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Effect of water repellent soil layer and its placement in soil columns on water infiltration

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Abstract

Soil water infiltration and its characteristics are important in water management both in agriculture and hydrology. Water repellency (WR) of soil, a phenomenon that often occurs in forest soils, reduces infiltration greatly and enhances soil degradation by various ways. In this study two sandy loam (SL) and clay loam (CL) soils were sampled from Kaleybar forest area, East Azarbaijan province, IRAN. They were artificially hydrophobized into two different degrees of WR by using stearic acid. Water drop penetration time test (WDPT) was applied to assess the severity of the repellency. Effects of the water repellent soil layer and its placement on cumulative infiltration and infiltration rate were investigated. Results indicated that in the both soils, the cumulative and average infiltration rates at the beginning of the experiment and the average steady state infiltration rate decreased with increasing repellency. The average value of the initial infiltration rate decreased from 1.37 (cm min^{-1}) to 1.21 (cm min^{-1}) in the sandy loam soil, and from 1.50 (cm min^{-1}) to 0.745 (cm min^{-1}) in the clay loam soil with increasing the severity of the repellency from degree 0 to 1. In the wettable soil column with upper water repellent layer the average value of initial infiltration rate decreased to 1.23 (cm min^{-1}) in SLsoil and to 0.762 (cm min^{-1})in the CL soil, respectively. The steady state infiltration rate reduced from 0.037 (cm min^{-1}) to 0.024 (cm min^{-1}) in the SL and from 0.020 (cm min^{-1}) to 0.016 (cm min^{-1}) in the CL soil with increasing WR. The steady state infiltration rate in WR soil column and soils with upper and lower WR layers were almost the same.

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Introduction

Water repellent soil is a soil that does not become immediately wet when a drop of water is placed on its surface. Soil water repellency is a situation that is formed by complex waxy organic compounds. During the decomposition, organic compounds covered soil particles and the soil becomes water repellent. Reports on the occurrence of water repellent soils (WRS) or hydrophobic soils have been published by researchers from different parts of the world under different climatic conditions, land uses, vegetation covers and soil textures (DeBano and Letey, 1969; Wallis and Horne, 1992; Doerr and Thomas, 2000; Ritsema and Dekker, 2003).

Soils which have hydrophobic properties (also called water repellent soils) can resist or retard surface water infiltration (Feng *et al.,* 2001). This, in turn, may lead to increased surface runoff (Burch *et al.,* 1989), soil erosion (Shakesby *et al.,* 2000) and fingered preferential flow, which may cause inhomogeneous distribution of water and nutrients in the root zone of crop plants and may accelerate pollutant transport to the groundwater (Ritsema and Dekker, 1996; Wang *et al.,* 1998; Carrillo *et al.,* 2000). Besides the retardation or resistance of surface water infiltration, water repellent soils have been associated with preferential flow (Van Dam, *et al.,* 1990).

Field observations have indicated that the rates of water infiltration into repellent soils are very irregular. The main difference between a hydrophilic and hydrophobic soil is the shape of the wetting front. Infiltrating water in a hydrophobic soil forms an unstable front with fingers. In hydrophilic soils, water can infiltrate as a flat horizontal stable Richards' type wetting front. According to Milly (1988), the wetting front in a hydrophobic soil is unconditionally stable when Richards' equation is used without hysteresis in the soil moisture characteristic curve (Nieber *et al.,* 2000). The infiltration capacity of a water-repellent soil was found to be 25 times lower than for a similar soil rendered hydrophilic by heating (DeBano, 1971). Wallis *et al.* (1990) found that the infiltration capacity was six times lower on a water-repellent dry sand than on adjacent moist, less repellent sands and, in a separate study (Wallis *et al.* 1991), reported that, for the first 5 min of measurement, a hydrophobic soil had only 1% of the potential infiltration capacity when hydrophilic. The effects of water repellency on infiltration are not yet fully understood. The purpose of this paper is to quantify the effects of soil water repellency on water infiltration rate in two soils with water repellent layer in different placement.

Materials and methods

Soil sampling

In this study two clay loam (CL) and sandy loam (SL) soils were sampled from Kaleybar forest area, East Azarbaijan province, Iran. They were artificially hydrophobized into two different degrees of water repellency by using stearic acid. Water drop penetration time test (WDPT) was applied to assess the severity of the repellency.

In the experimental set I, sandy loam soil was made water repellent by adding no (or 0) and 9 (g kg^{-1}) of water repellent stearic acid. In the experimental set 2, the clay loam soil was made hydrophobic by adding no (or 0) and 14 (g kg^{-1}) of extremely water repellent stearic acid. Water repellent soils were prepared by mixing with an acetone solution containing stearic acid.

