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Threshold water content beyond which hydrophobic soils become hydrophilic: The role of soil texture and organic matter content

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ABSTRACT

Hydrophobicity is a soil water repellency phenomenon, which results in difficulty of soil wetting. The objectives of this study were to determine the hydrophobicity index and water–soil contact angle for different soil classes and to define the threshold water content beyond which hydrophobic soils become hydrophilic. Soil samples were collected from nine soils in southern Brazil, where vegetation was composed mainly of natural grassland species. Undisturbed soil samples were collected in three soil layers (0–5, 5–10 and 10–20 cm) for the determination of bulk density, total porosity, macroporosity, microporosity and water retention curve. In these same layers, additional samples were collected for the evaluation of repellency index and soil–water contact angle; while soil sorptivity was analyzed using a micro tension infiltrometer. Among the soils, Hapludert, Dystrudept, Haplaquents and Albaqualf showed high hydrophobicity index and soil–water contact angles in the air-dried medium at three sampled soil layers, ranging from 0 to 20 cm depth. In hydrophobic soils, the repellency index and hydrophobicity persistence in the soil decreased with depth, reduction in organic content, and increase in water content. The Haplaquents and Endoaqualfs had greatest repellency index until the volumetric water content equilibrated reached tension of 10 kPa. The threshold water content beyond which hydrophobic soils become hydrophilic (θ_h) varied from 0.36 to 0.57 cm^3 cm^{-3}. The reduction in organic matter content of soil promotes the reduction of the repellency index by reducing the threshold water content beyond which hydrophobic soils become hydrophilic as well as hydrophobicity persistence in the soil. In conclusion, the threshold θ_h can be very different depending on the soil type and properties (texture and organic matter).

1. Introduction

Hydrophobicity is a phenomenon widely documented in several countries (Doerr et al., 2007; Hallett, 2008; Jaramillo, 2006). In Oceania (Deurer et al., 2011) and South America (Johnson et al., 2005; Vogelmann et al., 2010) hydrophobicity affects large areas and may thus cause serious problems in agricultural production.

Soil moisture content is the main risk factor responsible for the high variability of this phenomenon in the soil (Doerr et al., 2007; Hallett, 2008). Keizer et al. (2007) investigated the relationship between water content and hydrophobicity and its variability in space and time in a soil during a growing season of potato and maize in Portugal. The results confirmed that the transient behavior of soil wetting changed markedly from hydrophobic to hydrophilic within short periods, primarily due to the increase in soil water content. Johnson et al. (2005) and Madsen et al. (2011) pointed out that a fundamental aspect of hydrophobicity is its high variability both in time and space. The phenomenon does not manifest itself permanently, as it is presented with maximum intensity in the dry seasons and may then decrease or even vanish in the wet seasons (Wahl, 2008). A lengthy period of drying promotes an increase in hydrophobicity and imposes a high difficulty for re-wetting the soil which may need wetting for long periods to restore the soil water retention property (Rodríguez-Alleres et al., 2007).

Thus, it is expected that in a non-repellent soil with low water content, the initial wetting process is rapid due to high attraction forces existing between the soil particles and water. However, Dekker and Ritsema (1994) found that this process can be extremely slow in soils that exhibit hydrophobicity, even in conditions of low soil moisture. These authors reported that there is a transition zone or critical zone of soil moisture, defined by two water contents. The first is lower as is known as the minimum limit of soil water content below which the surface is water repellent, whereas the second is

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higher and represents the water content above which the surface is wettable. The same authors found that some soils, although with a certain degree of repellence, retained significant amounts of water, depending on their size fractions and organic matter content. Dekker et al. (2001) found that the soil has a critical content of water in which the hydrophobicity phenomenon manifests, defined as the critical limit of moisture for the occurrence of water repellency, and below this value there is the manifestation of repellency and above which the soil is not water repellent. This limit is herein defined as the threshold water content beyond which hydrophobic soils become hydrophilic.

We formulated the hypothesis that hydrophobic soils at high moisture contents show low hydrophobicity index, but significantly increases with reduced moisture from determined critical water content, abruptly reducing sorptivity and infiltration. The objectives of this study were to determine the repellency index and soil–water contact angle, and to define the threshold water content beyond which hydrophobic soils become hydrophilic in different soils and depths, with a varying granulometric composition and organic matter content.

We expected the water content beyond which hydrophobic soils become hydrophilic to be very different depending on the soil type and properties (texture and organic matter), which is a novel contribution to previous findings.

