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Development of actual water repellency in a grass-covered dune sand during a dehydration experiment

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ABSTRACT

Water repellency is a soil property which temporally changes in severity and is most pronounced when soils are dry. In the past, numerous researchers air- or oven-dried soil samples in the laboratory to determine the potential water repellency. However, measurement on air- and oven-dried samples can overestimate as well as underestimate the conditions occurring in the field under prolonged drought conditions. To reveal and determine realistic and potentially the highest persistence, we studied the influence of dehydration upon repellency in a dune sand grassland between 11 April and 5 September 2002, by artificially sheltering the soil. The shelter was built to protect the soil from getting wetted by precipitation during this period. The soil was sampled eight times in vertical transects over a distance of 75 cm to a depth of 33 cm during the dehydration period. On each sampling date soil water contents were measured and the persistence or stability of actual water repellency was determined in 120 field-moist samples collected at 8 depths. At the start of the dehydration experiment the mean volumetric soil water contents in the transect varied between 5 and 10.5%. At the end of the dehydration process the grass cover was wilted and yellow-brown and the soil profile dried-up to volumetric water contents between 1 and 2.5%. During the dehydration period, the average water storage in the upper 33 cm of the soil (total of 8 layers) decreased from 22 mm to less than 5 mm. Slightly water repellent and wettable dune sand layers at depths of 7 to 19 cm on 11 April were found to be altered into extremely water repellent soil within eight days of dehydration. The most extreme soil water repellency, with water drop penetration times of more than 6 h, was detected in large parts of the five soil layers sampled between depths from 9.5 to 33 cm on 4 June, 11 July and 5 September, 2002. The maximal water repellency was found to be evidently less in the organic rich surface layer in comparison with the organic poor deeper layers. For each soil layer the relation between soil water content and actual water repellency was determined. This resulted into three distinguished zones: a) a water repellent zone; b) a transition zone and c) a wettable zone. The threshold values of the volumetric water content that describe the transition zone varied per depth.

1. Introduction

According to Philip (1969), among others, dry soils are normally easily wetted by rainfall and irrigation. They state that the force of attraction between soil particles and water causes the water to lose its cohesiveness, i.e. the tendency to retain its droplet shape, allowing it to flow along the surfaces of the particles. The water thus disappears as a liquid drop, wetting the soil. However, since the publications of Krammes and DeBano (1965) and DeBano (1969) we know that if the attractive forces are neutralised or absent, e.g. because of the presence of a hydrophobic coating on sand grains or aggregates, there upon the water remains as a droplet, and the soil is said to repel water (i.e. it resists wetting). Such soils are considered to be water repellent and to exhibit hydrophobic properties, especially when they are dry. Water repellency has been observed in sand, loam, clay, and peat soils all over the world (e.g. DeBano, 1969; Dekker and Ritsema, 2000; Dekker et al., 1999, 2005b; Doerr et al., 2006; Jaramillo et al., 2000; Moral García et al., 2005). However, the phenomenon is most pronounced in course textured soils and is common in sandy soils supporting for instance turf or pasture grasses (Cisar et al., 2000; Dekker et al., 2005a; Oostindie et al., 2008, 2011).

Although water repellency of soils has several possible causes, numerous researchers agree that an organic coating on the soil particles causes the problem. However, mineral particles need not be individually coated with hydrophobic material; intermixing of mineral soil particles with particulate organic matter, like remnants of roots, leaves, and stems, may also induce severe water repellency (Bisdom et al., 1993; Morley et al., 2005).

Water repellency is influenced by season and soil water content. In general, repellency is most severe during summer and decreases or disappears during the winter months. This seasonal variation may be due to soil moisture conditions. Extended dry periods are helping to produce the formation of water repellent soils. Likewise, extremely wet weather can lessen or even eliminate water repellency for several weeks. The

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critical soil water content introduced by Dekker and Ritsema (1994) appears not to be a sharp static threshold above which a soil is wettable and below which a soil is water repellent, but rather a transitional range value. This range of critical soil water contents for a certain depth had been introduced by Dekker et al. (2001) as the "transition zone". Soil layers can be either wettable or water repellent within the transition zone, depending on the sequence of weather conditions and wetting history.

The persistence or stability of water repellency, as measured with the water drop penetration time test (Letey et al., 2000), can be highly variable, both temporally and spatially. Spatial variations in repellency have been shown to cause or enhance the formation of preferential flow paths (Ritsema et al., 1993). Water repellency may dramatically affect water and solute movement at the field-scale, a process which has often been underestimated (Bauters et al., 2000; Ritsema and Dekker, 1995; Wessolek et al., 2009). Water repellency and its spatial variability have been shown to cause decreased infiltration of irrigation water and precipitation, non-uniform wetting of soil profiles, increased runoff, and leaching due to preferential flow (Dekker et al., 2001; Ritsema and Dekker, 1996; Ritsema et al., 1997; Wessolek et al., 2009).

Several researchers, among which the authors of this paper, have in the past practiced and recommended air or oven drying samples in the laboratory to determine the potential 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 (Ritsema et al., 2008). Measurement of water repellency on air- and oven-dried samples in the laboratory can overestimate as well as underestimate the conditions occurring in the field under prolonged drought conditions (e.g. Buczko et al., 2002; Dekker et al., 1998, 2009; Greiffenhagen et al., 2006; Täumer et al., 2005; Wessolek et al., 2008; Ziogas et al., 2005). 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. The main objective of this study was to reveal and determine realistic and potentially the highest persistence of soil water repellency of soil samples, taken at different depths in the soil profile, under dry to very dry conditions.

