Estimating hysteretic soil-water retention curves in hydrophobic soil by a mini tensiometer-TDR coil probe

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Abstract

The precise and continuous measurement of hydraulic properties of hydrophobic soils is of vital importance for the understanding of soil-water interaction in hydrophobic soils. The water repellency (WR) persistence of a volcanic ash soil that was preheated for different temperatures between 20°C and 200°C was measured by the water drop penetration time test. Although the heat treatment lowered the soil organic carbon (SOC) content of soil, the persistence of water repellency was increased in soil samples heated between 60°C and 175°C. To study the hysteretic soil-water retention behaviour of the preheated soils during wetting and subsequent drying processes, a mini tensiometer-TDR coil probe was developed. The sensor was capable of measuring the soil-waster content (θ) and the soil-water potential (ψ) simultaneously in a small pocket of soil. The soil-water retention measurements by wetting and subsequent drying processes implied that; the water entry in term of soil-water potential is positive in water repellent soils.

Key Words

Soil-water repellency, soil-water retention, mini tensiometer-TDR coil probe

Introduction

Soil-water repellency (WR) accounts for influencing many of the key soil hydrological processes such as reduce infiltration and increase of overland flow (DeBano 1971), preferential flow (Wallis and Horne 1992), and reduction of soil-water availability (Bond 1972) in hydrophobic soils. The occurrence of WR reduces the affinity of soils to water such that they can resist wetting for a certain period of time ranging from a few seconds to hours or days (Doerr and Thomas 2000). Although the soil-water content (θ) and soil organic carbon (SOC) are the key factors controlling the soil WR, the occurrence and magnitude of WR are believed to be effected by several other soil and environmental conditions (Doerr *et al.* 2000). Moreover, it has shown that the spatial distribution of soil WR is not uniform even at smaller scales (Hubbert *et al.* 2006). However, most of regular soil-water measuring devices are incapable of simultaneous measurements of θ and ψ in such small resolution (Vaz *et al.* 2002). And, development of measuring device that can measure the θ and ψ at same spatial location within approximately the same bulk soil is of vital importance for the understanding of the soil-water interaction in water repellent soils. Thus, the objectives of this study were (i) to estimate the WR persistence of a volcanic ash soil prior to and after heat pre-treatment, (ii) to develop a mini tensiometer-TDR coil probe that can measure θ and ψ simultaneously at the approximately the same soil volume, and (iii) to investigate the effect of WR on soil-water characteristics during repeated wetting and drying processes, by using an experimental apparatus equipped with mini tensiometer-TDR coil probe.

Methods

Soil materials and physicochemical properties

Soil samples were collected from 0.00-0.05m depth layers of an excavated soil profile in a forested hill-site at Fukushima prefecture in north-eastern Japan (see Kawamoto *et al.* (2007) for further site description). The soil was a volcanic ash soil (Andisol) which was covered by various plant species dominated by red pine trees (*Pinus densiflora*). Soil samples were first hand sieved through a 2-mm mesh screen at the field water contents (0.45 m^3 m^{-3}) prior to all laboratory analysis. The soil texture was clay loam with 17.8% clay, 27.4% silt and 54.8% sand.

Heat pre-treatment and water repellency characterization

Soil samples initially at field moisture were placed on open metal dishes and heated at different temperatures either in an oven (20, 60, 105 and 125°C) or muffle furnace (150, 175, 190 and 200°C) for 24 hours. After cooling down to room temperature in oven/muffle furnace, the samples were kept in a room at 20°C and 75% relative humidity for 48 hours for equilibration. The SOC content of air-dried and preheated samples was determined using an automatic C-N analyzer (CHN corder MT-5, Yannaco, Kyoto). Water repellency persistence of preheated samples was determined by the water droplet penetration time (WDPT) test, and preheated soils were categorized into different classes according to Bisdom *et al.* (1993).

