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Methods for determining soil water repellency on field-moist samples

Louis W. Dekker,[1] Coen J. Ritsema,[1,2] Klaas Oostindie,[1] Demie Moore,[3] and Jan G. Wesseling[1]

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[1] In this paper we describe a simple and quick method for determining the presence of water repellency in a soil by using a small core sampler (1.5 cm in diameter, 25 cm long) and applying the water drop penetration time (WDPT) test at different depths on the sandy soil cores. Obtained results provide spatial distribution patterns of water repellency in a soil profile, demonstrating seasonal changes in repellency. An advantage of the method is that the soil is not disturbed by the sampling. For assessment of the persistence of water repellency in strongly to extremely water repellent soils, and for determination of the critical soil water contents, the WDPT test and volumetric water content determinations should preferably be performed in the laboratory.

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1. Introduction

[2] Water repellency can result in losses of plant-available water, reduced agricultural crop production, and deterioration of turf quality on sports fields. *Dekker et al.* [2005] indicated that since 1883 more than 1200 theoretical and applied research papers have been published on the topic of soil water repellency. At present, this bibliography contains more than 1700 papers, showing an increased interest by scientists in unraveling the causes, effects, and potential management strategies for the widely occurring phenomenon of soil water repellency.

[3] Despite substantial research and the significant implications for productivity and management of soils, soil water repellency and critical soil water content are still not regularly assessed in soil analyses or surveys. This is perhaps because practical methods for assessing this common behavior of soils under a range of moisture contents have not been readily available. This paper presents an overview of existing methods, including their limitations, and introduces a simple and easy to use field and laboratory method for determination of the occurrence and degree of water repellency.

2. Occurrence, Origin, and Hydrological Effects of Soil Water Repellency

[4] Water repellency appears to be the rule rather than the exception in field soils of many countries [*Dekker et al.*, 2005]. Water repellent soils have been identified in an increasing number of agricultural and natural environments around the world. At present, water repellent soils have been found and studied in several countries throughout America, Europe, Africa, Asia and Australia. From this great number of locations where soil water repellency has been identified, it is clear that soil water repellency is not geographically or climatically dependent. In fact soil water repellency is regularly observed in humid temperate climates as well as in arid and semiarid regions of the world [*Dekker et al.*, 2005]. It is also important to note that the occurrence of soil water repellency is not limited to any particular soil type. While it may develop most easily in sandy soils, water repellency has also been documented in loamy, peaty clay and clayey peat soils [*McGhie and Posner*, 1980; *Dekker and Ritsema*, 1996a, 1996b], as well as in heavy clay soils with grass cover [*Dekker and Ritsema*, 1996c].

[5] The exact chemical composition of substances responsible for the development of water repellency in soils is difficult to identify, but they are generally organic compounds that accumulate on and between soil particles. Organic compounds with hydrophobic (water repellent) properties are naturally abundant in the biosphere and may be released gradually into the soil. Examples include waxy substances from leaves [*Passialis and Voulgaridis*, 1999], root exudates [*Dekker and Ritsema*, 1996a; *Doerr*, 1998], fungi [*Fidanza et al.*, 2007], microbes [*Hallett and Young*, 1999] and decomposing organic matter [*McGhie and Posner*, 1981]. Furthermore soil water repellency might also develop locally because of oil spills [*Roy and McGill*, 2000b], extensive oil fires as observed in Kuwait [*Suleiman and Bhat*, 2004], or wildfires [*DeBano*, 2000]. Recently it has also been shown that regular irrigation applications of treated sewage water can lead to the development of soil water repellency due to dissolved organic substances in the sewage water [*Tarchitzky et al.*, 2007].

[6] The simple presence of the organic compounds, however, does not necessarily lead to the expression of water repellency in soils. Rather, it has been suggested that these compounds only cause soil water repellency when

[1]Soil Science Center, Alterra, Wageningen, Netherlands.
[2]Erosion and Soil and Water Conservation Group, Wageningen University, Wageningen, Netherlands.
[3]Aquatrols Corporation of America, Paulsboro, New Jersey, USA.

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they form a specific molecular arrangement [*Roy and McGill*, 2000a]. Since water repellent behavior is triggered below a certain soil moisture content [*Dekker and Ritsema*, 1994; *Dekker et al.*, 2001], it is possible that the specific molecular arrangement occurs near or at this critical water content value. Above the critical soil water content, a soil behaves as a wettable porous medium, below as a water repellent one. This change in state of the soil affects flow and transport processes drastically, leading to a completely different hydrological behavior for wettable versus water repellent soils.

