Dear Editor,

We would like to express our great appreciation to editor and reviewers for their constructive comments on our manuscript (Manuscript ID: hess-2017-668). We have revised the manuscript according to these comments and now submit a point-by-point response, a marked manuscript and a revised manuscript. We hope the revised manuscript would meet with publication requests.

In addition, the cost of English Language Editing for this manuscript was also was supported by the National Natural Science Foundation of China (41472220) and we hope to add it in Acknowledgement. We would be greatly appreciated if you could allow our request.

Looking forward to hearing from you

Best regards,

Dong-hui Cheng

A list of all relevant changes made in the manuscript

1. Performing T-test analysis between the performances of the three methods, and adding the corresponding results in revised manuscript.

2. Adding the advantage and disadvantages of proposed method in Section 4.2.

3. Adding two tables of detailed information for both validation and calibration data sets in revised manuscript.

4. Rewritten Section 3.1

5. Revising Section 4.3.1

6. Editing the English language of the whole manuscript

7. Revising other small points suggested by reviewers.

A point-by-point response to reviewers and editor

Reviewer 1 (F. Meskini-Vishkaee)

1.In response to reviewer's comment "Specific surface area (SSA) is a required parameter to obtain the values of α and β. The authors used a power equation with two fitting parameters (Eqn. 10) to estimate SSA proposed by Sepaskhah et al. (2010). Sepaskhah et al. (2010) used twenty soil samples from a depth of 0–30 cm were collected from different locations in Fars province, in the south of Iran to calibrate the power equation. In addition, a different set of data was used to validate the calibrated model. Their results indicated that in the range of around 20 up to 200 m^2 g^-1 the values of measured SSA were in quite a good agreement, while for SSA greater than 200 m^2 g^-1, the deviations increase distinctly. As respects higher SSA is related to finer texture soils that usually have underestimation problem of estimated SWCC from PSD, Indeed, I think use power model to estimate SSA cannot be useful to improve estimated SWCC in fine-textured soils. ", the authors mentioned that in proposed method, the values of parameter α and β were firstly figured out using SSA and the measured SWC, and then these parameters were used for predicting SWC as input parameters. For the predicted SWCs of fine-textured soils which calculated from the parameter α and β, the errors from estimated SSA, to some extent, could been offset by the parameter α and β. Besides, the parameter α and β were main used to estimate the volume fraction of the slit-shaped spaces, thus the estimation accuracy of SSA influence the estimation of the volume fraction of the slit-shaped spaces, consequently the degree of improvement of predicted SWC.

Comment a:

The main objective to estimate SMC from PSD is to have SMC data when this data is not available. However, as mentioned above, SMC data is needed to develop proposed model for the accurate estimation especially for the fine-textured soils.

Response:

The SWRC data is not needed until developing proposed model. When predicting the SWRC, required input data include the PSD, the measured water content and the bulk and particle densities.

2. Regardless good performance of proposed model, SSA is used to develop model and SSA measurement is very difficult, thus it must be estimated. The proposed model is an estimation method that needs to estimate its input parameters. It is a disadvantage of proposed model.

Comment a:

The authors noted that the results illustrated that the improved method here applied well to a wide range of soils, while the scaling approach performed better for fine- and medium-textured soils. The validation results illustrate that the

SMC predicted using the proposed method provided the best predictions of the SMC, closely followed by the scaling approach, and the traditional method performed worst. Did the authors do any statistical analysis between the performances of three models? Is there any significant difference between three models? The authors could perform a paired T-test analysis between proposed and Meskini-Vishkaee models for mean model performance in different soil textural classes.

Response:

We have performed a T-test analysis between the performances of three methods. The results showed that there is a significant difference between performance of improved method and traditional method (p=0.001). Only for sand samples, the performance of improved method and scaling approach have significant statistics difference (p=0.01).This content have been added in Section 4.2.

Comment b:

Even if there was a significant difference between two desired models, the proposed model is a complex model with some input parameters that is need to estimate from some difficult properties such as SSA. It is correct that the assumption of pore space geometry containing slit-shaped spaces may be affected on the accuracy of the estimation, but on the other hand, this assumption could be increased the model inputs and complexity.

Response:

As the reviewer mentioned that the principle of proposed model is complex, but if you have understood its calculation procedure, it would be easy to predict the SWRC of multiple samples in Excel or other software.

Comment c:

I think that the authors have to add some more discussion to explain the advantage and disadvantages of proposed model. Moreover, performing statistical analysis between model performances is necessary and must be added to the manuscript text.

Response:

We have added the statistical analysis results between model performances in Section 4.2. Meanwhile, we have added the advantage and disadvantages of proposed model in this section.

3. The authors provided detailed information of both validation and calibration data sets in two tables in response to reviewers. I think these tables have to add in main text of manuscript. Note: offering of the statistical criteria for each soil textural classes is not necessary. Presenting of the mean, max and min of all data for both dataset is enough.

Response:

We go along with the suggestion of reviver above, and we have added two tables of detailed information for both validation and calibration data sets in revised manuscript.

Reviewer 2

Comment 1: Throughout the entire manuscript, I strongly suggest using "soil water retention curve", rather than "soil water characteristic curve", as it is by far the more established (and clear) name for the curve you are estimating (indeed, usually two soil water characteristic curves are considered: water retention curve and hydraulic conductivity curve). Consistently, I would adopt the acronym SWRC (or simply WRC) instead of SWC.

Response:

We agree with the reviewer's viewpoint above, and we have adopted "soil water retention curve" instead of "soil water characteristic curve" in the revised manuscript.

Comment 2: Section 3.1

This modified section now gives more information about how water potential in silt shaped voids has been calculated. However, this section should be rewritten and better organized:

Response:

We go along with the comments of reviver above. This section has been rewritten in the revised manuscript.

Comment 3: Page 5, line 20: the values of the parameters of Table 2 are here discussed before introducing Table 2 and the way such parameters were estimated. Section 3.1 should contain only general (theoretical) arguments, and the eventual confirmation given by the estimated parameters should be discussed afterwards.

Response:

We agree with the reviewer's viewpoint above, we have moved the eventual confirmation given by the estimated parameters to Section 4.3.1.

Comment 4: Page 5, equation (7): I don't see the necessity of writing this equation, as it is exactly the same as equation (4) (cos $\varepsilon = 1$), written in terms of water potential rather than in terms of suction head. You should simplify your discussion by simply stating that you are using exactly the same equation in circular voids and in slits.

Response:

Although the capillary theory are commonly used in equation (4) and equation (7) which calculated the suction head in central pore and slit-shaped spaces, the equivalent pore radius are different in these two equations. Consequently, it's more understandable to write equation (4) and equation (7) in manuscript. We revised the corresponding discussion but retained the original content.

Comment 5: Page 5, lines 24-26: you state that 6502 is smaller than 5000, while it is obviously not so. This is again the issue of the intrinsic negative values of water potential that I already raised in my previous report. You should decide if you want to refer to suction head (as you write in your answer to my previous comment), or to water potential (as in equation 7), and then stick consistently to this choice throughout the entire manuscript.

Response:

Thank reviewer for pointing out my mistake. The suction head will be used throughout the entire manuscript, the false statement on Page 5, lines 24-26 has been revised,

Comment 6: Page 5, lines 25-26: I don't agree with this statement. The values of suction head do not demonstrate anything about the dimensions of the voids where the meniscus is supposed to be located. They are, instead, a consequence of the dimensions, which are in turn a consequence of the estimated values of the parameters α and β, that you are discussing here, before explaining how they were estimated and which results you obtained (see my previous comment in this respect).