Tension table with combined mini tensiometer-TDR coil probe

To determine the soil-water characteristic curves for preheated soils with different WR persistence, an experimental set up was arranged as shown in Fig. 1. The setup was composed of a plastic column, a Marriott tank, and a mini tensiometer-TDR coil probe. The mini tensiometer-TDR coil probe was made by guiding a 50Ω copper wire (0.3 mm diameter) along the outside wall of a Perspex pipe. The coil was coated and fixed to pipe by a Polyethylene resin, and surrounded by four 0.3 mm diameter copper wires that soldered to the earth wire of the coaxial cable. The porous cup tensiometer was fixed next to the TDR coil, at the tip of the Perspex tube. The mini tensiometer-TDR coil probe was fixed to a 50 mm diameter plastic ring by side through a rubber stopper, and coaxial cable was connected to a metallic cable tester (Tektronix 1502C) and a personal computer, respectively. The open end of the Perspex tube was connected, through a flexible tube, to a digital pressure transducer that connected to a data logger.

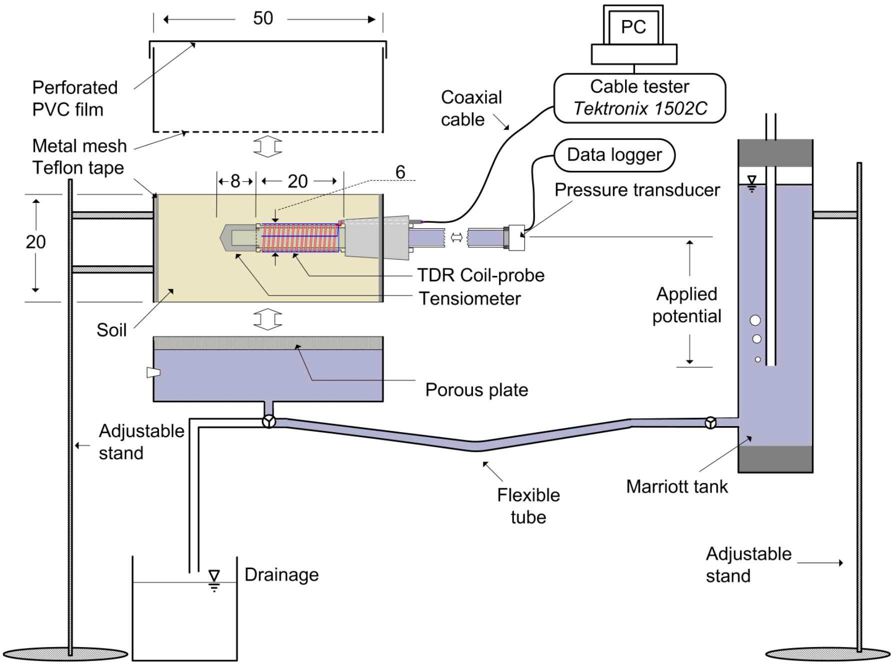


Figure 1. Schematic diagram of the tension table with mini tensiometer-TDR coil probe (all dimensions are in millimetres).

Measurement of soil-water characteristics of water repellent soils

First, the lower part of assemble was saturated, and kept continually under saturation by adjusting the Marriot tank. The ring with TDR-tensionmeter assemble was mounted on lower ring, and fixed by adhesive tapes. The preheated and equilibrated soil sample at air-dry moisture was then uniformly packed in the middle ring, with the same dry bulk density as field (0.56 Mg m^{-3}). Soil surface was covered by another Perspex ring with a metal mesh fixed at the bottom and a perforated PVC film on top. The hydraulic characteristics of soil representing different WR classes were determined by a series of repeated wetting and drying processes.

Results and Discussion

Effect of heat pre-treatment on soil water repellency

The heat treatment lowered the SOC content of soil, and changed the WR persistence of soil (Fig. 2). The soil sample which was dried at 20°C was strongly water repellent (WDPT, 60-600s), however heating at temperatures between 105 and 175°C increased the persistence of WR to extremely water repellent state (WDPT, > 3600s). In contrast, water repellency was disappeared when heated at and above 175°C.

