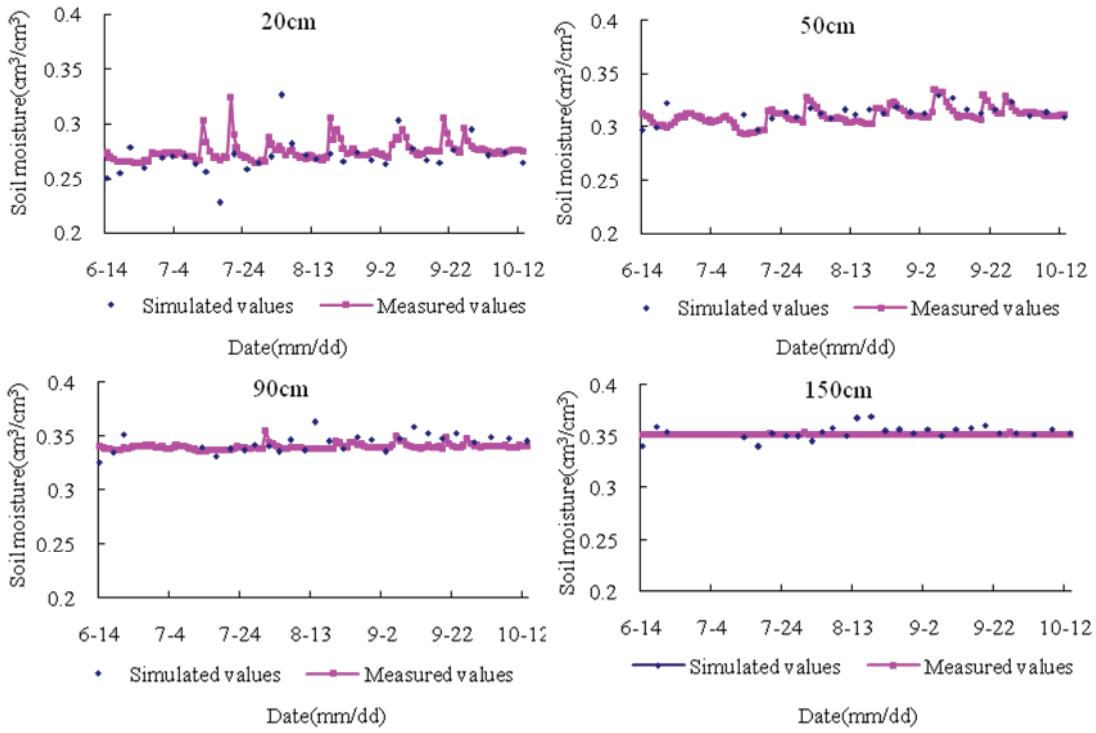

Fig. 3 Simulation values and measuring values of soil moisture

Table 2 Hydraulic parameter of clay sand (No.6) after model identification

Lithology	θ_r	θ_s	a	n	K_s	l
Cay sand	0.08814	0.3768	0.0135	1.16	150	0.5

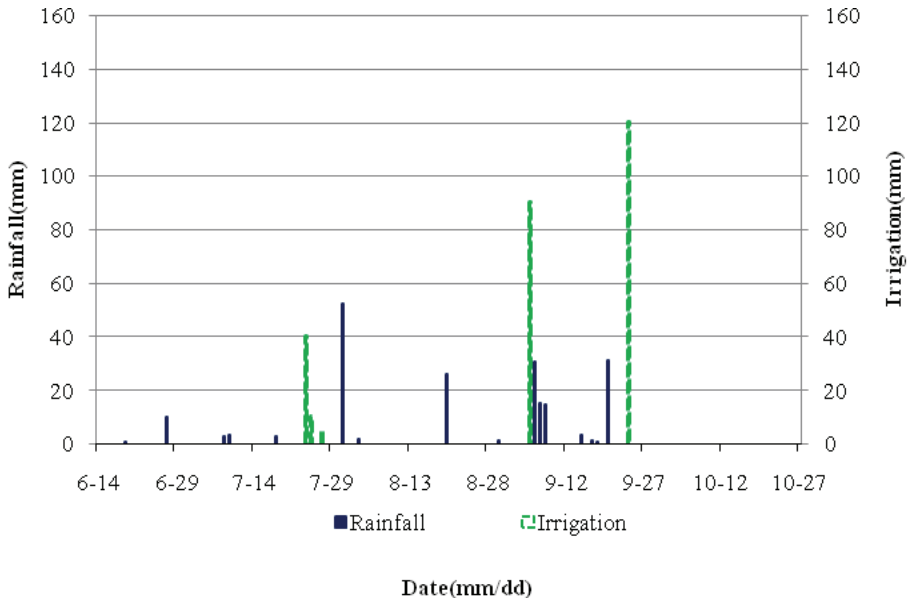

Fig. 4 Distribution of precipitation and irrigation of No.1 test quadrat

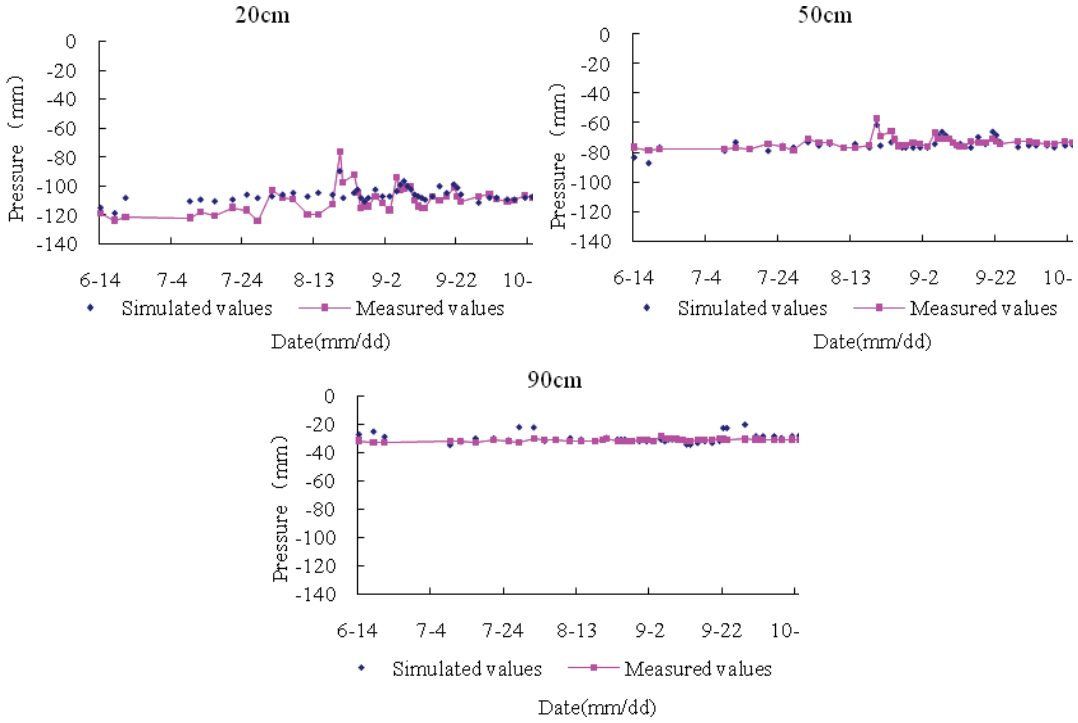

Fig. 5 Simulation values and measuring values of the soil negative pressure

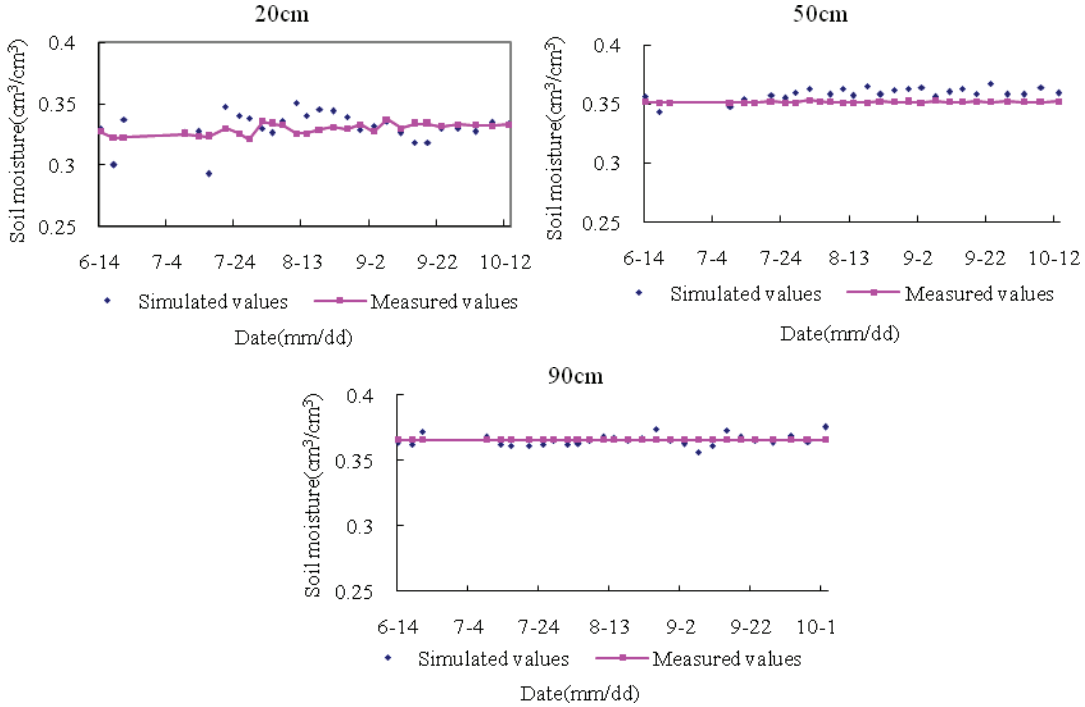

Fig. 6 Simulation values and measuring values of soil moisture

4 Parameter verification

For soil hydraulic parameters obtained by inversely calculating method, 01 test quadrat with the same lithology in the same test area was utilized to verify. It was known that rainfall and irrigation volume distribution of 01 test quadrat was as Fig. 3, groundwater level was kept 1.2 m in buried depth, and the simulated value and measured value of soil moisture content was contrasted and analyzed as follow Fig. 4, Fig. 5 and Fig.6.

5 Accuracy analysis

