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Prediction of Soil Water Retention And Available Water Of Sandy Soils Using Pedotransfer Functions

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Abstract

Quantitative knowledge of the unsaturated soil hydraulic properties is required in most studies involving water flow and solute transport in the vadose zone. Direct measurement of such properties is often expensive and time-consuming. In this study, extended nonlinear PTF were established and its prediction performance for soil water retention and available water content were compared to those of artificial network for the Aeolian sandy soils at Beigou in Zhangwu country. PTFs were evaluated based on root mean square errors (RMSE) and mean errors (ME) between the observed and predicted values for the following depth intervals (0-20cm, 20-40cm). Results showed ENR and ANN with bulk density far underestimated soil water at certain suction with ME values ranging from -0.02 to -0.15 cm^3/cm^3, while ANN, ANN with soil water at certain suction overestimated soil water at 10 kPa, 33 kPa, 40 kPa and 200 kPa suctionin with ME values ranging from 0.04 to 0.16 cm^3/cm^3.

Keywords: soil water retention curve; available water content; pedotransfer function; artificial neural network

1. Introduction

The unsaturated soil hydraulic properties, such as the moisture retention curve and hydraulic conductivity are the crucial input parameters in water and solute transport modeling of unsaturated zone, and are difficult, expensive to measure directly. Direct measurements of hydraulic parameters are expensive and time-consuming. An alternative to direct measurement is the use of pedotransfer functions (PTFs) which translate existing surrogate data(e.g. particle size distribution, bulk density and organic matter content) into soil hydraulic data. PTFs are categorized into two main groups namely point

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pedotransfers and function pedotransfers [1-2]. Point pedotransfer predicts soil water at a pre defined suction, while function pedotransfers directly estimate hydraulic parameters of a closed-form equation [3-4], such as artificial neural network (ANN) [5]. ANN and extended nonlinear PTFs has been shown to lead to accurate estimate results if they are being applied in the similar soils where they be derived [6], ANN is a promising method to predict soil water retention curve and available water [7]. Some authors have established that PTFs require many input variables such as soil water at a predefined suction which performs the best prediction results [6]. But to our knowledge there has been very little information about prediction performance of these PTFs with different input data on the Aeolian sandy soils of the northeastern china. Therefore, this study was carried out to evaluate performance of PTFs to determine the soil water retention and available water for typical sandy soil in Zhangwu County soils in the Northeastern China based on a data set coving measured basic soil properties, soil water retention curves.

2. Materials and methods

2.1 Site description and soil sampling strategy

The study sites are Beigou in the Zhangwu region of northwestern Liaoning in northwestern China. Beigou is a village lies on the verge of north of keerqing sand. The climate of Liaoning is a temperate monsoon climate with a unimodal rainfall distribution. Most of the rain falls between June and August, with an average of 500mm. Soils in the study sites are classified as Aeolian sandy soils. Soil sampling was done using a stratified even grid sampling method where a 100×60m plot was subdivided into sixty 10×10m subplots. Soil bulk density samples were collected at surface depths from 8 to 12cm.

All cores were subjected to laboratory measurements to determine the particle size distribution with CIS-100 grainsize analyzer; the particle size distribution was further classified as sand (SA), silt (SI), and clay (CL) according to USDA. The cores were oven-dried at 105℃ to determine dry bulk density(BD). Organic carbon, OC in soil was determined with Elementar Vario EL Ⅲelemental analyzer，whereas organic matter content, OM, was calculated by multiplying the organic carbon content by 1.724. The soil water retention data were measured on 100cm^3 soil samples using a pressure membrane apparatus.

2.2 Extended Nonlinear Regression (ENR)

Extended Nonlinear Regression (ENR) method of Scheinost et al [8] was used to develop six different combinations of variables for predicting the van Genuchten parameters.

2.3 Artificial neural network (ANN)

Artificial neural network (ANN) may be performed in computer software program of Rosetta using a feed forward neural network which allows users to estimate water retention parameters in van Genuchten equation [4].