2. Materials and methods

2.1. Description of study site

A laboratory study was conducted during the 2011 summer season on soil samples from nine different soils from Rio Grande do Sul State, southern Brazil. According to the Köppen climatic classification, the climate of the area is Cfa, subtropical humid, consisting of four distinct seasons, with mild winters and hot summers and well distributed rains throughout the year. The mean annual rainfall ranges from 1500 mm to 1700 mm, and the mean annual temperature is 17 °C (Nimer, 1990).

2.2. Description of soil morphological attributes and vegetal composition

In the study sites, morphological properties were described according to Schoeneberger et al. (2002). Diagnostic horizons were identified in the field and composite samples were collected for the determination of chemical and physical properties in the laboratory. Afterwards, the soils were classified using the Brazilian Soil Classification System (EMBRAPA, 2006) and the Soil Taxonomy (Soil Survey Staff, 2010) (Table 1). The geographical coordinates of the sampling points were recorded using a GPS (Table 1), and a site location map was elaborated (Fig. 1).

The sampling sites showed no evidence of recent anthropogenic activities, such as soil tilling, and all areas have been used as pasture for beef cattle. Collection of soil samples was carried out mainly in natural field to pursue quasi-uniformity in plant species for all sampling points. Plant samples were also collected and later classified and described in the laboratory to determine the flora composition (Table 2). All sample collections and descriptions were performed in the summer of 2011, showing a predominance of summer plant species over winter species, and thus there may be expected differences in the floristic composition when assessed at other seasons (De Quadros et al., 2003).

2.3. Sample collection

At each site three different points were sampled, all with the similar flora composition. In each of the points, four undisturbed soil samples were collected from three soil layers (0–5, 5–10 and 10–20 cm), in all locations (as indicated in Fig. 1), using soil cores, 5.7 cm in diameter and 4 cm high, for the determination of soil bulk density, porosity, macroporosity and microporosity. Twelve samples were collected per layer in a given soil and a total of thirty-six (36) samples were collected in each soil type. Disturbed soil samples were also collected in the same locations and layers for the determination of granulometric composition and organic carbon content.

2.4. Determination of organic matter

The soil organic carbon content was determined by the methodology described in Nelson and Sommers (1996). In short, soil organic matter was oxidized with potassium dichromate solution in the presence of concentrated sulfuric acid. After heating in the block digestion, the excess potassium dichromate solution was titrated with ammonium ferrous sulfate in the presence of diphenylamine indicator. The organic carbon values obtained were converted into organic matter, by multiplying with 1.724 as it has been established that 58% of organic carbon is contained in any composition of soil organic matter (Nelson and Sommers, 1996).

2.5. Soil hydro-physical characterization

The granulometric composition was determined using the pipette method (Gee and Bauder, 1986). Sand was separated by sieving, clay was quantified by sedimentation based on the Stoke's law, and silt was calculated by the difference between total soil mass and sum of clay plus sand.

For the determination of soil water retention, undisturbed soil samples were saturated by capillarity and then exposed to water tensions of 1, 6 and 10 kPa, in a sand column (Reinert and Reichert, 2006) and the tension of 33 and 100 kPa using the Richards chamber (Klute, 1986). Soil water contents at tensions of 500, 1000 and 1500 kPa were determined using with water potential psychrometry

Table 1
Soil classification according to soil taxonomy (Soil Survey Staff, 2010), Brazilian System of Soil Classification (EMBRAPA, 2006), parent material and geographical coordinates of the soil sampling points.

Soil taxonomy	SiBCS[a]	Parent material	Latitude	Longitude
Dystrudept	Cambissolo Háplico Eutrófico	Basalt	S 29° 38′ 41.5″	W 53° 45′ 19.6″
Hapludox1	Latossolo Vermelho Distrófico	Basalt	S 28° 40′ 30.8″	W 53° 35′ 47.0″
Hapludox2	Latossolo Vermelho Distroférrico	Basalt	S 27° 54′ 27.2″	W 53° 18′ 08.5″
Haplohumult	Argissolo Vermelho-Amarelo Alumínico	Sandstone	S 29° 43′ 35.7″	W 53° 45′ 23.3″
Paleudalf	Argissolo Vermelho Distrófico	Sandstone	S 29° 43′ 12.4″	W 53° 42′ 10.8″
Haplaquent	Gleissolo Háplico Distrófico	Basalt sediments	S 29° 43′ 08.7″	W 53° 42′ 07.2″
Albaqualf	Planossolo Háplico Eutrófico	Basalt sediments	S 30° 02′ 26.6″	W 53° 40′ 42.7″
Endoaqualf	Luvissolo Háplico Órtico	Granite	S 30° 08′ 26.6″	W 53° 35′ 37.7″
Hapludert	Vertissolo Ebânico Órtico	Basalt	S 30° 43′ 14.7″	W 55° 47′ 41.5″

[a] SiBCS — Brazilian Soil Classification System.