[7] Infiltration into a water repellent soil is slower and more variable than into a wettable soil. If the surface of a soil is water repellent and it starts raining, water will not infiltrate into the soil immediately. It will first pond on the soil surface and, if there are any microtopographical or macrotopographical contours, then flow to the lower depressions. Instead of flattening out by lateral diffusion the wetting front in a water repellent soil might lead to the formation of ‘‘fingers’’ or ‘‘preferential flow paths’’ [*Ritsema and Dekker*, 1994].

3. Methods for Assessing Soil Water Repellency

[8] Most of the various techniques for measuring and classifying soil hydrophobicity are described by *Wallis and Horne* [1992], *Hallett and Young* [1999], *Bachmann et al.* [2000], *Letey et al.* [2000], *Wang et al.* [2000], and *Roy and McGill* [2002].

[9] *Letey et al.* [1962] reported a technique for measuring the water-solid contact angle for soils using a capillary rise approach. *Tillman et al.* [1989] measured the sorptivity of water and ethanol in soil columns and used the ratio of ethanol sorptivity to water sorptivity to calculate the index of water repellency. *Carrillo et al.* [1999] described a laboratory device for measuring the water entry pressure of a soil, which has relevance to field cases because it affects infiltration, while *Bachmann et al.* [2000] proposed the sessile drop method for determining soil water repellency using a goniometer-fitted microscope. *Watson and Letey* [1970] proposed using the measurement of the liquid surface tension which wets the soil material with a 90° contact angle as an index of water repellency. Some researchers used a similar procedure except that they recommended measuring the molarity or percentage (rather than surface tension) of ethanol in a droplet of water required for infiltration within 10 s [e.g., *King*, 1981, *Wallis and Horne*, 1992; *Roy and McGill*, 2002]. Normally, the molarity of ethanol droplet (MED) or ethanol test uses a series of aqueous ethanol solutions prepared in concentrations ranging between 0% and 36%. Drops of the various solutions are placed on the surface of soil samples, and the degree of soil water repellency is then defined as the ethanol percentage or molarity of the least concentrated ethanol solution that is absorbed by the soil in a mean time of <10 s. However, some researchers have set the duration of contact time at <3 s [e.g., *Crockford et al.*, 1991; *Doerr and Thomas*, 2000; *Cofield et al.*, 2007] and others at <5 s [e.g., *Karnok et al.*, 1993; *Dekker and Ritsema*, 1994; *Crabtree and Henderson*, 1999], making direct comparisons between studies difficult. Besides, comparisons are hard to make because samples are sometimes sieved, air dried or oven dried, which all affect the measured values.

[10] The most commonly used method to assess soil water repellency is the ‘‘water drop penetration time’’ (WDPT) test [*van't Woudt*, 1959; *Dekker and Jungerius*, 1990; *Bisdom et al.*, 1993; *Dekker and Ritsema*, 1994]. It involves placing droplets of distilled water onto the surface of a soil sample and recording the time for their complete infiltration. This test broadly determines the presence of soil water repellency and how long it persists in the contact area of a water droplet. To distinguish between wettable and water repellent soils, an arbitrary WDPT threshold of 5 s [*Bisdom et al.*, 1993] has been used widely. Compared to all the other available measurement techniques to assess soil water repellency, the WDPT test is used by scientists and practitioners more than any other because it is inexpensive (only a water dropper and watch are required) and easy to perform in the field and in the laboratory.

[11] Certain researchers, including the authors of this paper, have in the past practiced and recommended air or oven drying samples in the laboratory to determine the potential persistence of soil water repellency, using the method outlined by *Dekker and Ritsema* [1994]. However, recent studies have clearly shown that air and oven drying do not necessarily provide information that is relevant to field conditions. On the contrary, air and oven drying appear to produce or create some quite different conditions than those observed in the field under prolonged drought conditions [e.g., *Dekker et al.*, 1998; *Buczko et al.*, 2002; *Newton et al.*, 2003; *Taümer et al.*, 2005; *Ziogas et al.*, 2005; *Diehl and Schaumann*, 2007]. This means that the best way to correctly reveal information about the water repellency condition of a soil is to make measurements directly in the field or as an alternative in the laboratory on field-moist samples shortly after gathering. According to *King* [1981] and *Roy and McGill* [2002] the MED and ethanol percentage tests at soil moisture contents higher than air dry do not provide reliable results on the assessment of soil water repellency. At present the WDPT method appears to be the only suitable test for assessing the degree of water repellency on field-moist samples.