Response:

On the basis of capillary theory, suction head can be associated with pore radius with the capillary equation (Ding et al., 2016). Besides, Jayakody et al. (2014) calculated the pore size using the capillary theory. Consequently, the pore size can be estimated using suction head under the assumption of considering the capillary forces only. We have revised the statement to make it clear and this aspect have been moved to Section 4.3.1.

Comment 7: Page 5, line 27: the word "included", instead of "contained", would be more appropriate and would make the concept clearer to the reader. My concerns about soil surface area and soil specific surface area have been addressed in section 4.3.2. Few minor issues in the newly added parts:

Response:

Considering the reviewer's suggestion above, the word "included" have been used in the revised manuscript.

Comment 8: Page 10, line 10: The meaning of the sentence "This effect may contribute to the lower SSA value for this texture than the fine-textured soil" is obscure. Please, reformulate it, or delete it.

Response:

According to the Reviewer's suggestion, we have deleted the sentence "This effect may contribute to the lower SSA value for this texture than the fine-textured soil".

Comment 9: Page 10, line 13: What does it mean "soil media data"?

Response: "soil media data" is a loose phrase, we have adopted "soil properties" in the revised manuscript.

Comment 10: Page 10, lines 19-21: The syntax of the two sentences, from "Overall" till the end of the section, is wrong.

Response: We have revised the sentences as "Therefore, more effort should be placed toward developing a more accurate transformation from the soil physical properties to S_{SA} to further improve the prediction of the SWRC."

Comment 11: Section 4.3.3 is called "Physical meanings of the parameters", while it actually gives no physical interpretation of the obtained values. Just a comparison with the results of the conceptually similar model by Or and Tuller (1999) is proposed. I also observe that the adopted model of the pore geometry is just conceptual (and not physical at all), so I would refrain from claiming that the obtained parameter values have any physical meaning, and I would use another name for this section.

Response:

We agree with the reviewer's viewpoint above, the name of Section 4.3.3 has revised as "The slit-shaped spaces and the S_{SA} at the sample scale".

References

Ding, D., Zhao, Y., Feng, H., Peng, X., and Si, B.: Using the double-exponential water retention equation to determine how soil pore-size distribution is linked to soil texture, Soil & Tillage Research, 156, 119-130, 2016.

Jayakody, K. P. K., Shimaoka, T., Komiya, T., and Ehler, P.: Laboratory determination of water retention characteristics and pore size distribution in simulated MSW landfill under settlement, International Journal of Environmental Research, 8, 79-84, 2014.

Predicting the ~~soil water characteristic curve~~soil water retention curve from the particle size distribution based on a pore space geometry containing slit-shaped spaces

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Abstract. Traditional models employed to predict the ~~soil water characteristic curve~~soil water retention curve (~~SWC~~SWRC) from the particle size distribution (PSD) always underestimate the water content in the dry range of the ~~SWC~~SWRC. Using the measured physical parameters of 48 soil samples from the UNSODA unsaturated soil hydraulic property database, these errors were proven to originate from an~~the~~ inaccurate estimation of the pore size distribution. A method was therefore proposed to improve the estimation of the water content in the high suction range using a pore model comprising a circle-shaped central pore connected to slit-shaped spaces. I~~; i~~n this model, the pore volume fraction of the minimum pore diameter range and the corresponding water content were accordingly increased. The predicted ~~SWC~~SWRCs ~~predicted~~ using the improved method reasonably approximated the measured ~~SWC~~SWRCs, ~~and~~ which were more accurate than those obtained using the traditional method and the scaling approach in the dry range of the ~~SWC~~SWRC.

1 Introduction

The ~~soil water characteristic curve~~soil water retention curve (~~SWC~~SWRC), which represents the relationship between the water pressure and water content, is fundamental to researching water flow and chemical transport in unsaturated media (Pollacco et al., 2017). Direct measurements of the ~~SWC~~SWRC consume both time and money (Arya and Paris, 1981; Mohammadi and Vanclooster, 2011), while estimating the ~~SWC~~SWRC from the particle size distribution (PSD) is both rapid and economical. Therefore, a number of associated conceptual and physical models have been proposed.

The first attempt to directly translate a PSD into an ~~SWC~~SWRC was performed by Arya and Paris (1981) (here ~~in~~after referred to as the AP model). In this model, the PSD is divided into multiple size fractions and the bulk and particle densities of the natural-structure sample are uniformly applied to each particle size fraction, from which it follows that the ~~relative~~ pore fraction and the corresponding ~~relative~~ solid fraction are equal. Thus, the degree of saturation can be set equal to the cumulative PSD function. The soil suction head can be obtained using the capillary equation based on a "bundle of cylindrical tubes" model, and the pore size in the equation is determined by scaling the pore length and pore volume (Arya et al., 2008). Based on the principle of the AP model, many researchers have focused on improving the suction head calculations, which are commonly based on the capillary equation; but~~however, various~~ methods that are used to translate the particle diameter into the pore diameter are different (Haverkamp et al., 1986; Zhuang et al., 2001; Mohammadi and Vanclooster, 2011; Jensen et al., 2015). Some models estimate the pore diameter based on the particle packing patterns (e.g., the MV model){Meskinivishkaee, 2014 #120}, while others utilize the proportionality factor between the pore size and the associated particle diameter (e.g., the HP model and the two-stage approach){Haverkamp, 1986 #75}{Jensen, 2015 #131}. However, the scheme employed to estimate the water content has not been modified and follows the approach of the AP model. The ~~SWC~~SWRC predictition~~ng~~ models which use~~have~~ the same scheme to predict the water content and only improve the suction head calculation are referred to~~termed as~~ the traditional models in following text.

However, these traditional models underestimate the water content in the dry range of the ~~SWC~~SWRC (Hwang and Powers, 2003; Meskini-Vishkaee et al., 2014). Therefore, some researchers have attempted to improve the water content calculation approach by attributing model errors to both a simplified pore geometry and an incomplete desorption of residual water in the soil pores within a~~the~~ high suction head range (Tuller et al., 1999; Mohammadi and Meskini-Vishkaee, 2012). Recent findings have revealed the existence of corner water, lens water and ~~film water~~ water filmswater filmsin soils at high matric suction heads (Tuller et al., 1999; Mohammadi and Meskini-Vishkaee, 2012; Or and Tuller, 1999; Shahraeeni and Or, 2010; Tuller and Or, 2005). Therefore, Mohammadi and Meskini-Vishkaee (2012) predicted a~~the~~ ~~SWC~~SWRC based on the PSD while considering the adsorbed ~~water film~~water films and lens water between the soil particles, and slightly improved upon the traditional MV model. Tuller et al. (1999) proposed a pore space geometry containing slit-shaped spaces and derived a corresponding ~~SWC~~SWRC that considered both the ~~water film~~water films and water inside the angular-shaped pores; however, the ~~SWC~~SWRC failed to describe experimental data at an intermediate water content due to the limitations of the gamma distribution function used to characterize the pore size distribution (PoSD) (Lebeau and Konrad, 2010). Moreover, this model was mathematically complex. (Mohammadi and Meskini-Vishkaee, 2013) incorporated the residual water content into the MV model and consequently decreased the magnitude of the underestimation in the dry range of the ~~SWC~~SWRC. However, an accurate estimation of the residual water content remains a challenge. Meskini-Vishkaee et al. (2014) improved the traditional MV model by defining a soil particle packing scaling factor.~~,~~ T~~and t~~his method could improve the estimation of the ~~SWC~~SWRC, and is particularly significant for~~ the~~ fine- and medium-textured soils.

