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The Effect of Air Entry Values on Hysteresis of Water Retention Curve in Saline Soil

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Abstract: Problem statement: The saline soil in Northeast Thailand is caused by saline groundwater rise in unsaturated zone to accumulate as salt at soil surface. **Approach:** This problem had been exacerbated in the last few decades by human activities e.g., deforestation and salt mining. This salinity problem can be solved by capillary rise control of saline groundwater flow. **Results:** The soil water retention curve formulation was essential for the control procedure design. In this study, the soil water retention curves of saline soil samples were derived by the hanging column and pressure plate apparatus techniques. The hysteresis of the curves together with air and water entry values were scrutinized from the primary wetting and drying retention curves. **Conclusion:** The experimental results showed that the degree of hysteresis varies with the air entry value of the soil. The new finding can be very useful in modeling for salinity control.

Key words: Capillary rise, Northeast Thailand, saline soil, unsaturated soil, water entry values

INTRODUCTION

The soil water retention curve is a relationship between pressure head of soil water and water content in unsaturated soil. The relationship varies with water flow process which flow into or out of the soil section. When water is flowing into the soil section it is called wetting process. The water retention curve of the wetting process from the initial stage of air-dry soil until saturated condition is a unique curve, called the primary wetting curve. Similarly, the primary drying curve is obtained from a draining process of saturated soil until the soil is very dry. Wetting and draining processes of soil water conditions between saturated and air-dry condition, produce the scanning curves. The two primary curves form the boundaries of all scanning curves as shown in Fig. 1. This phenomenon is called hysteresis.

The air-entry value is identified as the point at the largest pores which air can enter into the soil. When the suction is larger than the air-entry value then the soil starts to desaturate. The amount of water in soil decreases significantly with increasing suction in the transition stage. Eventually a large increase in suction leads to a relatively small change in the water content and is the residual stage. The hysteresis can affect the accuracy of unsaturated flow calculations. The objective of the study is to relate air-entry value to the degree of hysteresis, which is the helpful to assess the accuracy of soil water flow calculation.

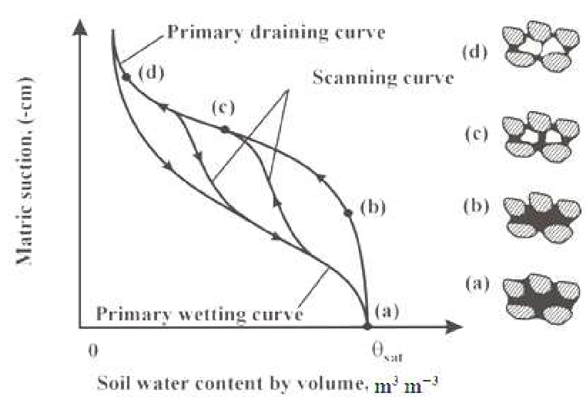

Fig. 1: The characteristics of hysteresis retention curve

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MATERIALS AND METHODS

Saline soil samples from six different sites around the city of Khon Kaen, northeast Thailand, were used in this study. Each soil sample was tested for its water retention curves for both primary drying and primary wetting curves. Then from the curves, we obtained the degree of hysteresis and the air entry value for each soil. The details are as follows.

Saline soil samples: We collected soil samples from six saline soil patches around the city of Khon Kaen, northeast Thailand. Both undisturbed and disturbed samples were collected from 5 cm below the soil surface. The disturbed samples were used for size distribution analysis and salinity measurement. The undisturbed samples were collected by stainless steel soil cores of 5 cm inside diameter and 5 cm length making up about 100 cm^3 in volume. The undisturbed samples were measured for their soil water retention curves, porosity and saturated hydraulic conductivity.

The particle size distributions were analyzed using sieve analysis for the grain size coarser than 0.054 mm and sedimentation analysis for the finer grain size. From the particle size distribution curve, the fractions of sand: silt: Clay and d_{50}, were derived. The soil textures were also identified. The results of the fractions, d_{50} and soil textures of the soil samples are in Table 1.

