# An Improved Method for Measuring Soil Shrinkage Curves with Consideration of Crack Formation

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## Background and Objectives

- Soil shrinkage curve (SSC) denotes the relation between soil volume and soil water content from saturation to oven drying.
- For vertisols, soil cracking during drying is an important phenomena, but is usually ignored during the measurement of SSC.
- Image analysis provides a useful way to quantify soil crack areas.

**The study aimed to improve the measurement of SSC with consideration of crack formation.**

## Materials and methods

### 1. Soil properties

Soil sample was collected from Fuyang City, Anhui province, China. The soil, with a special residual black layer and a Shajiang layer (Fig. 1), has the characteristics of vertisols: high clay content and shrinks during drying process (Fig. 1). Table 1 lists the basic properties of the soil.

Fig.1 Shajiang layer and shrinking cracks of the soil

Table 1 The properties of studied soil

| Soil layer | pH | SOC | sand | silt | clay |
|---|---|---|---|---|---|
| | | g/kg | | % | |
| 0-20 cm | 7.56 | 14.75 | 50.37 | 13.63 | 36.00 |

### 2. Methods

Laboratory experiments were performed in a temperature regulated container (20 ± 1°C). The relative humidity was about 30 to 40% and no apparent wind was observed.

The soil sample was mixed with water (90% water content), and the slurry was transferred into a rubber container (25 mm in height and 11 mm in diameter) with three soil thickness: 4.5, 9 and 16 mm. Each thickness was replicated three times.

During the dehydration process, we calculated the crack areas using image analysis. The crack depth was obtained by inserting a needle to the crack and measuring the portion of needle that located in the crack with a caliper (accuracy of 0.01 mm). The subsidence depth of was also measured with the caliper. Meanwhile, soil water content was determined gravimetrically.

We applied three different equations to fit the SSCs,

(1) The Cornelis Equation (2006):

$$e(\vartheta)=e_r + a\left[exp\left(\frac{-b}{\vartheta^c}\right)\right] \qquad [1]$$

(2) The Peng and Horns Equation (2005):

$$e(\vartheta)=e_s + \frac{e_s-e_r}{[1+(x\vartheta)^{-p}]^q} \qquad [2]$$

(3) The Nelder Equation (1961):

$$\mu = a' + \frac{c'}{1+exp[-b'(\theta-m)]} \qquad [3]$$

where $e$ is void ratio , $e_r$ and $e_s$ are the void ratios at oven dryness and at saturation, respectively; $\vartheta$ is moisture ratio; $\mu$ is the specific volume; $\theta$ is mass water content; and $a$, $b$ , $c$ ,x, p ,q, a', b', and m are fitting parameters.

## Results and Discussion

### 1. The cracking process as affected by sample thicknesses

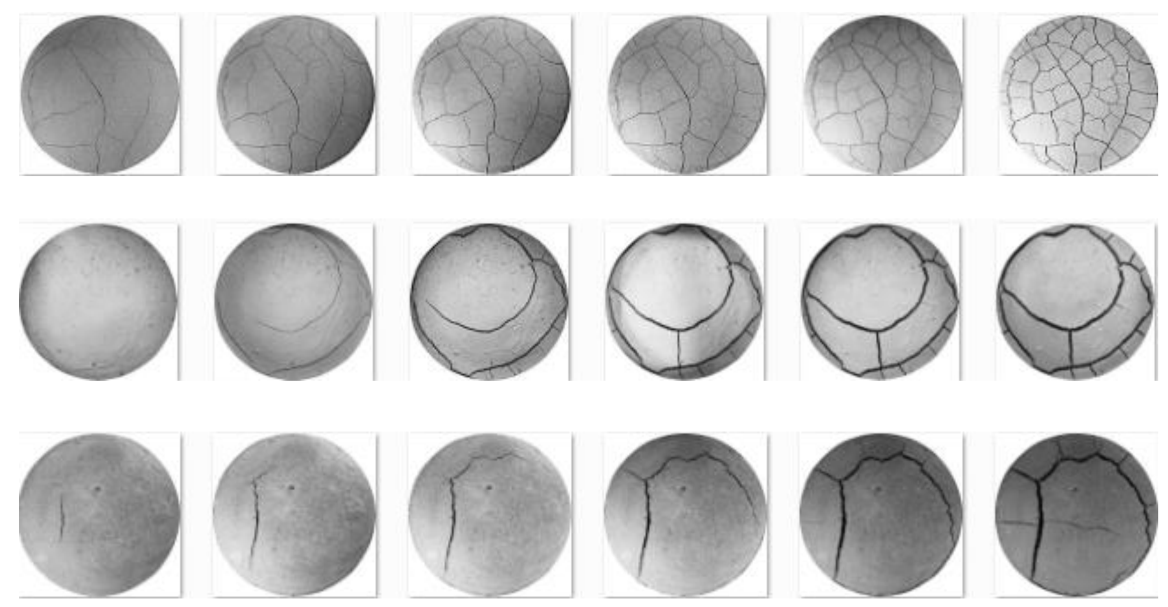


Fig. 2 The cracking process of soil samples with different thicknesses

During the dehydrating process, soil matric potential decreases, and soil surface tension is increased gradually. When the stress is greater than strength between soil particles, soil starts to crack.