Many traditional models are based on a “bundle of cylindrical tubes” representation of the pore space geometry (Arya and Paris, 1981;Zhuang et al., 2001), which results in intrinsic errors when predicting the water flow in variably saturated soils. Consequently, some researchers have considered pore networks as bundles of triangular tubes, which could incorporate the contribution of water in pore corners to the water content (Helland and Skjæveland, 2007). A new pore geometry model comprised of~~ing~~ a polygon-shaped central pore connected to slit-shaped spaces was proposed by Tuller et al. (1999) to provide a more realistic representation of natural pore spaces (Tuller et al., 1999; Or and Tuller, 1999; Tuller and Or, 2001). This pore model could represent a foundation for accurately describing the water status in natural soils, particularly in arid environments.

Therefore, t~~T~~he objectives of this study were~~ therefore~~ to evaluate the leading factors that lead to an~~the~~ underestimation of the water content in the dry range of the predicted ~~the SWC~~SWRC using traditional methods and to furthermore propose a method for accurately estimating the water content using a pore space geometry containing slit-shaped spaces to improve the prediction of the ~~SWC~~SWRC.

2 Basic descriptions

The relationship between the PSD and the PoSD is a fundamental element when predicting the ~~SWC~~SWRC from the PSD. Hwang and Powers (2003) found that the nonlinear relationship between the PSD and the PoSD is~~would be~~ more appropriate than the linear relationship applied in the AP model and therefore described both the PSD and the PoSD as lognormal distributions. However, since the PSD and PoSD of soils do not strongly follow a lognormal distribution, this model performed very poorly for moderately fine-textured soils (Hwang and Choi, 2006). Obtaining an accurate PoSD from the PSD of a soil is highly difficult, and the errors that arise from this approach could cause inevitable errors in the predicted ~~SWC~~SWRC. However, the underestimation of the water content in the dry range of an ~~SWC~~SWRC has not been comprehensively evaluated from this perspective.

In this study, the measured PoSDs of 48 soil samples were compared with the PoSDs calculated using a traditional model (they were actually the corresponding PSDs) to identify the origins of the errors and their effects on the accuracy of the predicted ~~SWC~~SWRC. The provided 48 soil samples exhibited a wide range of physical properties (Table 1)~~,~~ and~~ they~~ were selected from the UNSODA unsaturated soil hydraulic property database, which contains 790 soil samples with general unsaturated soil hydraulic properties and basic soil properties (e.g., water retention, hydraulic conductivity, soil water diffusivity, PSD, bulk density, and organic matter content) (Nemes et al., 2001). The maximum, minimum and mean values of the soil bulk density and the percentages of clay and sand of the used soil samples for calibration stage were presented in Table 2.

(1) Calculating the PoSD using a traditional model

Traditional models commonly assume that the pore volume fraction of each size fraction can be set equal to the relative solid fraction(Arya and Paris, 1981). Thus, the cumulative pore volume fraction can take the following form:

$$\sum_{j=1}^{j=i} v_j = \sum_{j=1}^{j=i} \omega_j; \qquad i = 1, 2, \cdots\cdots n \tag{1}$$

where ω_j is the solid fraction of the jth particle fraction, v_j is the pore volume fraction associated with the jth fraction, and n is the total number of size fractions in the PSD.

The routine procedures employed among the several traditional models to translate a particle diameter into a pore diameter are different. The equivalent pore diameter can be derived from physical properties, including the bulk density and the particle density, or from the proportionate relationship between the pore size and associated particle diameter. Although the former can logically characterize a pore, a complicated pattern can slightly reduce the model performance. While~~,~~ the

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latter approach is easy to use, and its rationality has been demonstrated by some researchers (Hamamoto et al., 2011;Sakaki et al., 2014). Here, the latter technique is~~was~~ applied, and it can be expressed as

$$d_i = 0.3D_i \tag{2}$$

where D_i is the mean particle diameter of the *i*th fraction (μm) and~~,~~ d_i is the corresponding equivalent pore diameter (μm). Inputting the PSD data, then the calculated pore diameters are sequentially paired with corresponding pore volume fractions to obtain a c~~C~~alculated PoSD.

(2) Estimating the PoSD from the ~~SWC~~SWRC

It is generally difficult to measure the PoSD of a soil; however, the PoSD can be indirectly obtained using the measured water content and suction head (Jayakody et al., 2014). The cumulative pore volume fraction of the *i*th fraction is equal to the ratio of the measured water content to the saturated water content (Eq. (3)):

$$\theta_i = \theta_s \sum_{j=1}^{j=i} \nu_j; \qquad i = 1, 2, \cdots\cdots n \tag{3}$$

where θ_s is the saturated water content ($cm^3\ cm^{-3}$)~~,~~ and θ_i is the measured water content ($cm^3\ cm^{-3}$).

Meanwhile, the corresponding pore diameters are derived on the basis of Laplace's equation and Eq. (4):~~.~~

$$\psi_i = \frac{2\sigma \cos\varepsilon}{r_i g \rho_w} \tag{4}$$

where ψ_i is the suction head (mH_2O), ~~,~~ σ is the surface tension ($kg\ s^{-2}$), ε is the contact angle between the soil particle and water, r_i is the pore radius (m), and ρ_w is the density of water ($kg\ m^{-3}$). Assuming for water at 20℃ ~~,~~ σ=7.275×10^{-2} $kg\ s^{-2}$, ρ_w=998.9 $kg\ m^{-3}$, g=9.81 $m\ s^{-2}$, and ε=0°(Mohammadi and Vanclooster, 2011), then transforming r_i to d_i and substituting numerically the values of the constant~~s~~ yield~~s~~ a simplified expression as Eq. (5):~~.~~

$$\psi_i = \frac{3000}{d_i} \tag{5}$$

where ψ_i is the suction head (cmH_2O) and~~,~~ d_i is the pore diameter (μm). Then, the pore diameters calculated by Eq. (5) were sequentially paired with the cumulative pore volume fractions calculated by Eq. (3) to obtain a PoSD, which could be considered a measured PoSD.

The calculated and measured PoSD data were fitted using a modified logistic growth model (Eq. (6)) (Liu et al., 2003):

$$w_i = \frac{1}{1 + a\exp\left(-bd_i^c\right)} \tag{6}$$

where w_i is the cumulative pore volume fraction with diameters smaller than d_i (%)~~,~~ and a, b, and c are the fitting parameters (dimensionless). This model produced a good fit for the PoSD data employed in this study with a coefficient of determination (r^2) that ranged from 0.972 to 0.999.

The measured pore volume fraction curves for the typical samples, namely, sand (code: 3172) and clay (code: 2360), and their calculated curves using the traditional model are presented in Fig. 1. The small maps embedded in Fig. 1 exhibit the measured and calculated PoSD curves, which~~. Figure 1~~ show that the calculated PoSD curves approximately coincide with the measured curves in the larger pore diameter range, while~~ the calculated values~~ in the smaller range, which corresponds to the higher suction range on the ~~SWC curve~~SWRC, the calculated values are obviously smaller than the measured values. The underestimation of the pore volume fraction in the smaller pore diameter range can consequently lead to an underestimation of the water content in~~at~~ the~~a~~ higher suction range. In particular, the calculated pore volume fraction associated with the smallest pore diameter ($d \leq 0.6$ μm) was far less than the measured pore fraction. These results illustrated that the underestimation of the pore volume fraction with respect to the smallest pore diameter ($d \leq 0.6$ μm) was a key factor with regard to the underestimation of the water content in the dry range of the ~~SWC~~SWRC.~~ ~~In addition~~Besides~~, the underestimation of the pore volume fraction is associated with an oversimplified pore space geometry, which traditional models have generally characterized as a bundle of cylindrical capillaries. The measured and calculated pore curves of the other 46 soil samples behaved in the same fashion, and those curves are provided in the S~~s~~upporting I~~i~~nformation (Fig. S1).