Soil salinity was measured for each disturbed soil sample. The air dried soil was mixed with distilled water at the ratio of 1:5 by weight for 24 h. The mixture was filtered and measured for electrical conductivity. The $EC_{1:5}$ was converted to the value for the saturated extract EC_e by conversion factor[11]. The salinity values for the samples are in Table 2.

Table 1: Soil distributions and textures of the experimental soils

Site	Size distributions (%) Sand	Silt	Clay	D_{50}(mm)	Textures
St1	78.40	12.80	8.80	0.080	Sandy loam
St2	64.80	26.70	8.50	0.085	Sandy loam
St3	59.80	18.60	21.60	0.070	Sandy clay loam
kk1	60.00	31.00	9.00	0.072	Sandy loam
kk2	30.00	46.00	24.00	0.035	Loam
kk3	80.00	17.00	3.00	0.130	Loamy sand

Table 2: The physical properties of the experimental soils

Site	θ_r	Bulk density (kg m^{-3})	Porosity	K_{sat} (cm day^{-1})	salinity (ms cm^{-1})
St1	0.062	1,676.00	0.330	113.68	38.40
St2	0.030	1,516.00	0.350	315.92	1.20
St3	0.069	1,609.00	0.480	4.27	36.90
kk1	0.030	1,429.00	0.400	137.30	11.76
kk2	0.070	1,282.83	0.450	25.99	13.10
kk3	0.020	1,697.93	0.480	201.60	17.60

The bulk density, porosity and hydraulic conductivity of the samples were measured from undisturbed samples by standard methods[4,7]. The falling head method was used for K_{sat} measurement. These values are in Table 2. The saturated water content of soil can be taken as the porosity of the soil[10]. However, the residual water content θ_r was measured gravimetrically from air dried soil then converted to volumetric value using bulk density. The values of θ_r are also in Table 2.

Water retention curve construction: The primary drying retention curves were constructed by two apparatus. The hanging column was applied for the saturated sample down to about -1.5 m pressure head. Then the pressure plate apparatus was used for the pressure head less than -1.5 m. However, this pressure plate method cannot be used for the wetting curve construction. Only the hanging column method can be applied to construct a scanning wetting curve in the pressure head range from -1.5 m to saturated condition. Fig. 2 shows the measurement primary drying curves by 'o' and the scanning wetting curves by '+'. From the guides of the primary drying curve and the scanning wetting curve then the primary wetting curve can be constructed as the dashed line in Fig. 2. Both primary curves (wetting and drying) were fitted by the van Genuchten equation[2,8,13]:

$$\theta = \theta_r + \left(\theta_S + \theta_r\right)\left(\frac{1}{1+\left(\alpha|h|\right)^n}\right)^m \quad (1)$$

Where:

- θ = Water content of soil
- θ_r and θ_S = Water content of soil at air-dried and saturated conditions respectively
- $|h|$ = Absolute value of pressure head of soil water
- α, n and m = Parameters determined by fitting the equation to experimental data and assuming m = 1-1/n

The resulting primary wetting and drying curves are shown as dashed and solid lines respectively in Fig. 3a-f.

Degree of hysteresis: The difference between the two curves (wetting and drying) is called hysteresis. At a particular pressure head, we get the different values of water content. The degree of hysteresis is therefore identified by the ratio of the maximum difference of water content (between wetting and drying curves) to the difference of θ_S and θ_r, written in an equation form as:

$$r = \frac{\Delta\theta_{max}}{\theta_s - \theta_r} \quad (2)$$

Where:

r = Degree of hysteresis

$\Delta\theta_{max}$ = Maximum difference of water content

Air entry value evaluation: Air entry value of the soil is the metric suction value that must be exceeded before air recedes into the soil pores. It is the critical pressure head at which air starts to displace water in a porous medium. On the other hand, the water entry value is the lowest suction that water can enter into the saturated soil (Fig. 2). Therefore, the infiltration process involves water-entry at the wetting front and the drainage process involves air-entry at the soil surface.