For all soil thicknesses, the cracking area and subsidence depth increased with decreasing soil water content.

The occurrence of cracking, however, differed among the three thicknesses: for the 9 and 16 mm samples, cracking occurs at one point and extended; for the 4.5 mm sample, multiple cracks appeared simultaneously.

### 2. Crack morphologies with different sample thicknesses

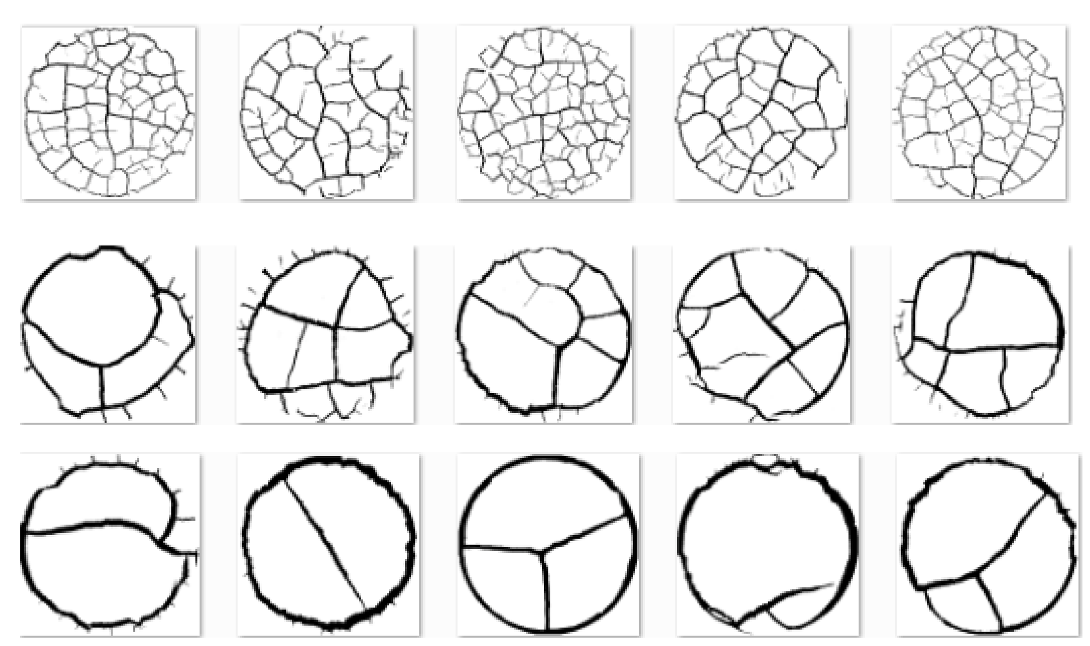


Fig. 3 Crack morphologies with different sample thicknesses

With the increase of sample thickness, the crack nodes and numbers decreased, and the crack width increased (Fig. 3). It is because soil normal stress and stress between particles increase as soil thickness increase, stress state change during desiccation.

### 3. Soil shrinkage curves as related to sample thicknesses

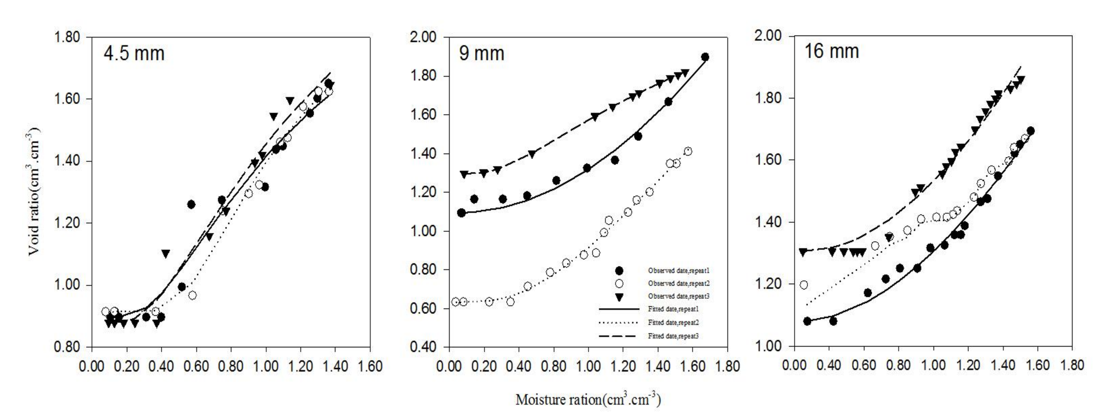


Fig. 4 SSC (Eq. [1]) with different samples thicknesses.