3 Improved method

3.1 Estimating the pore volume fraction

In this study, the soil pore structure was conceptualized within a pore model in which the elementary unit cell is composed of a relatively larger circle-shaped central pore connected to two slit-shaped spaces (see Fig. 2). Relative to the polygonal central pore connected to the slit-shaped spaces as described by Or and Tuller (1999), both the slit width and the slit length are proportional to the diameter of the associated central pore d and are therefore expressed as αd and βd, respectively.

When estimating the pore volume fraction using the pore model described above, the volume fractions of the central pore and slit-shaped spaces are distinguished. ~~The slit-shaped spaces are accordingly classified into the smallest central pore size~~ Considering ~~since~~ that the sizes of the slit-shaped spaces are smaller than ~~the~~that of the minimum central pore~~ diameter~~, the slit-shaped spaces are accordingly classified into the smallest central pore~~. The particle sizes of our samples range from 2 to 2000 μm, and the corresponding pore sizes are between 0.6 and 600 μm; meanwhile, the largest slit width calculated from the parameters in Table 2 is 0.24 μm. In addition, the drainage potential in slit-shaped pore is given as Eq.(7) based on the capillary theory (Derjaguin and Churaev, 1992).~~

~~$$\mu = \frac{-2\sigma}{\rho \alpha d}$$~~

~~(7)~~

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where μ is the critical potential (J kg^{-1}). For the widest slit-shaped spaces, the critical suction head of slit snap-off calculated using Eq.(7) is 6202 cmH_2O (the potential is converted to the suction head), which is smaller than the critical suction head of 5000 cmH_2O calculated using Eqs. (2) and (5) for the minimum central pore. This also demonstrates that the equivalent pore diameter of a slit space is smaller than the minimum central pore diameter. .Therefore, the pore volume fractions of the soil samples were simplified into those of the central pores, but the volume fractions of the minimum central pores containedincluded the volume fractions that of all slit-shaped spaces. UsingCoupled with the geometric relationship described in Fig. 2 and the traditional assumption that the volume fraction of each unit cell (i.e., the central pore connecting toand two slit-shaped spaces) is equal to the relative particle mass fraction, using the geometric relationship described in Fig. 2, the volume fractions of the central pore and slit-shaped spaces can be calculated respectivelyseparated; , then the pore volume fractions with respect to- of different sizes can be readily obtained.

The procedure utilized to calculate the pore volume fractions is shown in Fig. 3. Assuming that the soil pores are composed of numerous unit cells with various sizes, the fraction of the *i*th unit cell is equal to the relative particle mass fraction ω_i. The addition of The sum of the slit pore volume fractions of various sizes ($\zeta_2+\zeta_3+\ldots\ldots+\zeta_i$) and the volume fraction of the smallest unit cell (ω_1) and the sum of the slit pore volume fractions of various sizes ($\zeta_2+\zeta_3+\ldots\ldots+\zeta_i$) results in form the volume fraction of the smallest pore (v_1). Successively accumulating that volume fractionit with the other central pore volume fractions of other central pore (i.e., v_2, v_3, $v_4\ldots$) provides the PoSD of a sample. The slit pore volume fraction, ζ_i, the volume fraction of the smallest pore v_1 and the volume fractions of the other pores v_i were calculated using Eqs. (78), Eq. (98) and Eq. (910), respectively:

$$\zeta_i = \omega_i \frac{2\alpha\beta d_i^2}{2\alpha\beta d_i^2 + \frac{\pi}{4} d_i^2}$$

(78)

$$v_1 = \omega_1 + \sum_{2}^{n} \zeta_i$$

(89)

$$v_i = \omega_i - \zeta_i$$

(910)

where ζ_i is the slit pore volume fraction, v_i is the volume fraction of the *i*th pore fraction, and α and β are the scaling parameters of the slit width and the slit length, respectively.

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3.2 Values of *α* and *β*

To obtain the values of *α* and *β*, an expression containing both of these parameters with respect to the specific surface area (S_{SA}) was applied here. The S_{SA} of the pore as shown in Fig. 2 can be described using a geometrical relationship as follows:

$$S_{SA} = \frac{\phi}{1000\rho_b}\sum_{i=1}^{n}\omega_i \frac{4\beta d_i + \pi d_i}{2\alpha\beta d_i^2 + \frac{\pi}{4}d_i^2}; \qquad i = 1, 2, \cdots\cdots n$$

(10~~1~~)

where S_{SA} is the specific surface area (m^2 g^{-1}), d_i is the pore diameter (m), ρ_b is the bulk density (kg m^{-3}) and Φ is the measured porosity. Therefore, an important requirement for the calculation of the *α* and *β* values is an estimation of the ~~sample-scale value of~~ S_{SA}~~-~~ at sample-scale. Here, a power equation was applied as follows (Sepaskhah et al., 2010):

$$S_{SA} = 3.89 d_g^{-0.905}$$

(1~~2~~1)

where S_{SA} is the estimated specific surface area (m^2 g^{-1}), and d_g is the geometric mean particle size diameter (mm) obtained using Eq. (12~~3~~) (Shirazi and Boersma, 1984):

$$d_g = \exp\left(f_c \ln M_c + f_{si} \ln M_{si} + f_{sa} \ln M_{sa}\right)$$

(12~~3~~)

where f_c, f_{si} and f_{sa} are the clay, silt and sand fractions (%) of the soil sample, respectively, M_c, M_{si} and M_{sa} are the mean diameters of clay, silt and sand that are empirically taken as 0.001 mm, 0.026 mm and 1.025 mm, respectively.

Consequently, the quantitative relationship between the parameters *α* and *β* can be obtained using Eq. (10~~1~~)~~,~~ a~~A~~ssociated with the additional constraint of Eq. (11~~2~~), and the values of *α* and *β* can be theoretically solved if the measured ~~slit~~ volume fraction of the slit-shaped pore or the measured ~~SWC~~SWRC is known. However, an analytical solution is difficult to derive due to the high nonlinearity of both equations. Here, a trial and error approach was adopted that was much easier than the analytical method. Conveniently, the UNSODA database provided a great deal of soil information, including the measured ~~SWC~~SWRCs and diverse soil physical properties.

The routine procedure for handling a soil sample involved the following steps. First, given the initial value of *α*, the value of *β* was calculated using Eqs. (10~~1~~)-(12~~3~~), after which the PoSD was predicted using Eqs. (7~~8~~)-(9~~10~~). Subsequently, the ~~SWC~~SWRC was estimated using the method described in Sect. 3.3. Finally, the values of *α* were~~as~~ changed repeatedly until the newer predicted ~~SWC~~SWRC was in good agreement with the measured ~~SWC~~SWRC and ~~-~~the water content corresponding to a suction head of 5000 cmH_2O was within 90% of the measured data (see Fig. S2 in the ~~su~~Supporting I~~i~~nformation). The results for the 48 soil samples indicated that the *β* values exhibited a broad variation range ~~of variation~~ for all samples, while the *α* values showed regular changes with the soil texture. The relationship between the sand contents and

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the α values for~~ the~~ 48 samples is shown in Fig. 4, which clearly demonstrates that the values of α are similar to~~for~~ samples with specific sand contents.