Since, water-entry value is the threshold for infiltration and air-entry value for drainage, they can be estimated from the soil water retention curves[1,3,5,6]. According to the study of Wang *et al*.[12], the values of water-entry (h_{we}) and air-entry (h_{ae}) correspond to the inflectional capillary pressure (h_c) for wetting retention curve and drainage retention curve, respectively. They can be determined from[9]:

$$h_c = \frac{1}{\alpha}\left[\frac{n-1}{n(m+1)-n+1}\right]^{1/n} = \begin{cases} m^{1/n}/\alpha & \text{for} \quad m = 1-1/n \\ 1/\alpha & \text{for} \quad m = 1-2/n \end{cases} \quad (3)$$

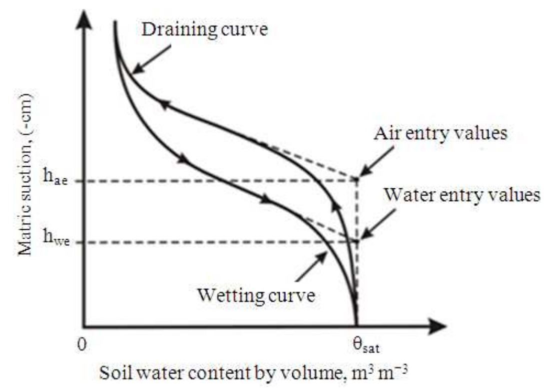
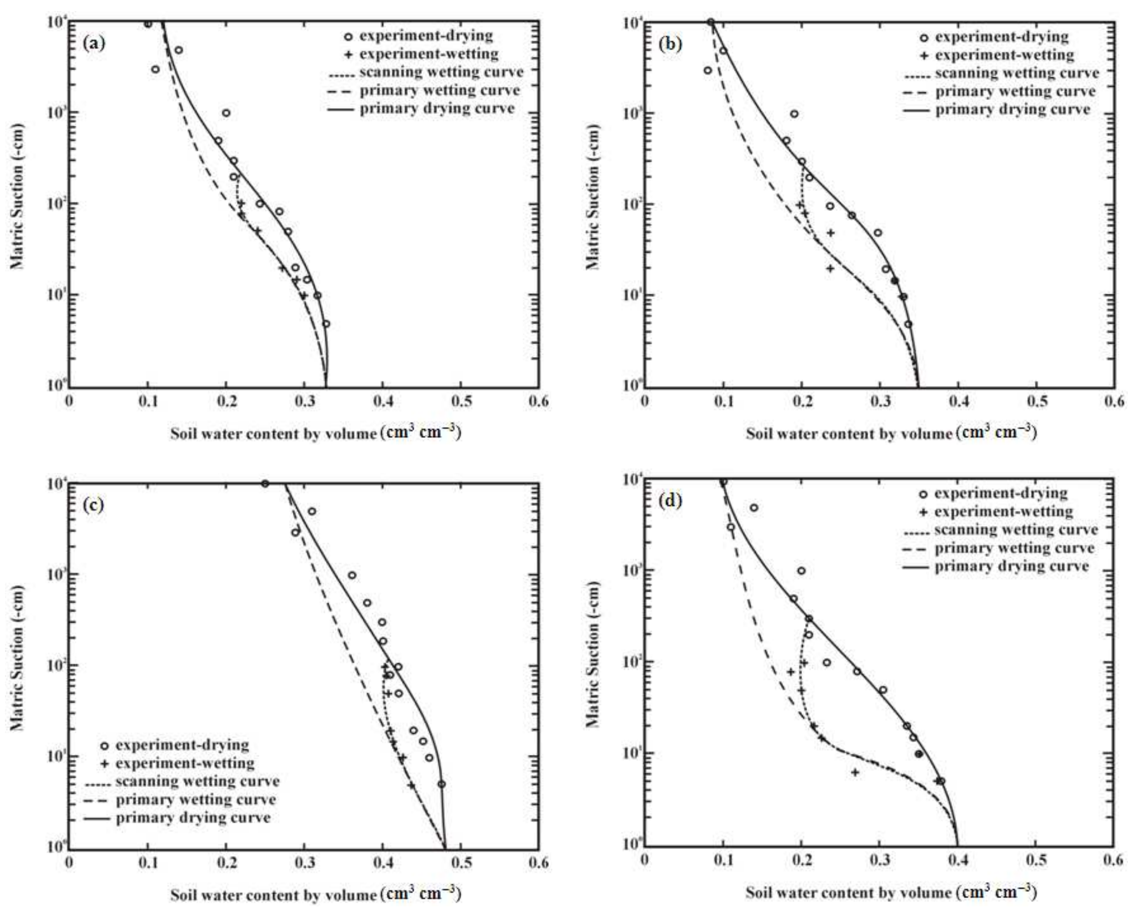