Water drop penetration time test

The persistence of water repellency of the soil samples was examined using the water drop penetration time (WDPT) test (King, 1981). Soil water repellency (WR) was measured in triplicates by the WDPT method, by placing a 40 µl drop of distilled water on the soil surface and recording the time which elapsed until the water drop infiltrated.

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 classification of the persistence of soil water repellency as described by

Dekker and Jungerius (1990). Thus seven classes of repellency were distinguished based on the time for water drops to infiltrate the soil: class 0, wettable, non-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 r pellent (600 s–1 h); and extremely water repellent (more than 1 h). Further subdivided into class 4, 1–3 h; class 5, 3–6 h; and class 6, 6 h. WDPT of thestudied soils and their degrees of WR are presented in Table 1.

Infiltration-rate measurements

Cumulative infiltration measurements were conducted in duplicates on the air-dried soil samples. For this purpose, a 10 cm long, 6 cm i.d. PVC soil column was used. A fine-wire screen was attached at the lower end of the soil column to retain the soil and allow air to escape during infiltration. To avoid preferential flow of the water between the soil and the column walls during infiltration, the inner surface area of the column was coated with a film of water-repellent material (Paraffin). Duplicates of air-dried soil samples were packed into the column in about 3 cm lifts and the soil column was gently tapped until the desired height was reached, from which the soil bulk density for the sandy loam (1.4 g cm^{-3}) and clay loam (1.3 g cm^{-3}) soil was calculated. To examine the effect of the water repellent layer on water infiltration, two other soil columns were prepared with a water repellent layer (3 cm thickness) at depth of 0-3 cm and 5-8 cm in the wettable soil column, respectively. Schematic diagram of soil column is presented in Fig.1.

A rubber o-ring attached to a fine-wire screen was pressed down into the column along its wall to the depth of the soil surface to prevent water infiltration through the column walls during the initial stage of infiltration. To maintain a constant water head at the soil surface during infiltration, a Mariotte bottle was connected through a port in the column located 1 cm above the soil surface. The soil column was placed on a platform which enabled lifting and lowering it to the desired height. The Mariotte bottle was filled with distilled water and placed on a balance (0.01 g). To initiate infiltration, the soil column was lowered to the height at which the water-ponding depth at the soil surface reached 3 cm, and this was set as zero time. The reduction in the weight of the Mariotte bottle was recorded as a function of time at 2-min increments. The infiltration rate was calculated from the decrease in the weight of the Mariotte bottle as a function of time. The time at which the wetting front reached the lower end of the column was recorded and the leached soil solution was collected at 2-min increments.

Results and discussion

Cumulative infiltration

The cumulative infiltration as a function of time, for the wettable soils, water repellent soils, and wettable soil with a water repellent layer are presented in Figs. 2 and 3. As can be seen, cumulative infiltration decreased with increasing water repellency in the both sandy loam and clay loam soils. Cumulative infiltration after 60 min in the wettable SL and CL reached to 5.72 cm and 4.38 cm respectively. In the water repellent soil columns this value was 3.89 cm for SL and 3.37 cm for CL soil. The reason for this is that the water repellent soil layer limits water infiltration into the soil due to reduced sorptivity of the soil surface particles. Moody *et al.* (2009) expressed that sorptivity was inversely related to the degree of water repellency. In soil columns with water repellent layer at depth of 0-3 cm cumulative infiltration is slightly more than water repellent soil columns (3.47 cm). When the water repellent layer was located at a depth of 5-8 cm, rapid reduction in cumulative infiltration was observed in 8 (min) and 40 (min) after the experiment starting in SL and CL soils, respectively. This indicated that water flow reached to the water repellent layer and this layer retarded water infiltration.

For the wettable soils, water outflow was observed in the lower end of the soil column after about 34 and 94 min, for the SL and CL respectively. In the water repellent SL and CL soil columns after 52 and 100 min water outflow occurred. For the soil columns, excluding the upper water repellent soil layer, observed after 48 min (SL) and 98 min (CL), these value for the soil columns with lower water repellent soil layer were 39 and 97 min, respectively. Prior investigations have shown that Water repellent soils can resist or retard infiltration (Doerr and Thomas 2000) and the respective infiltration patterns of repellent and wettable soils are different (Tillman *et al.* 1989).

Table 1. WDPT and water repellency degrees for the studied soils.

