

Particle size conditions water repellency in sand samples hydrophobized with stearic acid

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Introduction

Water repellency (WR; Fig. 1) is a property of soils that reduces water infiltration capacity and also affects evaporation, erosion, structure and the hydrological behaviour of soils. Soil WR is associated with content and chemical nature of soil organic matter, vegetation, microorganisms, soil mineralogy and soil type, texture and other processes such as wildfires. Severity of soil WR may change over time affecting geomorphological and hydrological soil processes. This variation depends on soil moisture content, and is related with the wetting/drying cycles and seasonal variations of soil moisture. In water repellent soils, WR has been observed to increase linearly with water content, with soils becoming wettable above a critical water content. But other authors have observed that soil WR varies nonlinearly with moisture content, peaking around wilting point, and decreasing rapidly when moisture content approached field capacity. Other soils show some degree of repellency when water content is very low (after oven drying), but WR declines and increases again reaching a second peak, after which soil becomes wettable.



Figure 1. Water repellency in a soil aggregate.

However, although soil WR and its causes are well known phenomena, there are still gaps in research and contradictions reported by different researchers. The relationship between soil WR and texture, hydrophobic organic matter content, soil moisture content or drying temperature must be studied under field and laboratory conditions to better understand the involved mechanisms and processes. In this research we study the effect of these factors in WR from sandy soils hydrophobized with stearic acid under laboratory conditions.

Experimental design

Quartz sand samples were collected from the top 15 cm of homogenous sand horizons from coast of Cádiz (SW Spain). When present, macroscopic organic residues were removed first by dry sieving (2 mm) and later by immersion of sand samples in distilled water, carefully removing any floating residues from the water surface. Oxidizable organic matter content was removed using H₂O₂ (6%). Sand samples were oven-dried (80 °C, 24 h) and carefully homogenised and separated into different sieve fractions: 0.5-2 (coarse sand, CS), 0.25-0.5 (medium sand, MS), and 0.05-0.25 mm (fine sand, FS). At this stage, complete wettability of all samples was checked.

Sieve fractions were each divided into various subsamples and a selection contacted with solutions of stearic acid (SA) in diethyl ether. These were mixed, using a magnetic stirrer, in glass beakers until all the diethyl ether had evaporated, avoiding precipitation of excess SA on the wall of glass beakers or as a layer above the sand (Fig. 2). A range of subsamples of sand containing 0.5, 1, 5, 10, 20 and 30 g kg⁻¹ SA were obtained (Figure 1 shows detailed views of CS sieve fractions coated with SA).

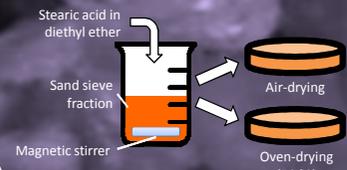


Figure 2. Experimental design.

Individual sand subsamples were placed in Petri dishes, moistened with distilled water until 10% water content in weight, and homogenized. A set of subsamples (3 sieve fractions x 6 SA contents) was left air-drying at standard laboratory conditions, and another set was placed in an oven (50 °C). WR was determined every 24 h during 7 days. Soil moisture was determined immediately before soil WR assessment.

Discussion of results

Generally, time of drying and, thus decreasing soil moisture content, resulted in increased soil WR (Fig. 4). Extreme WR was rapidly reached in oven-dried CS and MS samples, and in oven-dried FS samples at SA content ≥ 5 g kg⁻¹. In contrast some irregularities were observed in air-dried samples. Soil WR from MS samples at SA content 0.5 g kg⁻¹ and FS samples at SA contents 0.5-5 g kg⁻¹ showed a peak between 2 and 5-6 days after wetting (all samples became extremely water repellent after 7 days of treatment). This means that it is crucial to consider the whole WR soil moisture curve and not only a single moisture point when evaluating soil WR.

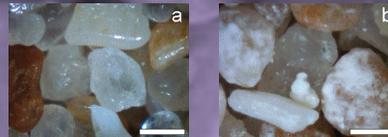


Figure 3. (a) CS sieve fraction before SA addition. (b) CS sieve fraction after 30 g kg⁻¹ SA addition. Scale bars are 1 mm.