4. Determining the Presence of Water Repellency in the Field

[12] In slightly water repellent soils it is possible to measure the persistence or stability of water repellency in the field in situ with the WDPT test. For this purpose soil cores were taken to a depth of 25 cm using a small (1.5 cm wide and 25 cm long) core sampler.

[13] Beginning on 10 September 2004 water repellency was determined at intervals of 25 cm over a length of 12.5 m across a fairway of a Dutch golf course. The water repellency was measured in the field by placing drops of water on the cores at 1 cm intervals beginning at the surface (see Figure 1). Depths of the water repellent soil layers (with WDPT >5 s) were recorded. The advantage of taking samplings every 25 cm is that a two-dimensional visualization can be made of the occurrence of water repellent and wettable soils along a transect measuring several meter in length and 25 cm in depth (see Figure 2). This information shows the investigator how water is most likely to flow into and through the soil under the conditions encountered during the sampling campaign. Generally, one can assume

Figure 1. Soil core sampler containing a 25-cm-long water repellent sandy column, as shown by the water drops remaining on the soil surface.

that during an infiltration event most water will flow through the wettable soil parts while almost no water movement will take place in and closely around the dry water repellent soil pockets.

[14] A major part of the soil in the fairway was water repellent on 10 September and the transect shows that on this date the water repellency regularly started at the surface and ended at a depth between 10 and 22 cm (see Figure 2). Interspersed between the water repellent regions were vertically oriented wettable regions, indicating the existence of preferential flow paths. The diagram of 27 September shows a thin wettable surface layer and the development and increase of preferred flow paths. By 8 December a region of the soil had been transformed into wettable soil, however several dry areas with water repellency were still present. We detected even locally dry, dusty water repellent sand in the fairway on 10 May 2005, after a period with numerous rain events. The recurrence and further increase of water repellency in 2005 is evident in the diagrams of 7 June and 1 August, as shown in Figure 2.

[15] It is evident that water repellency is influenced by seasonal conditions and soil water content and that repellency is most pronounced during periods with drier weather conditions (generally in spring and summer) and decreases or disappears during wetter periods (late autumn and winter). Figure 3 shows the water repellent soil volume from the surface to a depth of 25 cm on three sampling days in 2005. The soil in the upper 10 cm of the 10 May transect was completely wettable, whereas at these depths the 5 July transect showed water repellent soil volumes exceeding 95%. Thereafter a decrease in water repellent soil volume was detected on 1 August. It is worthy to note that not only a large decrease took place in the upper 5 cm, but also at depths between 20 and 25 cm.

5. Assessment of Water Repellency on Field-Moist Samples in the Laboratory

[16] In soils with strong to extreme water repellency soil core sampling and subsequent measurements are too time consuming and therefore doing the measurements on field-moist samples in the laboratory is more desirable [*Dekker et al.*, 2001; *Greiffenhagen et al.*, 2006]. The soils can be sampled at different depths using steel cylinders (100 cm^3), with a diameter and height of 5 cm, or (50 cm^3), with a diameter of 5 cm and a height of 2.5 cm. Taking volumetric soil samples has the advantage that also the volumetric soil water content can be measured [*Dekker and Ritsema*, 1994]. The cylinders can be pressed vertically into the soil, emptied into plastic bags, and used again. The closed plastic bags should preferably be transported to the laboratory as quickly as possible. Measurements should be performed immediately after arrival to minimize any temperature increase in the samples, condensation in the plastic bags, water redistribution in the samples etc. The water repellency of the field-moist samples can be measured immediately after recording their wet weight.