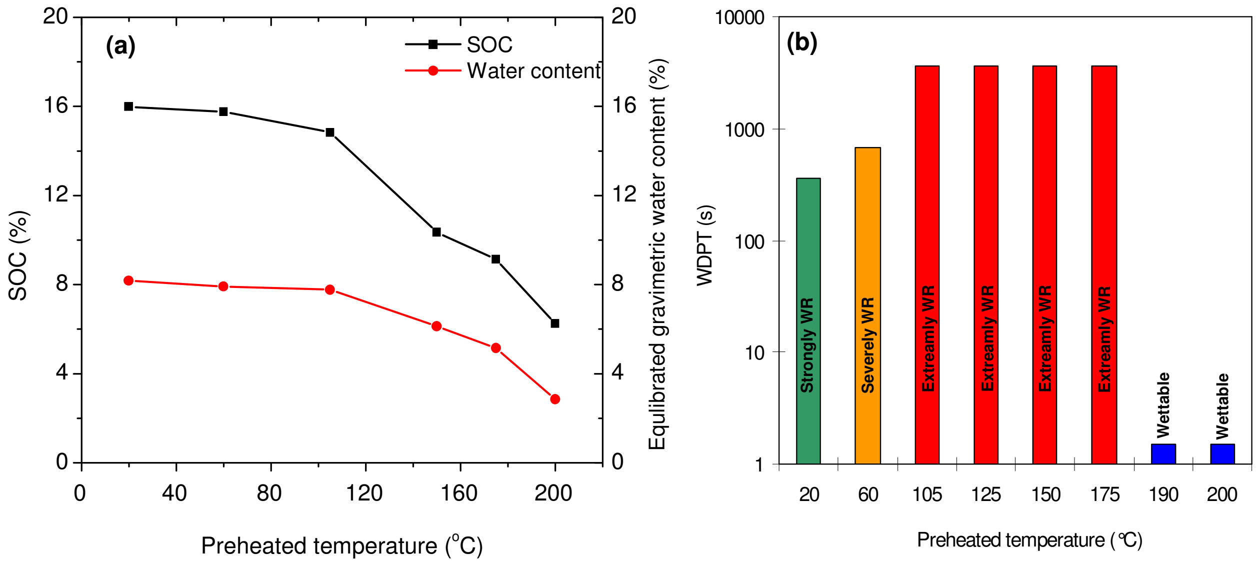


Figure 2. The impact of heating temperature on (a) the SOC content and equilibrated soil-water content, and (b) the WDPT and WR classes (Bisdom *et al.* 1993) of the 0.0-0.05m depth layer of Fukushima volcanic ash soil.

Simultaneous measurement of θ and ψ during wetting-drying cycles

A typical result of a simultaneous measurement of θ and ψ during the wetting process of extremely WR soil (preheated at 105°C) is shown in Fig. 03. It is noted that the extremely and severely WR soils were difficult to be wetted, therefore, the wetting process was started with positive water pressure (e.g. 5 cm of water head as indicated in Fig. 3). Thereafter, wetting process was controlled by switching between water supply and cut-off conditions to obtain the equilibrium state of θ and ψ. Once the equilibrium was reached, wetting process was resumed. The controlled wetting process was continued until the soil becomes fully saturated showing stable water content approximately equal to saturated water content. The water content (θ) and applied water pressure were frequently measured (1 to 3 min. intervals) and recorded at each step of change.

