相対湿度が水滴接触角と水滴浸入時間に及ぼす影響

Effects of Relative Humidity on Sessile Drop Contact Angle and Water Drop Penetration Time

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INTRODUCTION

Soil water repellency has an influence on soil moisture dynamics. The primary effect of water repellency is the reduction of infiltration rate. Water repellency varies non-linearly with soil water content and it may break down when exposed to water for long time. Soils are wettable at higher water content. Repellency appears, increases up to a maximum, and decreases again with decreasing water content. Increasing repellency with increasing relative humidity (RH) has been observed in air dried soils.

Many techniques have been developed to measure water repellency and its water dependency. Measuring the contact angle and the water drop penetration time (WDPT) of a soil gives an idea about the degree and the persistence of water repellency, respectively.

There are many techniques to measure the contact angle. Most of them are equation based indirect methods with some conditions which cannot be always fulfilled. Sessile drop method (SDM, Bachmann, 2000) is a direct method to measure the contact angle of soil. This method has been identified as unable to measure water dependent repellency, because it basically uses monolayer of air dried soil.

The objectives of this study are (1) to assess the effect of RH on the sessile drop contact angle and WDPT, and (2) to find the relationship between contact angle and WDPT considering the effect of RH.

MATERIALS AND METHODS

Fine silica sand with 94% of mass ranging from 53 to 150 μm was used as a model soil. Repellency was artificially induced using stearic acid with 284.5 of molecular weight.

Stearic acid was mixed with silica sand to obtain 0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.065, 0.10, 0.14, 0.18, 0.22, and 0.24% of contents. Since stearic acid is insoluble in water, it was dissolved in diethyl ether and mixed with sand, in a fume hood. Samples were placed 2 hours in the hood to allow evaporation of diethyl ether and then kept for one day. Repellency was estimated using the SDM and the WDPT test. A monolayer of sample which was fixed on double sided adhesive tape glued to glass slide was used for the sessile drop contact angle measurements. For the WDPT measurement, about 5-g sample in weighing bottle with 30 mm in diameter and height was used. Samples were exposed to RH levels of 33, 57, 75, and 94% in chambers with saturated salt solutions at 25±1°C for 20 to 22 h. During the measurements, the RH of the room was adjusted to the respective RH of the chamber.

For the SDM, a drop of deionized water with 10-μL volume was placed on the sand surface with a micro-pipette. Digital micro-photograph of the horizontal view of the water drop was taken within 1 s and the contact angle was manually measured using the photograph.

Surface free energy of soil, γ_S (mN m^{-1}) was calculated with sessile drop contact angle (θ) using the equation developed by Carrillo et al. (1999) combining Good-Girifalco equation and Young's equation;

$$\cos\theta = 2\Phi\,(\gamma_S/\gamma_L)^{1/2} - 1 \qquad (1)$$

where γ_L is the liquid surface free energy, and Φ is the molecular parameter (0.6, Gilboa et al., 2006).

For the WDPT test, one drop of deionized water with 50 ± 1 μL of volume was placed on the soil surface with a burette at about 10-mm height. Weighing bottles were covered with the lid to minimize evaporation during the test. Time taken for complete penetration of the water drop was measured. Samples with WDPT ≤ 1 s were assumed as wettable and with WDPT ≥ 1 h were assumed as extremely repellent.

撥水性，相対湿度，接触角

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RESULTS AND DISCUSSION

The sessile drop contact angle increased with increasing RH from 33 to 94% (**Fig. 1**). This increase was smaller at lower stearic acid contents. The sessile drop contact angle rapidly increased up to about 0.065% of stearic acid content and then slightly increased up to about 0.22% of stearic acid, beyond which further increase of stearic acid did not increase the sessile drop contact angle. This pattern was nearly similar at RHs varying from 33 to 94% (**Fig. 1**).

The WDPT increased with increasing RH from 33 to 94%. At 33% RH, maximum WDPT was observed at 0.22% stearic acid content (**Fig. 2**). Samples at 57, 75, and 94% of RH became extremely repellent (WDPT ≥ 1 h) at 0.18, 0.14, and 0.10% of stearic acid contents, respectively. The increase of WDPT with RH was smaller at lower stearic acid contents (**Fig. 2**).