2.4 Evaluation criteria

Prediction performances of these PTFs were evaluated using RMSE and ME between the predicted soil water and the determined values and expressed as

$$RMSE = \frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2 \qquad (1)$$

$$ME = \sum_{i=1}^{N} \frac{(x_i - y_i)}{N} \quad (2)$$

3. Results and discussion

3.1Soil water retention curves estimated from PTFs

Fig 1 shows RMSE and ME values in 0-20cm and 20-40cm depth intervals. ME values of ENR were closer to 0 for soil water at different suction than those of the four ANN. ANN2 and ENR far underestimated soil water at certain suction with ME values ranging from -0.02 to -0.15 cm^3/cm^3, while ANN1, ANN3 and ANN4 overestimated soil water at water suction of 10 kPa, 33 kPa, 40 kPa and 200 kPa in 0-40cm depth intervals with value ranging from 0.04 to 0.16 cm^3/cm^3.

ENR resulted in the lowest RMSE values for predicting water at soil water suction of 33kPa and 40kPa, the next were ANN3 and ANN2, ANN1 and ANN4 were highest among the five models in 0-20cm soil depth intervals, while ANN2 were the higher than the other four PTFs in 20-40cm soil depth intervals. And RMSE showed a decreasing trend with suction increasing in 0-40cm soil depth intervals except for soil water at 6kPa in 0-20cm soil depth intervals. Overall, ANN3 and ENR perform superior than other PTFs. ANN1 and ANN4 showed similar results for predicting soil water.

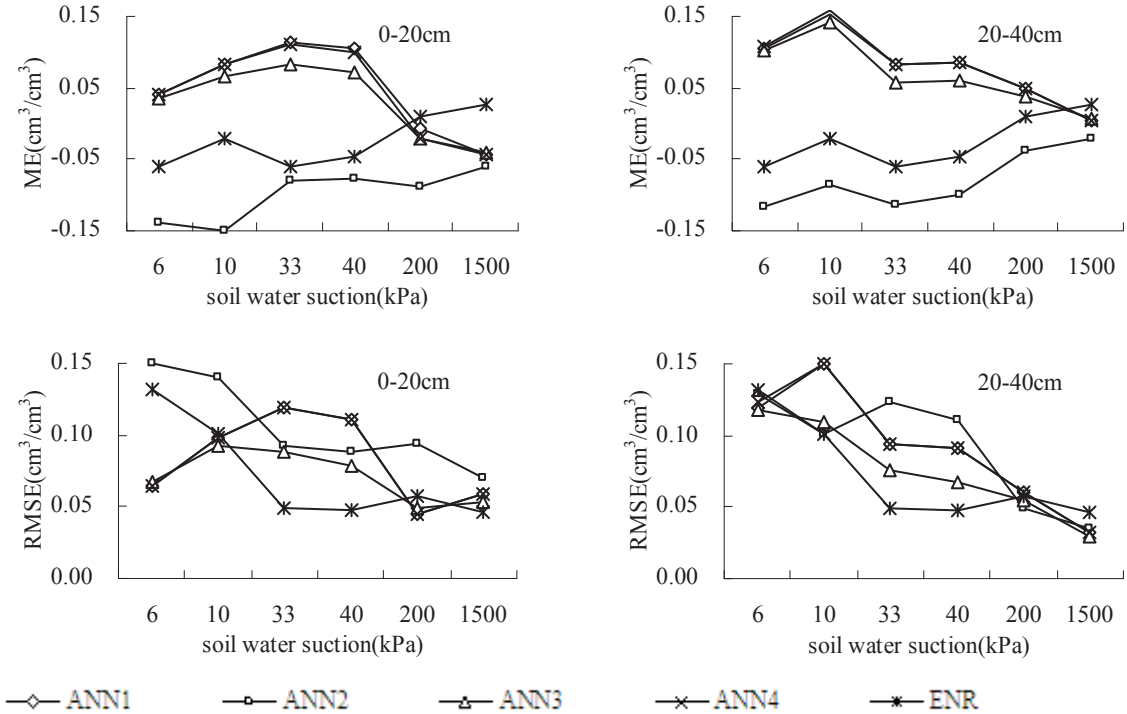

Fig 1 RMSE and ME for soil water at different soil water suction in 0-20cm and 20-40cm depth intervals

3.2 Available field available water from PTFs

The available water content is useful in many applications that involve plant, such as regional or global change soil-vegetation-atmosphere coupling studies, or for agricultural purposes. The available water content is loosely defined as the difference between field capacity and the permanent wilting point. The latter value is usually defined as $\theta_{1500kPa}$. Since pressure heads for field capacity (e.g., 6kPa, 10kPa, 33kPa), we evaluated the models for three available water contents: θ_{6kPa}-$\theta_{1500kPa}$ (referred as AWC1), θ_{10kPa}-$\theta_{1500kPa}$ (referred as AWC2), and θ_{33kPa}-$\theta_{1500kPa}$ (referred as AWC3).