The present paper describes the influence of dehydration upon developing and increasing the severity of actual soil water repellency in a pasture on native dune sand, by artificially sheltering the soil. Additionally, the maximal water repellency has been determined in four dehydrated 20 cm high grass covered soil columns. The column method was used to check if it is an appropriate alternative for determining the maximal soil water repellency, because it is an easier and faster method.

2. Materials and methods

2.1. Field-soil and soil sampling

The experimental field was located on a dune sand near Ouddorp, in the south-western part of The Netherlands. The soil consisted of fine sand with less than 3% clay to a depth of more than 3 m and was classified as Typic Psammaquent (Soil Survey Staff, 2006). The site was a grass-covered pasture and has not been tilled for at least several decades. An organic matter content on dry weight basis of 12.5% was present in the surface layer (0–2.5 cm) and of 9.5% in the second layer (2.5–5 cm). At depths of 7–9.5 cm an organic matter content of 4.8% was measured and at depths of 9.5–12 cm of 2.4%. It further decreased to 1.5% at depths of 14–16.5 cm and 1.1% at depths of 16.5–19 cm. Below this depth the organic matter content was found to be around 0.5%.

The soil was known to be severely to extremely water repellent to a depth of more than 50 cm during dry periods (Dekker and Ritsema, 1994; Dekker et al., 2000). The water repellency of this sandy soil is caused by a coating of the sand grains with hydrophobic material and the presence of hydrophobic particulate organic matter (Bisdom et al., 1993).

For the present study we investigated the development and increase of the persistence or stability of actual water repellency during dehydration of the sheltered soil during the period from 11 April to 5 September, 2002. A shelter consisting of a wooden frame (3 m × 3 m × 1.5 m) with a transparent plastic cover was built over the experimental plot to protect the grass-covered soil from getting wetted by precipitation.

During the drying process soil samples were taken at eight depths in vertical transects on 11, 19 and 24 April, on 1 and 15 May, and on 4 June, 11 July, and 5 September, 2002. The soil was sampled at depths of 0–2.5, 2.5–5, 7–9.5, 9.5–12, 14–16.5, 16.5–19, 21–26, and 28–33 cm, using sharpened steel cylinders with a diameter of 5 cm. At each depth 15 adjacent samples were taken over a distance of approximately 75 cm. The cylinders were pressed into the soil vertically, emptied into plastic bags and used again. The plastic bags were tightly sealed to minimise evaporation from the soil. The field-moist soil in the plastic bags was weighed and the persistence of actual water repellency was measured. All 960 samples had been oven-dried and weighed to calculate the volumetric soil water content.

Additionally four soil columns, including grass-cover were carved out in the field, using steel cylinders with a height and diameter of 20 cm on 11 April, 2002. These columns, excavated adjacent to the shelter, were placed under the shelter and allowed to dehydrate for two months. The soil columns were taken to study if this method offers an appropriate alternative to assess easier and faster the maximal persistence of soil water repellency in the upper layers of a grass covered soil. On 13 June the intact soil columns were sampled in threefold with sharpened steel cylinders with a diameter of 5 cm at depths of 0–2.5, 2.5–5, 7–9.5, 9.5–12, 14–16.5, and 16.5–19 cm. The samples were emptied into plastic bags and, after determining the persistence of water repellency, they were oven-dried to calculate the soil water contents.

2.2. Water drop penetration time (WDPT) test

The persistence or stability of water repellency of the soil samples was examined using the water drop penetration time (WDPT) test. If a water drop does not enter the soil spontaneously, the soil–water contact angle is greater than 90° and the soil is considered to be water repellent. The degree of water repellency changes with time after contact with water. The time for the drop to enter the soil (WDPT) provides an indication of the stability or persistence of the repellency (Letey et al., 2000). WDPT is a measure of the time required for the contact angle to change from its original value approaching 90°. Therefore, it is a measurement of the stability or persistence of the repellency. Three drops of distilled water from a standard medicine dropper were placed on the smoothed surface of a soil sample, and the time that elapsed before the drops were absorbed was registered. Owing to the moisture tension which depends on the temperature and air humidity (Doerr et al., 2002), we measured the persistence of water repellency of the soil samples in the laboratory under controlled conditions at a constant temperature of 20 °C and a relative air humidity of 50%. In general, a soil is considered to be water repellent if the WDPT exceeds 5 s (Dekker, 1998). We applied an index allowing a quantitative definition of the persistence of soil water repellency as described by Dekker and Jungerius (1990). In the present study seven classes of repellency were distinguished, based upon the time needed for the water drops to penetrate into the soil: class 0, wettable, non-water repellent (infiltration within 5 s); class 1, slightly water repellent (5 to 60 s); class 2, strongly water repellent (60 to 600 s); class 3, severely water repellent (600 to 3600 s); and extremely water repellent (more than 1 h), further subdivided into class 4, 1 to 3 h; class 5, 3 to 6 h; and class 6, >6 h.

We measured the water repellency of the field-moist samples, the so-called "actual soil water repellency" (Dekker and Ritsema, 1994). These measurements were performed immediately after assessing the