The relationship between the sessile drop contact angle and the WDPT (**Fig. 3**) showed that the WDPT was less than 1 s up to about 70° of contact angle. Samples became extremely repellent at contact angle between 89° to 94°. Between 60° to 89° of contact angle (0.2 – <3600 s of WDPT), $\log_{10}$ (WDPT) was highly correlated with sessile drop contact angle (R^2 = 0.96–0.99) by exponential relationship.

Neither the relationship between sessile drop contact angle and WDPT (**Fig. 3**) nor the relationship between soil surface free energy and WDPT (**Fig. 4**) was affected by RH. The WDPT was less than 1 s when the soil surface free energy was higher than 73 ± 3 mN m^{-1} (**Fig. 4**), that is, about the surface free energy of water (72 mN m^{-1}). Samples became extremely repellent at about 40 mN m^{-1} of soil surface free energy.

Water content at each stearic acid content increased with increasing RH (results not shown). The increase of stearic acid content did not affect the water content, that is, stearic acid did not affect the adsorption of water vapor.

Silica sand would be completely coated with hydrophobic material at about 0.22% of stearic acid content, because further increase of stearic acid did not increase the repellency (**Fig. 1**). Results showed that even if fully coated with hydrophobic material, the repellency of sandy soil increased with increasing RH.

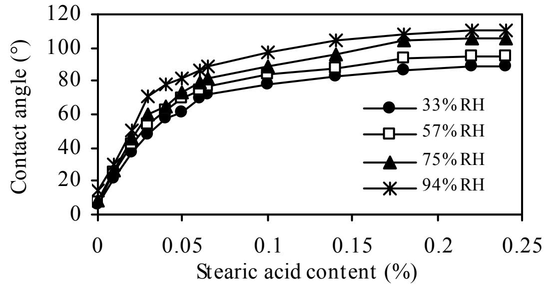

Fig. 1 Relationship between stearic acid content and sessile drop contact angle at different relative humidities (RH)

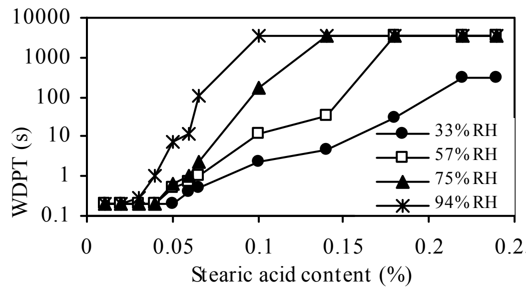

Fig. 2 Relationship between stearic acid content and water drop penetration time (WDPT) at different relative humidities (RH)

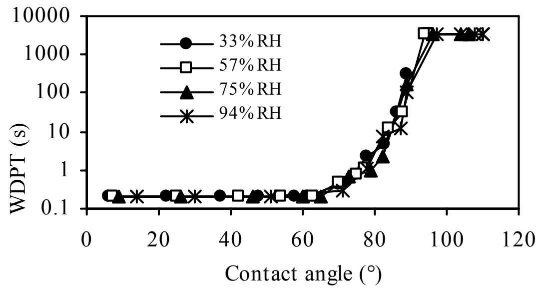

Fig. 3 Relationship between contact angle and water drop penetration time (WDPT) at different relative humidities (RH)

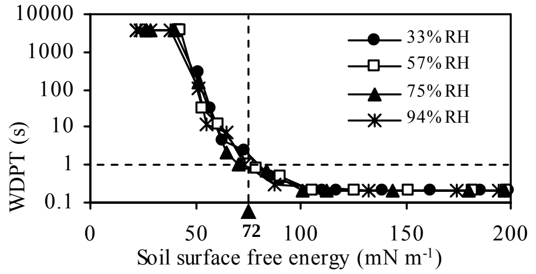

Fig. 4 Relationship between soil surface free energy and water drop penetration time (WDPT) at different relative humidities (RH)

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