Therefore, the approach was simplified by setting α as a constant for similar soil textures. The corresponding detailed descriptions are summarized in ~~Table 2~~Table 3. The values of α were in the range from 3.34E-05 to 2.12E-02, which were estimated by Or and Tuller (1999) using a pore~~-scale geometry~~ model comprising a polygon-shaped central pore connected to the slit-shaped spaces. According to the sand contents of the samples, ~~Table 2~~Table 3 is a reference for determining the α values that serve as input parameters in predicting the ~~SWC~~SWRC from the PSD here ~~in~~after.

3.3 Estimating the ~~SWC~~SWRC

The values of α and β for the various soil samples facilitated the acquisition of the volume fractions of the slit pores using Eq. (7~~8~~) and the PoSD using Eqs. (8~~9~~) and (9~~10~~). The water contents associated with different pore filling stages could be estimated by substituting the PoSD into Eq. (3), and the pore size and the corresponding suction head could be calculated using Eqs. (2) and (5). The ~~SWC~~SWRC could be ultimately obtained using the calculated suction heads and water contents.

4 Model validation

4.1 Data sources

Twenty-nine soil samples with a wide range of physical properties were also selected from the UNSODA database to validate the model; the codes of the samples are summarized in Table 4~~3~~ and their~~ –~~ detailed information are presented in Table 5. For the soil samples that were not provided with a saturated water content θ_s, the first data point of the measured ~~SWC~~SWRC corresponding to the lowest suction head was regarded as θ_s.

To generate a detailed PSD, a modified logistic growth model (Eq. (6)) was used to fit the measured PSD data. Here, the detailed PSD was generated at diameter classes of 2, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 500, 1000 and 2000 μm. The values of α were chosen from Table 3~~obtained~~ according to the sand contents of the soil~~the~~ samples~~, the details of which are included in Table 2~~. The values of β were obtained by substituting the S_{SA} values predicted using Eq. (11~~2~~) into Eq. (10~~1~~). Then, the PoSD was predicted using Eqs. (7~~8~~)-(9~~10~~). Finally, the ~~SWC~~SWRC was estimated using the methods, as described in Sect. 3.3.

The ~~SWC~~SWRC was also predicted using the traditional method presented in Sect. 2. In the traditional method, the predicted PoSD was equivalent to the PSD (~~ in~~ Eq. (1)) and was substituted into Eq. (3) to obtain the water content. The corresponding suction heads were predicted using Eqs. (2) and (5).

A scaling approach proposed by Meskini-Vishkaee et al. (2014) was used to compare with the proposed method to demonstrate its~~the~~ prediction performance. The detailed calculation procedures were described by Meskini-Vishkaee et al. (2014).

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The van Genuchten equation (Eq. (13~~4~~)) was used to fit the predicted~~SWC~~SWRC ~~data~~ calculated via the three ~~traditional method and the improved~~ model(Genuchten, 1980):

$$\frac{\theta-\theta_r}{\theta_s-\theta_r}=\left[\frac{1}{1+(a\psi)^n}\right]^m$$

(13~~4~~)

where θ is the water content ($cm^3\ cm^{-3}$), θ_r is the residual water content ($cm^3\ cm^{-3}$), and a, n, m, and θ_r are fitting parameters. The 29 samples exhibited good fits with an average r^2 value of greater than 0.999.

For each set of predictions, the agreement between the predicted water content ~~θ_p~~ and the measured water content ~~θ_m~~ was expressed in terms of the root mean square error (E_{RMS}), which is given by

$$E_{RMS}=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(\theta_{pi}-\theta_{mi})^2}$$

~~$E_{RMS}=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(\theta_p-\theta_m)^2}$~~

(14~~5~~)

where N is the number of measured data points, θ_{pi} is the predicted water content and θ_{mi} is the measured water content.~~,~~

4.2 Results

The predicted and measured ~~SWC~~SWRCs in Fig. 5 show~~ed~~ that the improved method exhibited good fits with the measured data in the entire range of the ~~SWC~~SWRC; moreover, the improved ~~proposed~~ method was clearly better than the traditional method and the scaling approach, especially in~~at~~ the dry range (the other 25 samples are listed in Fig. S3 in the S~~s~~upporting I~~i~~nformation). In this study, t~~T~~he scaling approach, which improved the performance of the original MV-VG model via scaling the ~~n~~ parameter n in van Genuchten equation, performed better than the traditional method ~~here~~ for clay (code:1360), loamy (code: 3190) and loamy sand (code: 3160). However, it performed worse for coarse-textured soil (e. g. sand (~~-~~code: 3144)), which may result from the relative small scaling degree of the parameter n and the poor fit~~ting~~ of the fitting equation to the measured PSD data in their study. In general, the improved method here applied well to a wide range of soils, while the scaling approach performed better for fine- and medium-textured soils.

Table 6~~4~~ shows~~ed~~ the E_{RMS} of the improved method, the scaling approach and the traditional method for samples used in model validation. The E_{RMS} values range from 0.017 to 0.054 for the improved method (with an average of 0.028), from 0.026 to 0.060 for the scaling approach (with an average of 0.037) and from 0.040 to 0.106 for the traditional method (with an average of 0.061). In terms of the E_{RMS}, the improved method provided the best predictions and the traditional method performed the worst. The results also showed that there is a significant difference between performance of the improved method and traditional method (p=0.001). Only for the sand samples does the performance of improved method and scaling approach exhibit a significant statistical difference (p=0.01). ~~Among the three methods mentioned above, the improved method provided the best predictions and the traditional method performed worst.~~

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The accuracy of the predicted ~~an~~ ~~SWC~~SWRC ~~predicted~~ using the improved method depends on the accuracy of the corresponding predicted pore volume fractions. The calculated and measured pore volume fraction curves in Fig. 6 indicate that the predicted pore volume fraction curves using the improved method are more similar to the measured data than those predicted using the traditional method, thereby showing that the proposed method performed better. The errors in the predicted pore fractions using the traditional method mainly occur at the minimum pore size (d≤0.6 μm), which proves the errors of the predicted SWRC using the traditional method originate from the neglect of small pores, such as slit-shaped spaces in natural sample. ~~while the proposed method greatly improves the volume fraction at this pore size and consequently improves the water content in the high suction range. These improvements are mainly attributed to the pore model containing slit-shaped spaces, demonstrating that this pore model is better for predicting the SWC from the PSD than the concept of a bundle of cylindrical tubes.~~ The proposed method used the pore model containing slit-shaped spaces to represent the pore space geometry and consequently improved the prediction of the SWRC. However, the uncertainties are unavoidable when choosing the parameters α and β for unknown media, which is the main factor affecting the accuracy of the predicted SWRCs.

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4.3 Discussion~~s~~

4.3.1 The suction head calculation in the slit-shaped spaces

When capillary water coexists with adsorptive water in the narrow pores, the capillary ~~force~~ and surface forces including ionic-electrostatic, molecular, structural, and adsorption forces~~ones~~ contribute to the potential energy of water in the slit-shaped pores (Tuller et al., 1999;Iwamatsu and Horii, 1996). When considering only the capillary forces ~~only~~, the drainage potential in slit-shaped pore is given as Eq. (15~~7~~) (Derjaguin and Churaev, 1992)~~, while the applicability of this formula is limited by the width of the slit. A correction of taking into account the effect of adsorption force at the slit surfaces will have to be made for thin slit-shaped spaces.~~

$$\mu = \frac{-2\sigma}{\rho \alpha d} \qquad (15)$$

where μ is the critical potential (J kg^{-1}).