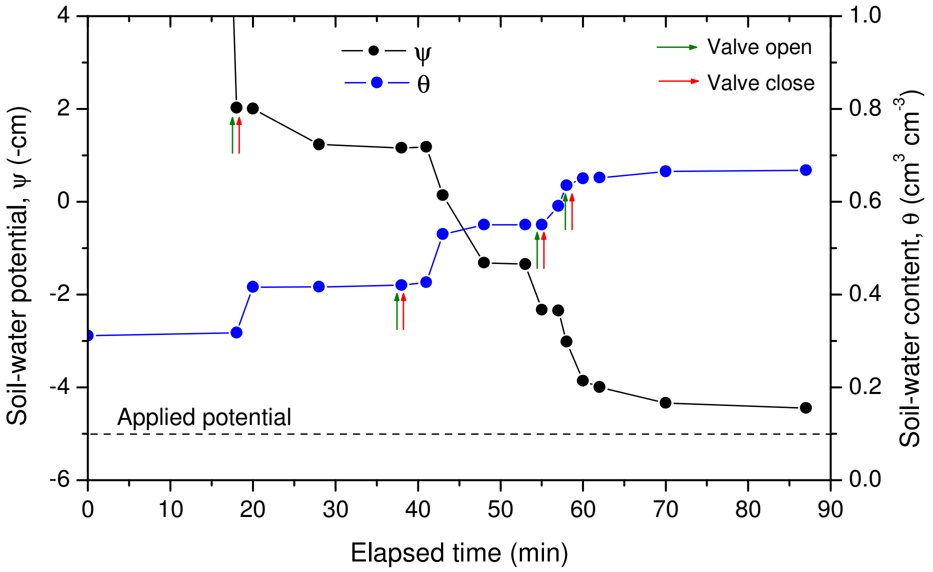
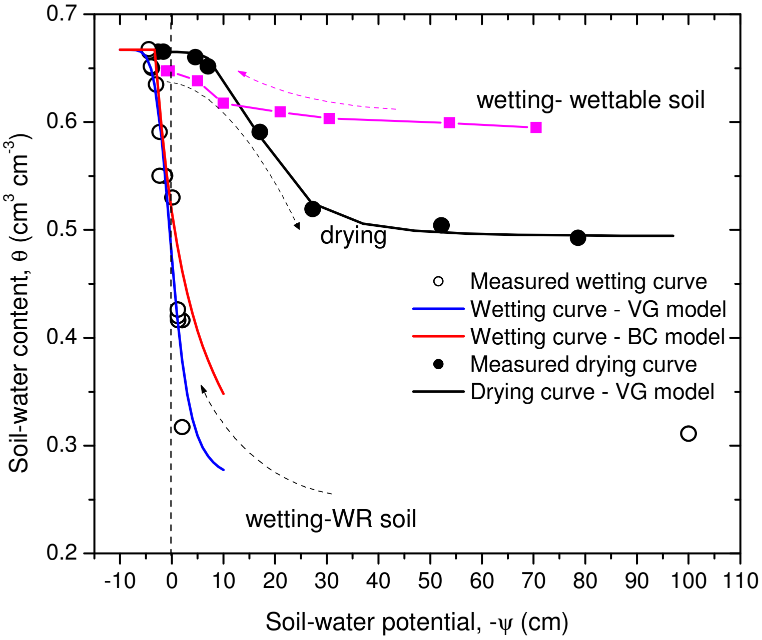


Figure 3. Change in soil-water content and soil-water potential during controlled wetting process of the extremely water repellent soil.

Soil-water retention characteristics of water repellent soil

The soil-water content at each step of equilibrium is plotted against the corresponding soil-water potential to obtain the soil-water retention curve. The Fig. 04 shows the soil water characteristic curves obtained from the relationship described in Fig. 03, together with drying curve.



Wetting curve WR soil
VG model parameters

$\theta_s=0.67$, $\theta_r=0.27$, $\alpha=0.10$, $n=6.01$

BC model parameters

$\theta_s=0.67$, $\theta_r=0.13$, $\lambda=1.22$, $h_b=(-3.3)$

Drying curve
VG model parameters
$\theta_s=0.67$, $\theta_r=0.49$, $\alpha=0.05$, $n=4.66$

Figure 4. The wetting curve and the main drying curve of the extremely water repellent soil.

Conclusion

The water repellency persistence of a volcanic ash soil was measured after preheating at different temperatures between 20°C and 200°C. The preheated soil showed elevated water repellency when drying between 60 and 175°C; however the soil became completely wettable heating beyond 175°C. The soil-water characteristics of preheated soils were assessed by a newly developed mini tensiometer-TDR coil probe which allowed simultaneous measurement of both the soil-water content and soil-water potential for same soil volume. The water-entry into water repellent soil occurred under positive soil-water potential, and the mini tensiometer-TDR coil probe were capable of measuring change of θ and ψ even during the rapid infiltration at positive water potentials.

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