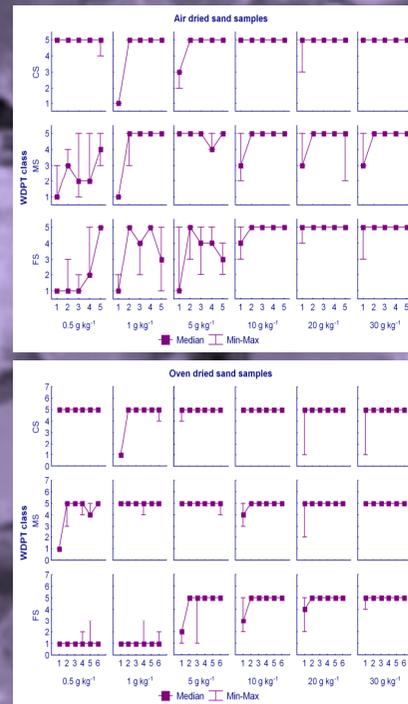


Figure 4. WDTP classes (median and range) from different sieve fractions (CS, MS and FS) and stearic acid concentrations in air- and oven-dried samples in time.

What are the hydrological or geomorphological consequences of this finding? Runoff rates and erosional responses may vary in function of the velocity of drying/moistening processes, and further research under field conditions is necessary. Soil WR from air-dried samples with SA contents below 10 g kg⁻¹ increased with SA content (especially in FS and MS). Small WR variations were observed only for SA content ≥ 10 g kg⁻¹, independently of particle size and soil moisture (Fig. 4). This suggests that sand particles with SA content < 10 g kg⁻¹ may only be partially coated with globules of SA, with a high proportion of wettable exposed mineral surface. However, different particle sizes induced different responses. After several days of air-drying, wettability from FS samples with SA 0.5-5 g kg⁻¹ is due to the high proportion of uncoated mineral surface.

In samples with SA contents above 10 g kg⁻¹, most of the mineral surface is coated with a hydrophobic layer. MS samples showed a similar behaviour, although extreme soil WR was achieved with just 1 g kg⁻¹ SA after 1 day of treatment. Almost all air-dried CS samples showed extreme repellency (Fig. 4), even at 0.5 g kg⁻¹ SA content. There are some possible explanations for this:

- First, water droplets were confined to certain points of sand particles, with air bubbles entrapped in the pores (Fig. 5). As a result, the surface of sandy samples may be considered superhydrophobic.
- Second, hydrophobic organic substances need a certain interval of time for water repellent sand particles to become wettable, since re-organization of polar molecules in the hydrophobic coating of sand particles requires a certain period of time.

The step from hydrophobic to wettable conditions also depends on the size of water droplets (droplets 4.58 mm in diameter were used here) in relation with the size of sand particles. The 50 µL droplets used for WDTP assessment may contact only 8-16 particles of CS in comparison with > 120 for FS, providing greater representative sampling of the surfaces of the latter. This could explain differences between CS and MS/FS sieve fractions. Erratic behaviour showed by FS and MS sieve fractions at 0.5-5 g kg⁻¹ may be due to contact of water droplets with a higher proportion of areas not covered by hydrophobic coatings. Coarse sand particles became extremely water repellent at just 0.5 g kg⁻¹ SA, and further increases in SA content did not increase soil WR. Sand particles are not immobilized, and may move while in contact with water (Figs. 5 and 6). We speculate that movements of sand particles during infiltration may cause new intact hydrophobic surfaces to come in contact with water, enhancing this process.

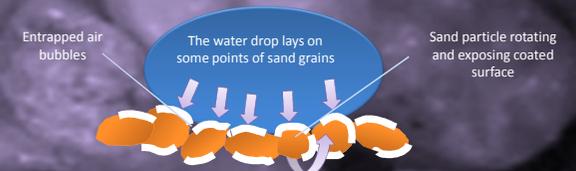


Figure 5. Detail of a water droplet in contact with SA coated sand.

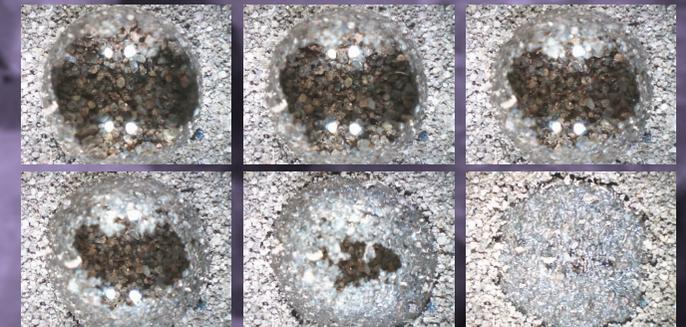


Figure 6. Infiltration of a droplet (50 µL) in water repellent sand (infiltration took 5 minutes).