While the applicability of this formula is limited by the width of the slit. Tuller and Or (2001) defined a critical slit spacing (αd^*) by Eq. (16) that ~~would~~ classifies~~y~~ the slit sizes responding to capillary drainage and adsorption-~~-~~dominated drainage. In the case of slit-shaped spaces greater than αd^*, the capillary-based slit drainage is ~~would be~~ applied.

$$\alpha d^* = \sqrt{-\frac{9A_{svl}}{4\pi\sigma}} \qquad (16)$$

where~~,~~ A_{svl} is the Hamaker constant for solid-vapor interactions through the intervening liquid, usually set as -6.0E-20 J (Tuller and Or, 2001). The value of αd^* is 0.591 nm, which~~it~~ means that ~~for slit-shaped spaces greater than 0.591 nm, the~~ Eq. (15~~7~~) could be applied to calculate the drainage potential in the slit-shaped spaces in this study.

In our study, the critical drainage suction head for the minimum central pore calculated using Eq.(4) is 5000 cmH_2O, while that of the widest slit-shaped spaces calculated using Eq. (15) is 6202 cmH_2O (the potential is converted to the suction head). This result illustrates that all slit-shaped spaces are still filled with water when the suction head is up to the critical drainage suction head for the minimum central pores. On the other hand, the largest slit width calculated from the parameters in Table 3 is 0.24 μm, which is smaller than the minimum pore diameter of 0.6 μm. According to the above analysis, it is reasonable that the volume fractions of the minimum pores include the volume fractions of the minimum central pores and all slit-shaped spaces.

4.3.2 The effects of the estimated S_{SA} ~~values~~

The S_{SA} values estimated using Eq. (1~~2~~1) could affect the accuracy of the predicted ~~SWC~~SWRC. Fig. 7 shows that an overestimation of the S_{SA} ~~would~~ prompts the dry range of the ~~SWC curve~~SWRC to move in the direction of ~~a~~ larger water content, and vice versa. When the estimated S_{SA} value was altered by 10% and -10% of its accurate value for ~~the~~ loamy sand (code: 3170), the water content~~s~~ with respect to the highest suction head were higher and lower, respectively, by approximately 0.007 $cm^3\ cm^{-3}$ than those of the original ~~SWC~~SWRC. For ~~the~~ clay (code: 4680), the water contents were higher and lower by approximately 0.009 $cm^3\ cm^{-3}$ at the same 10% and -10% alterations, respectively. Consequently, for ~~the~~ coarse-textured soil, the water content and prediction error of the ~~SWC~~SWRC changed relatively little for the same degree of change ~~of~~ in the S_{SA}. ~~This effect may contribute to the lower S_{SA} value for this texture than the fine-textured soil.~~ Fig. 7 also showed that a relatively small error appeared between the calculated and measured ~~SWC~~SWRCs when the error of the estimated S_{SA} ~~error~~ was within 20 %.

Previous work has shown~~ed~~ that the S_{SA} of soil is closely dependent upon the soil texture and ~~that it~~ could be estimated from the soil properties~~soil media data~~ and PSD (Sepaskhah and Tafteh, 2013;Resurreccion et al., 2015). The method used to estimate the S_{SA} in Sect. 3.2 was presented by (Sepaskhah et al., 2010), who estimated the S_{SA} based on the geometric mean particle size diameter as shown in Eq. (12) with an r^2 value of 0.88. Moreover, the appropriateness of this equation was validated using 64 soil samples by (Fooladmand, 2011). Sepaskhah et al. (2010) pointed out that the deviations increased distinctly for measured S_{SA} greater than 200 $m^2\ g^{-1}$. In the proposed method, the estimated S_{SA} is mainly used to gain the parameters α and β and to estimate the volume fractions of the slit-shaped spaces;~~,~~ thus, the estimation accuracy~~te~~ of S_{SA} influences the dry range of the ~~SWC curve~~SWRC (Fig. 7) and ~~,~~ equivalently the degree of improvement in the ~~of~~ predicted ~~SWC~~SWRC. Therefore, more effort should be placed toward developing a more accurate transformation from the soil physical properties to S_{SA} to further improve the prediction of the SWRC.

4.3.3 The slit-shaped spaces and the S_{SA} at the sample scale~~Physical meanings of the parameters~~

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Since the central pore diameter d is proportional to the corresponding particle diameter D, the slit width αd, the slit length βd and the specific surface area S_{SAi} of each unit cell are associated with the particle size. The calculated values of αd, βd and S_{SAi} of clay, silt, fine sand and coarse sand particles for the loamy sand (code: 3170) are listed in Fig. 8. The results confirm that the pores formed by bigger soil particles are large with a correspondingly large slit width αd; this is similar to the results of~~in~~ Or and Tuller (1999), and the values are of the same order of magnitude. It is common knowledge that larger soil particles tend to have large surface areas, and therefore, the slit length formed by the contact of soil particle edges should be relatively long, leading to the positive relationship between the slit length βd and the particle diameter as shown in Fig. 8. This result is different from that in Or and Tuller (1999), where the slit length βd was inversely proportional to the particle diameter. In addition, the S_{SAi} of the ith particle fractions decreased with an increase in the particle diameter, which is consistent with the findings of Or and Tuller (1999) and is in accordance with the general understanding of the S_{SA}.

5 Conclusions

The traditional models employed to translate the PSD into the ~~SWC~~SWRC underestimate the water content in the dry range of the ~~SWC~~SWRC. The errors originate from a setting that the cumulative PoSD is equal to the corresponding PSD, which resulted in an underestimate of the pore volume fraction of the minimum pore diameter range and consequently the water content in the dry range of the ~~SWC~~SWRC. If slit-shaped pore spaces are taken into consideration when estimating the PoSD with a pore model comprising a circle-shaped central pore connected to slit-shaped spaces, the pore volume fraction of the minimum pore diameter range will be accordingly increased; therefore, the ~~SWC~~SWRC can be more accurately predicted ~~from the PSD~~. The estimation of the α and β values is a key step to predicting the ~~SWC~~SWRC in the proposed method. The α values were obtained using 48 measured soil samples, and those values served as input parameters ~~while~~ for predicting the ~~SWC~~SWRC; then, the β values were readily calculated using a constraint on the estimated S_{SA}. The validation results illustrate that the ~~SWC~~SWRCs predicted using the proposed method provided the best predictions of the ~~SWC~~SWRCs, closely followed by the scaling approach, and the traditional method performed ~~-~~worst.

Competing interests. The authors declare ~~that they have~~ no conflicts of interest.

Acknowledgments and data

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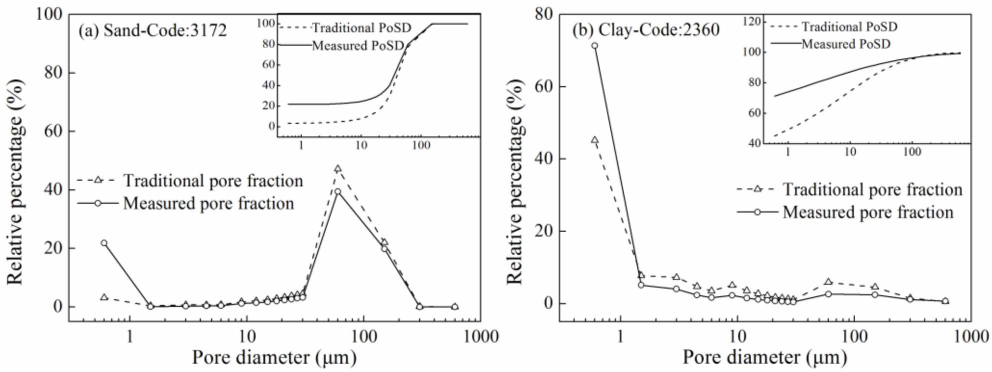


Figure 1: Measured vs. calculated pore volume fraction curves for (a) sand (code: 3172) and (b) clay (code: 2360). The measured and calculated PoSDs are ~~embedded~~ in the insets at the tops~~s~~ of the figures.