Utilize HYDRUS-1D software to inversely calculate the soil hydraulic parameters, and then carry out a simulated calculation for 01 test quadrat. The relative mean error (RME) between measured value and predicted value was taken as the criterion of simulated calculation accuracy. The result showed that the mean error rate of the simulated value and measured value with the buried depth of 20 cm was 3.01%; for 50 cm, it was 1.98%; and for 90 cm, it was 0.95%. The mean error rate of the simulated value and measured value of soil was 5.93% with the buried depth of 20 cm, and the rates were 3.72% and 9.31% respectively with the buried depth of 50 cm and 90 cm. As the groundwater level was 1.2 m in buried depth, the negative-pressure with the buried depth of 90 cm should be relatively stable and change slightly, the simulated value of soil negative-pressure and measured value of soil moisture content were relatively stable, but the measured value of negative-pressure fluctuated a lot. So it was inferred that there existed measured probe fault of soil negative-pressure with the buried depth of 90 cm.

6 Conclusions

This article calculated soil hydraulic parameters according to the measured data of soil moisture content, which was chosen in different periods from field-test-site in situ includes soil profile moisture content and soil water potential. It also utilized the measured value and simulated value of soil profile moisture content and soil water potential with the same lithology and in different periods to verify the rationality of oil hydraulic parameters calculated by the software. The result showed that in the simulating calculation by utilizing HYDRUS-1D software to inversely calculate the soil hydraulic parameters, the predicted value and the measured value fitted well, simulating soil moisture movement rule obviously. Depending on the monitoring data of soil moisture in field, and obtaining soil hydraulic parameters directly by utilizing HYDRUS-1D software was a simple and practical method with higher accuracy to calculate soil hydrodynamic parameters, which had a lot of superiority.

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