[17] Three drops of distilled water are placed on the smoothed surface of a soil sample, using a standard medicine dropper, and the time that elapses before the drops are absorbed is determined. As noted above, in general a soil is considered to be water repellent if the WDPT exceeds 5 s. *Dekker and Jungerius* [1990] described an index, allowing a quantitative classification of the persistence of soil water repellency. They distinguished the following seven classes of repellency on the basis of the time needed for the water drops to penetrate into the soil: class 0, wettable, nonwater

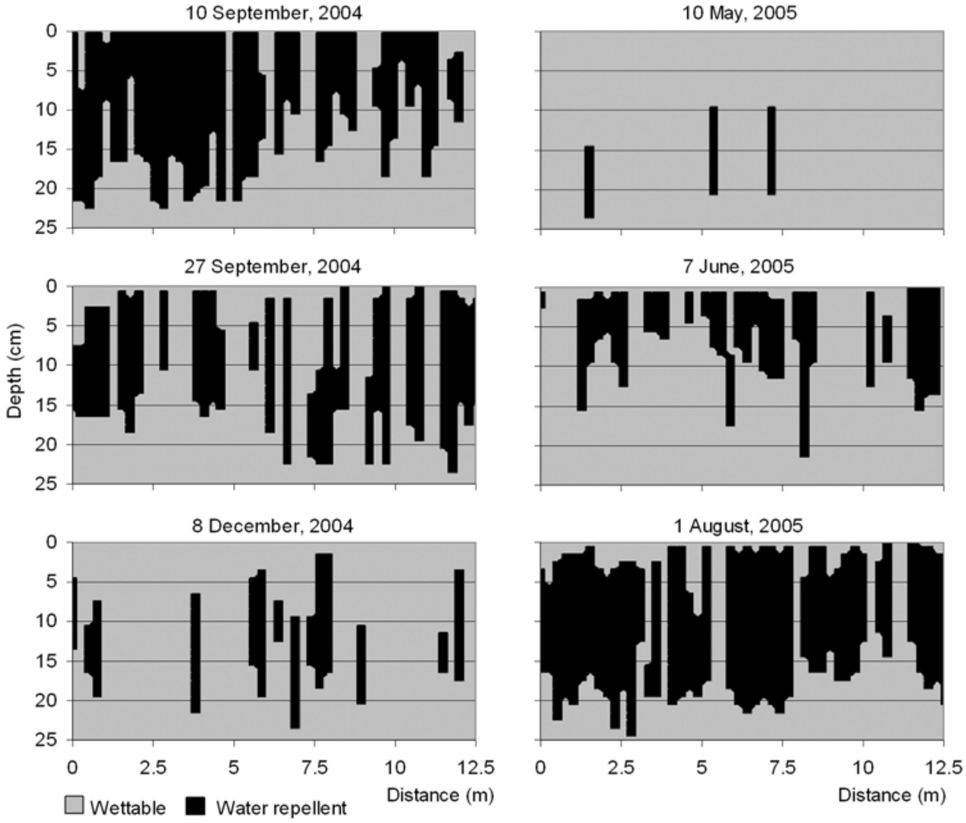

Figure 2. Spatial distribution of wettable and water repellent soil in 12.5-m-long and 25-cm-deep transects on six sampling occasions. The water repellent soil parts are dry and are difficult to rewet by infiltrating water.

repellent (infiltration within 5 s); class 1, slightly water repellent (5–60 s); class 2, strongly water repellent (60–600 s); class 3, severely water repellent (600–3600 s); and extremely water repellent (>1 h), further subdivided into class 4 (1–3 h); class 5 (3–6 h); and class 6 (>6 h). An example of the persistence of actual water repellency in a grass-covered sandy soil is given in Figure 4. This informa-

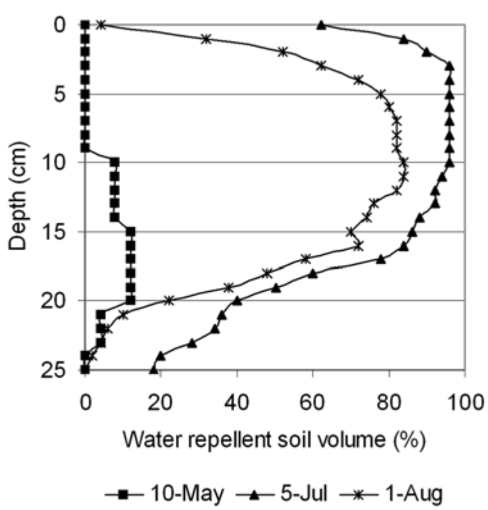

Figure 3. Percentage of water repellent soil volume (n = 50) between 1 and 25 cm depth on three sampling occasions.