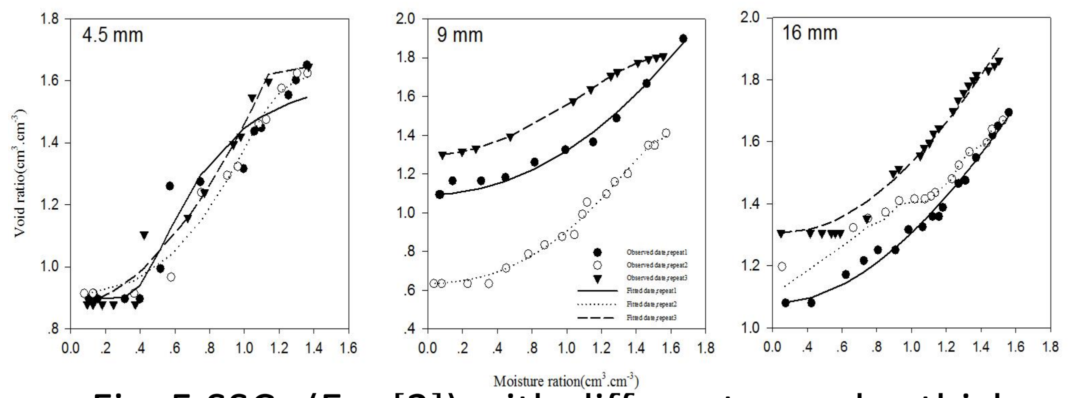


Fig. 5 SSCs (Eq. [2]) with different samples thicknesses

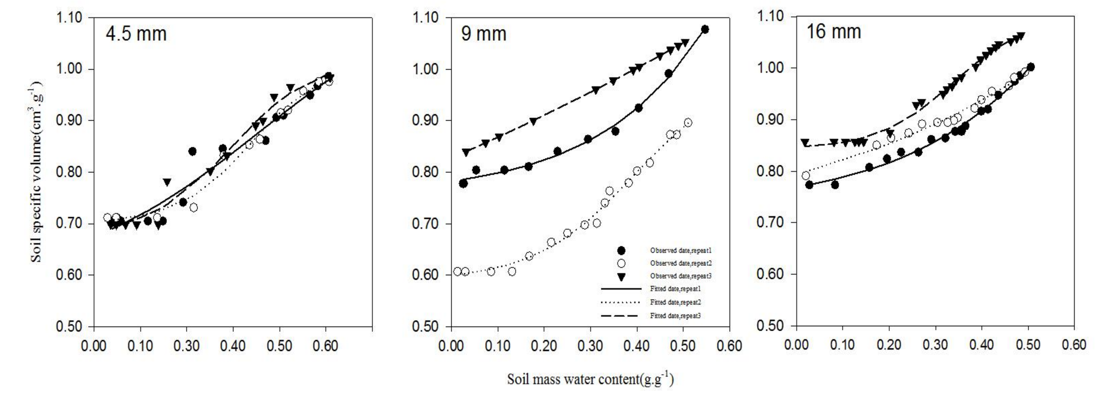


Fig. 6 SSCs (Eq. [3]) with different samples thicknesses

The three equations are able to represents the SSCs for all sample thicknesses, with the $R^2$ values greater than 0.9 (Figs. 4, 5, and 6). However, the repeatability is best for the samples with a thickness of soil is 4.5 mm.

Our measurements indicated during the dehydration process, water content distributed non-uniformly in the 9-mm and 16-mm samples: higher in the bottom layer and lower in the upper layer, indicating a difference in water loss rate inside the sample (Fig. 7). The 4.5-mm soil sample, on the other hand, showed relatively homogeneous water contents and a uniform soil shrinkage.

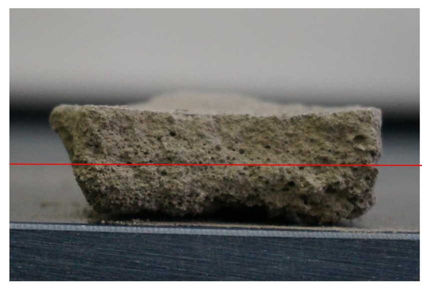


Fig. 7 A picture of the 16-mm-thick soil sample showing the nonuniform distribution of water.

## Conclusions

1. The propagation of cracking process varies with sample thickness. At the stress state changes, effective stress among particles is higher in thicker samples than that of thinner samples.
2. SSCs can be fitted well with equations for all three sample thickness. but in thicker soil, soil water loss rates are different which lead to uniform shrinkage, The thickness of 4.5 mm is a suitable to measure when consideration of cracks.

## Reference

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**November 17, 2015**