Fig. 2: The determination of air entry values (h_{ae}) and water entry value (h_{we}) by soil water retention curve



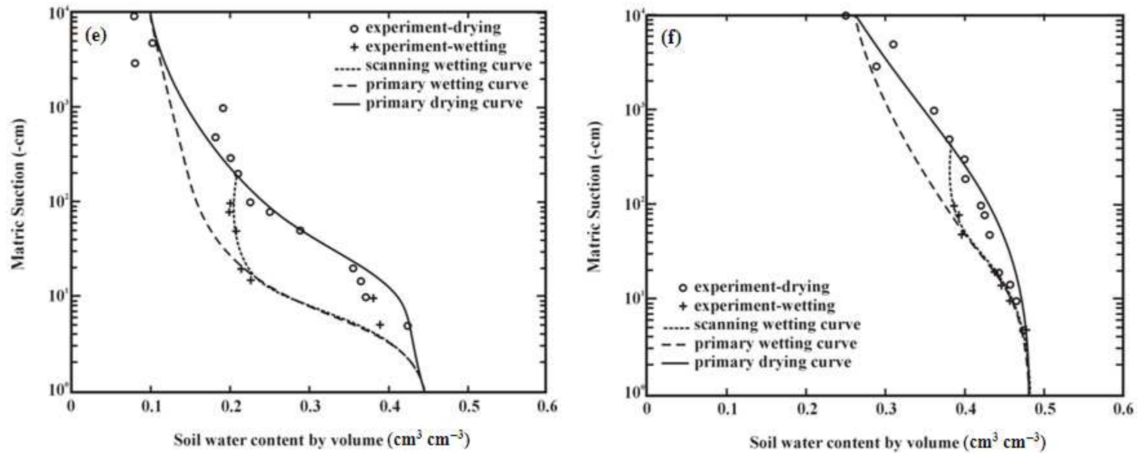


Fig. 3: Soil water retention curves for (a): Sandy loam, D_{50} = 0.080 (b): Sandy loam, D_{50} = 0.085 (c): Sandy clay loam, D_{50} = 0.070 (d): Sandy loam, D_{50} = 0.072 (e): Loam, D_{50} = 0.035 (f): Loamy sand D_{50} = 0.130