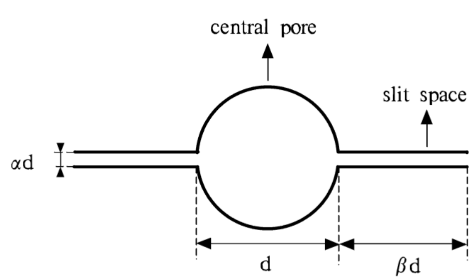


Figure 2: Pore ~~space geometry~~ model containing two slit-shaped spaces (*d* denotes the diameter of the central pore, and *αd* and *βd* denote the widths and lengths of the slit-shaped spaces, respectively).

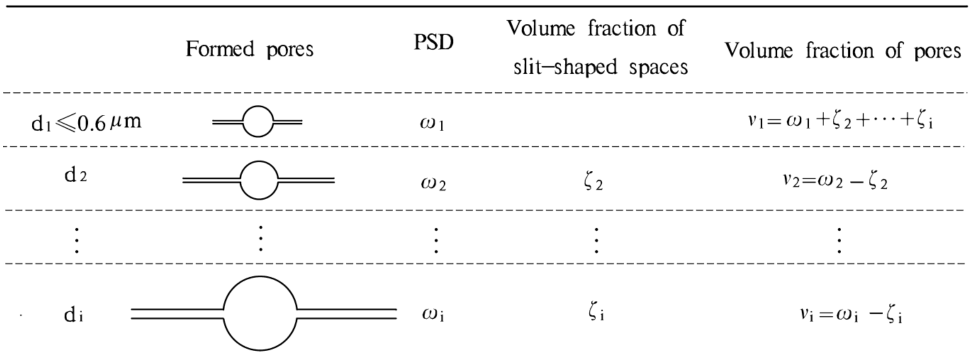


Figure 3: Schematic of the procedure used to calculate the pore volume fraction.

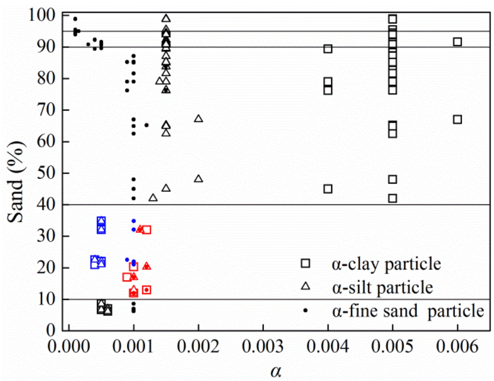


Figure 4: The α values for ~~the~~ 48 soil samples with different sand contents. The α values for ~~specific samples of~~ clay, silt, and fine sand of specific samples are listed in Fig.~~ure~~ 4 except those of the coarse sand particles, which are the same value of 0.0004 for all of the samples. For the samples with sand contents ranging from 10-40%, two sets of α values are observed. The α values for the silt contents ~~of~~ less than and more than 50% are highlighted in red and blue, respectively, thereby reflecting the dominant functions of the silt or clay particles on the hydraulic properties of ~~the~~ typical samples.

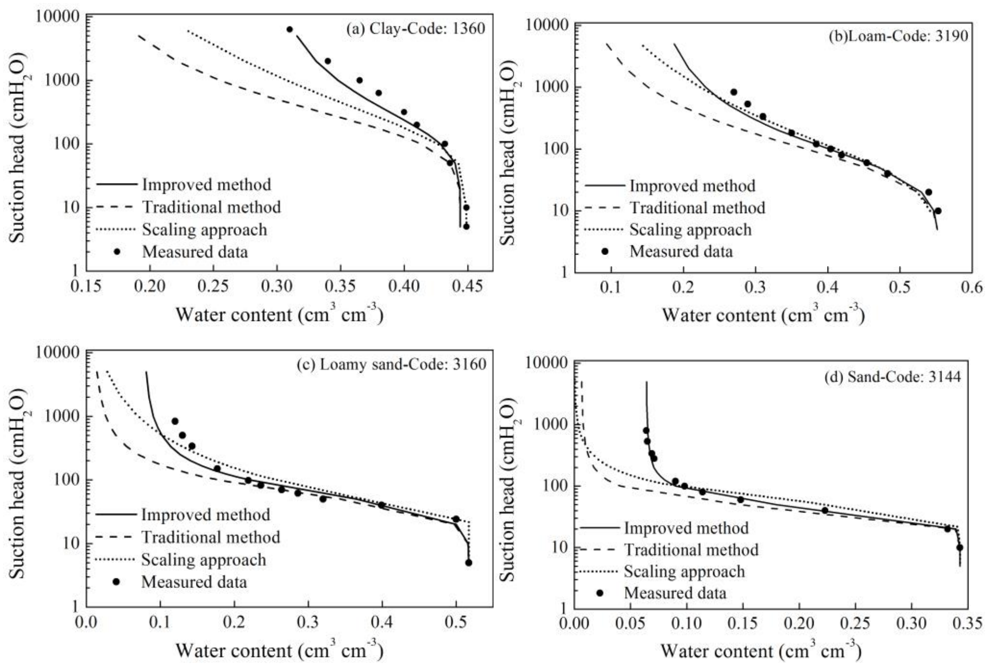
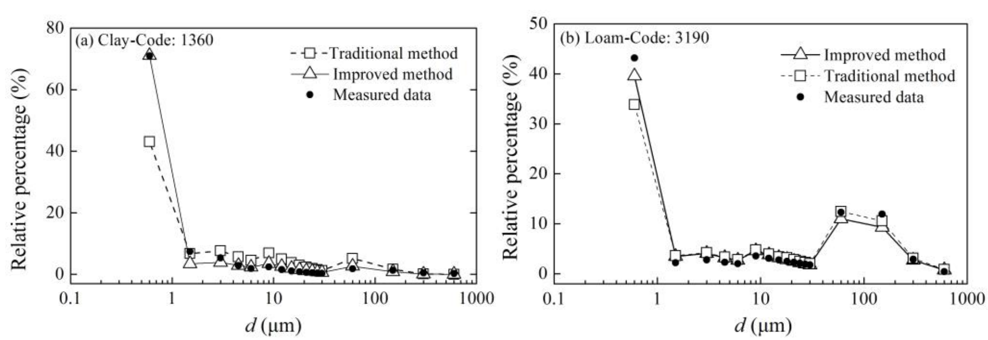


Figure 5: Measured and predicted ~~SWC curve~~SWRCs for clay (code: 1360), loam (code: 3190), loamy sand (code: 3160) and sand (code: 3144).



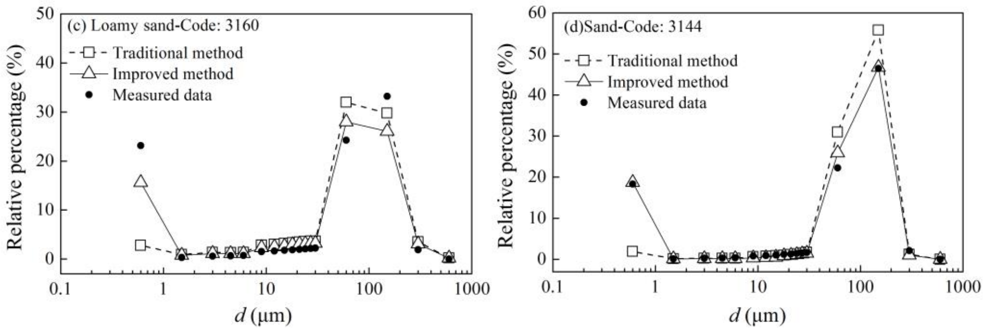


Figure 6: The measured and predicted pore volume fraction curves using the improved method and traditional method for clay (code: 1360), loam (code: 3190), loamy sand (code: 3160) and sand (code: 3144).