The results in Table 4 show that, in general, ENR, ANN1 and ANN3 developed from this study underestimated available water content values, while ENR for SWC2 and SWC3 were very closer to the measured available water content comparing with ANN except for SWC1 at the 0-20cm soil depth intervals according to ME and RMSE. As regards to ANN, Adding to bulk density would not improve artificial network, but the model of additional adding θ_{6kPa} decreased ME values from -0.13 and -0.07 cm^3/cm^3 (ANN2) to 0.05 and 0.12cm^3/cm^3 (ANN3), but RMSE did not decreased from ANN2 (0.07 and 0.14 cm^3/cm^3) to ANN3 (0.07and 0.14cm^3/cm^3), except for SWC1 in 0-20cm soil depth intervals and SWC3 in 20-40cm soil depth intervals. The model of additional adding θ1500kPa did not decrease ME and RMSE. It implied that ANN with additional adding bulk density and soil water at certain suction did not improve prediction performance of pedotransfer function, which is different from PTFs for soil water retention curve.

In soil vertical direction, ME values of ENR and ANN2 for SWC1 and SWC2 in 0-20cm soil depth intervals were lower than those in 20-40cm soil depth intervals, which is contrary to those of SWC3, RMSE values showed similar results. On the contrary, ME and RMSE values of ANN1, ANN3 and ANN4 increased with the increasing of the soil depth except for SWC3 and SWC1 of ANN4 prediction. The reasons may be that that difference of PTFs for soil water at low suction and high suction as shown in Fig1.

Table 1 the estimated available soil water using pedotransfer function

			SWC1 (cm^3/cm^3)	SWC2 (cm^3/cm^3)	SWC3 (cm^3/cm^3)		SWC1 (cm^3/cm^3)	SWC2 (cm^3/cm^3)	SWC3 (cm^3/cm^3)
ENR	0-20cm	ME	-0.11	-0.08	-0.07	RMSE	0.12	0.08	0.08
	20-40cm	ME	-0.07	-0.04	-0.08	RMSE	0.11	0.07	0.10
PSD	0-20cm	ME	0.07	0.12	0.10	RMSE	0.10	0.14	0.13
	20-40cm	ME	0.09	0.14	0.07	RMSE	0.12	0.15	0.10
PSDBD	0-20cm	ME	-0.13	-0.11	-0.07	RMSE	0.14	0.11	0.09
	20-40cm	ME	-0.09	-0.07	-0.09	RMSE	0.10	0.07	0.11
PSDBD6	0-20cm	ME	0.07	0.10	0.06	RMSE	0.10	0.12	0.10
	20-40cm	ME	0.09	0.12	0.05	RMSE	0.11	0.12	0.07
PSDBD615	0-20cm	ME	-0.17	0.22	0.17	RMSE	0.17	0.24	0.20
	20-40cm	ME	-0.14	0.25	0.16	RMSE	0.14	0.26	0.17

4. Conclusions

ENR and ANN PTFs were used to estimate soil water rentention and available water content. Whether 0-20cm and 20-40cm soil depth intervals, ENR PTFs performs best for soil water points and available water between θ_{10kPa}, θ_{33kPa} and $\theta_{1500kPa}$; for ANN, ANN3 for soil water retention curve

performed superior than the other ANN, ANN3 for SWC1 and SWC3 performed slightly better than ANN1, while ANN2 for SWC2 performed slightly better than the other ANN. Therefore, pedotransfer were derived in this study may be used to estimated soil hydraulic properties in sandy soil. ANN with θ_{6kPa} may improve prediction performance of soil water retention curve and available water content between θ_{10kPa}, θ_{33kPa} and $\theta_{1500kPa}$; but ANN with additional $\theta_{1500kPa}$ may not improve prediction performance of soil water retention and available water.

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