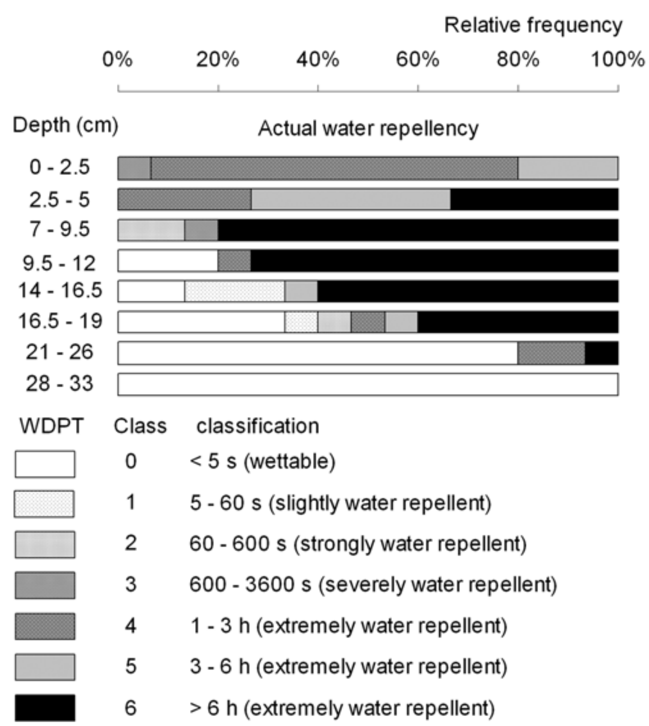

Figure 4. An example of the relative frequency of wettable and water repellent soil samples per layer, indicating that water repellency is most extreme in the 7–9.5 cm layer of this particular soil (n = 15).

tion allows construction of a detailed profile of the relative wettability or repellency of the area tested which can be used in developing soil and irrigation management strategies.

[18] The advantage of measuring the volumetric soil water content simultaneously with assessing if a certain soil layer is wettable or water repellent is that the critical soil water content below which the soil is water repellent can be determined [*Dekker et al.*, 2001]. A good estimation of the critical soil moisture content per depth of a soil can be obtained by measuring numerous samples, preferably ranging from wet to dry, while also checking for water repellency [see also *Ziogas et al.*, 2005; *Wessolek et al.*, 2008]. This type of information is very useful for practitioners so they can aim to keep the soil profile from drying to below the critical level if possible in order to prevent development of water repellency, because it is better to prevent than to cure water repellency.

6. Discussion and Conclusions

[19] A number of methods exist to determine the occurrence and degree of soil water repellency, several of them are specialized and require specialized equipment and are best suited for use in the laboratory. However, most of these methods are performed on air- or oven-dried samples which can overestimate as well as underestimate the conditions occurring in the field under prolonged drought conditions. Thus, samples should preferably be taken under dry conditions in order to reveal and determine the most realistic and highest degree of water repellency that occurs in the field. Therefore, we recommend the use of field-moist samples for testing soil water repellency.

[20] Previous studies indicate that it is not possible to describe the water repellency of soils only as a static property but rather as a range of possible states of water repellency depending on the existing soil water condition. The first level of evaluating water repellency in soils is simply the characterization of soils as either wettable or water repellent. In the present paper a simple and practical field method is introduced which consists of using a small core sampler and taking soil cores within short distances and immediately conducting the WDPT test on them. This will result in information on the spatial distribution of water repellency in a soil profile. Performing this method on several dates during the seasons will give information on the temporal changes. An advantage of this method is that nearly no disturbance of the soil takes place and that it can be performed for example in greens and fairways of golf courses and in sports fields.

[21] The persistence or stability of water repellency, and the underlying critical soil water contents per layer (below which the soil becomes water repellent) for strongly to extremely water repellent soils can be assessed on field-moist samples in the laboratory. Simultaneous testing for the presence of soil water repellency and critical soil water content provides valuable information for more complete understanding of soil water dynamics and will contribute to more effective advice and management of soils, water, crops and the environment.

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L. W. Dekker, K. Oostindie, C. J. Ritsema, and J. G. Wesseling, Soil Science Center, Alterra, Droevendaalsesteeg 4, NL-6708 PB Wageningen, Netherlands. (louis.dekker@wur.nl)

D. Moore, Aquatrols Corporation of America, 1273 Imperial Way, Paulsboro, NJ 08066, USA.