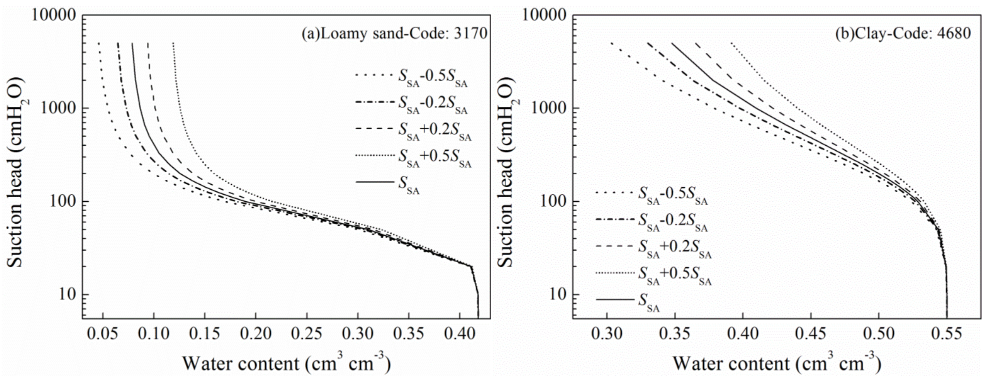


Figure 7: The effects of ~~an~~ a change in ~~alteration of~~ the estimated S_{SA} on the ~~SWC~~SWRC for (a) loamy sand (code: 3170) and (b) clay (code: 4680). S_{SA} denotes the accurate value of the specific surface area.

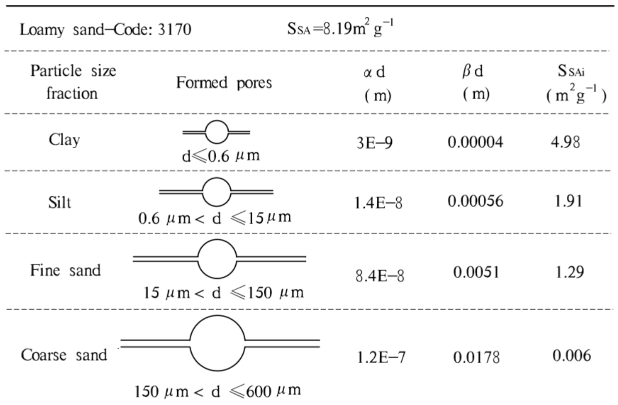


Figure 8: The calculated slit width αd, slit length βd and S_{SAi} for loamy sand (code: 3170).

Table 1: Codes and textural classes of the 48 soils selected from UNSODA

UNSODA codes	Textual class
4681, 4680, 2362, 2360, 1400, 1383, 4121, 1361, 2340	Clay
3191, 1091, 2530, 2531	Loam
2102, 3150, 3161, 3171, 1160, 3170, 3130, 1031, 4011, 4020	Loamy sand
1464, 1466, 2100, 3340, 4650, 3142, 1050, 1023, 3141, 3163, 3164, 3165, 3172, 4051, 4520, 4521	Sand
3202	Sandy clay loam
3200, 3203, 4162	Sandy loam
4042, 4180, 4070, 4673, 1341	Silt loam

Table 2: Basic soil properties of 48 samples for the model calibration

Soil texture	Number of		Clay (%)	Sand (%)	ρ_b (g m^{-3})
Clay	9	Min	41.5	6.1	1.08
		Max	58.2	36.0	1.64
		Average	50.2	14.1	1.29
Loam	4	Min	14.0	42.0	1.36
		Max	23.0	67.0	1.63
		Average	17.3	50.5	1.46
Loamy sand	10	Min	3.0	76.2	1.32
		Max	10.4	89.4	1.60
		Average	6.1	83.2	1.46

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Sand	16	Min	0.7	89.6	1.41
		Max	4.6	98.9	1.70
		Average	2.5	93.4	1.55
Sandy clay loam	1		2.7	62.5	1.70
Sandy loam	3	Min	10.5	64.9	1.27
		Max	19.4	76.3	1.70
		Average	15.0	68.8	1.50
Silt loam	5	Min	10.5	21.0	1.49
		Max	15.7	34.8	1.56
		Average	12.6	26.5	1.52

~~Table 2~~Table 3: The estimated values of α for various soil textures

Sand content (%)	Silt content (%)	α			
		Clay $D \leq 2$ μm	Silt 2 μm$<D\leq 50$ μm	Fine sand 50 μm$<D\leq 500$ μm	Coarse sand 500 μm$<D\leq 2000$ μm
0-10		0.0005	0.0005	0.001	0.0004
10-40	0-50	0.001	0.001	0.001	0.0004
	50-100	0.0005	0.0005	0.001	0.0004
40-90		0.005	0.0015	0.001	0.0004
90-95		0.005	0.0015	0.0005	0.0004
95-100		0.005	0.0015	0.0001	0.0004

Table 4~~3~~: Codes of the 29 soil samples selected from UNSODA for the model validation

UNSODA codes	Textual class
1360, 4120, 2361, 3282, 1320	Clay
3190, 1370	Loam
3160, 3152, 1030, 1090, 4010	Loamy sand
3155, 3144, 1463, 3132, 4000	Sand
4620, 4621, 1102, 2341	Sandy clay loam
3290, 3310	Sandy loam
4531, 4510	Silt loam
3031, 3032, 1372, 1362	Clay loam

Table 5: Basic soil properties of 29 samples for the model validation

Soil texture	Number of soil		Clay (%)	Sand (%)	ρ_b (g m^{-3})
Clay	5	Min	43.0	5.4	1.10
		Max	57.0	32.0	1.50
		Average	51.0	14.4	1.31
Loamy	2	Min	16.5	47.9	1.41
		Max	29.2	43.6	1.45
Loamy sand		Min	1.7	75.5	1.37

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	5	Max	7.3	85.2	1.59
		Average	4.9	81.0	1.46
Sand	5	Min	1.1	90.1	1.46
		Max	4.4	97.5	1.58
		Average	2.3	93.4	1.53
Sandy loam	2	Min	11.4	56.8	1.44
		Max	12.6	65.7	1.46
Sandy clay loam	6	Min	9.8	28.0	1.21
		Max	30.7	69.7	1.53
		Average	22.8	43.2	1.45
Clay loam	4	Min	33.4	20.4	1.07
		Max	37.5	34.7	1.58
		Average	35.1	24.8	1.27

Table 64: The root mean square errors (E_{RMS}) of the predicted ~~SWC~~SWRC ~~predicted~~ using the improved method, the scaling approach and the traditional method

Soil texture	Number of soil sample	E_{RMS} Improved method	Scaling approach	Traditional method
Clay	5	0.022	0.032	0.056
Clay loam	4	0.034	0.041	0.079
Sandy clay loam	4	0.032	0.046	0.072
Loam	2	0.054	0.060	0.106
Loamy sand	5	0.020	0.026	0.048
Sand	5	0.017	0.028	0.042
Sandy loam	2	0.046	0.049	0.068
Silt loam	2	0.024	0.031	0.040

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