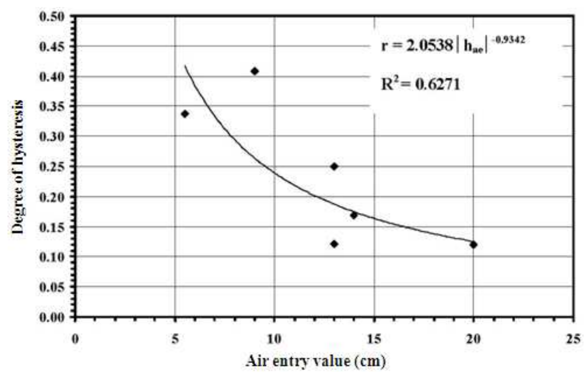


Fig. 4: The relationship between air entry value and degree of hysteresis

RESULTS

The measurement results of primary draining curves and scanning wetting curves are shown in Fig. 3 as 'o' and '+' respectively. The fitted van Genuchten equation (Eq. 1) for the primary wetting and drying curves are shown in Fig. 3 as dashed and solid lines, respectively. The parameters of the equation are in Table 3. The degree of hysteresis and the water and air entry values for each soil are shown in Table 4. And the air entry value is plotted with the degree of hysteresis in Fig. 4. The values of degree of hysteresis together with the suction heads at the maximum difference on hysteresis are in Table 4. The relationship can be written in an equation form as:

$$r = 2.0538 \left| h_{ae} \right|^{-0.9342} \quad (4)$$

where r is the degree of hysteresis and $|h_{ae}|$ is the absolute value of air entry head.

Table 3: Results parameter α and n in water retention curves

		Values from van Genuchten equation				
		Primary draining curve			Primary wetting curve	
Site	Textures	R^2	α	n	α	n
St1	Sandy loam	0.9616	0.032	1.280	0.099	1.240
St2	Sandy loam	0.9669	0.032	1.290	0.150	1.230
St3	Sandy clay loam	0.9449	0.035	1.120	0.700	1.080
kk1	Sandy loam	0.9676	0.052	1.280	0.890	1.190
kk2	Loam	0.9640	0.061	1.400	0.820	1.300
kk3	Loamy sand	0.9628	0.020	1.120	0.350	1.080

Table 4: Water content and suction head at maximum differences between the two primary curves

				Water content, θ		Entry value (cm)	
Site	Textures	Matric suction h, (cm)	Degree of hysteresis	Primary draining curve	Primary wetting curve	Air	Water
St1	Sandy loam	95.0	0.168	0.255	0.210	14.0	6.5
St2	Sandy loam	70.0	0.250	0.270	0.190	13.0	3.8
St3	Sandy clay loam	16.0	0.122	0.460	0.410	13.0	1.0
kk1	Sandy loam	25.0	0.338	0.330	0.205	5.5	3.5
kk2	Loam	19.0	0.408	0.380	0.225	9.0	2.8
kk3	Loamy sand	18.0	0.120	0.410	0.355	20.0	7.0

DISCUSSION

Most of saline soil used in this study show some degree of hysteresis (Fig. 3). The degree of hysteresis varies inversely and nonlinearly with the absolute value of the air entry value as in Fig. 4 and Eq. 4. The soil with high air entry value are those of the finer pore space represented by high proportion of finer particles. The finer grain soils have more uniform pore space and then lower degree of hysteresis than the coarse grain soils.

This finding facilitates modeling of unsaturated flow through saline soil. Normally, the primary drying retention curve can be obtained directly from the experiment and allow to calculate the air entry value (Eq.3). The degree of hysteresis can now be obtained from Eq.4. The value of maximum difference between the primary drying and the primary wetting curves can be determined from Eq.2. By considering the maximum difference value, if the value is quite small, thus the effect of hysteresis can be neglected. For large value of maximum difference, the corresponding wetting curve can be constructed from the guide of the primary drying curve and the size of maximum difference.

One way to circumvent the hysteresis problem is using the average values of α and n in the van Genuchten equation (Eq. 1) from the primary drying and wetting curves. The primary wetting curve, however, can be obtained as discussed before.

CONCLUSION

The relationship of the air entry value to the degree of hysteresis of the six samples of saline soil shows that the higher the air entry value the lower the degree of hysteresis. This relationship is specifically applied for saline soil in northeast Thailand. To be generalized we need more experimental results of saline soils from many other places. However, our findings show that when dealing with coarser and well graded soils the air entry values are low therefore their degrees of hysteresis are high. As a consequence, the calculation of soil water flow in such soil without taking hysteresis of soil water retention curve into account can be inaccurate. For finer grain soils, the calculation of soil water flow by using a single water retention curve can be appropriate.

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