Soil	Amount of added stearic acid (g kg^{-1} soil)	WDPT (s)	WR degree
Sandy loam	0	<1	0 (wettable)
	9	17	1 (slightly water repellent)
Clay loam	0	<1	0 (wettable)
	14.5	20	1 (slightly water repellent)

Table 2. Average initial (at t=2 min) and final infiltration rates of soils.

Experiment	Initial infiltration rate (cm min^{-1})		Final infiltration rate (cm min^{-1})	
	Sandy loam	Clay loam	Sandy loam	Clay loam
Wettable soil column	1.37^{b}	1.50^{c}	0.037^{c}	0.020^{b}
Water repellent soil column	1.21^{a}	0.745^{a}	0.024^{a}	0.013^{a}
Soil column with upper WR layer	1.23^{a}	0.762^{b}	0.024^{a}	0.014^{a}
Soil column with lower WR layer	1.35^{b}	1.55^{d}	0.026^{b}	0.014^{a}

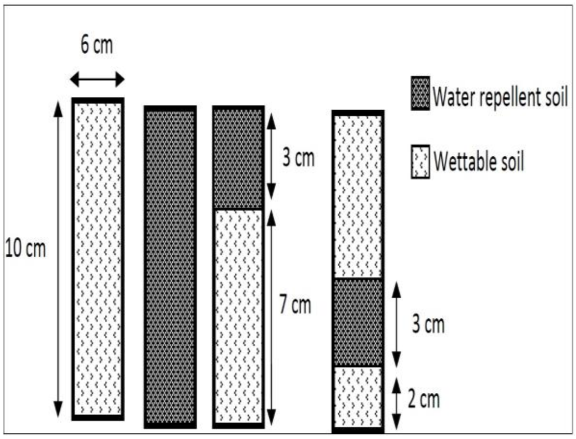

Fig. 1. Water repellent layer placement in soil columns.

Average infiltration rate

The average initial (t=2 min) and final infiltration rates of soils are presented in Table 1. The average rate of water infiltration decreased in the initial time with increasing degree of water repellency. It can be explained by decreasing sorptivity of soil surface in the WR soil compared to wettable soil. In the soil column with lower WR layer, initial infiltration rate is not affected because the soil surface layer is not water repellent, but the final infiltration rate of this soil is reduced in comparison with the wettable soil column. The average initial and final infiltration rates of the WR soil column and the soil with upper WR soil layer are almost the same. Reduced infiltrations with increasing degree of WR have also been reported in the study of Wang *et al.* (2000), Arye *et al.* (2011) and Pierson *et al.* (2008).

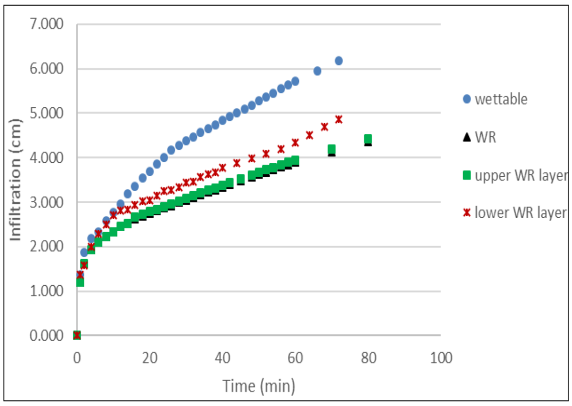

Fig. 2. Cumulative infiltration in the Sandy loam soil.

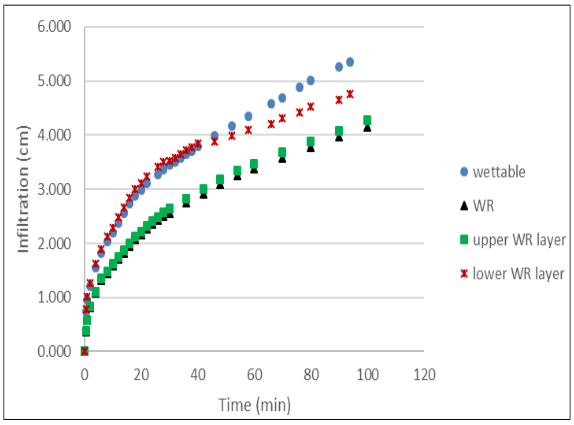

Fig. 3. Cumulative infiltration in the clay loam soil.

Statistical comparison indicates significant difference ($p<0.05$) between the initial and final infiltration rates in the both soils with varying degrees of water repellency. There was no significant difference ($p<0.05$) between the initial and final infiltration rates of the WR soil and wettable soil with upper WR layer, except in the initial rate for CL.

Conclusions

The results of this research indicated that the presence of the WR layer could affect cumulative infiltration and infiltration rate. The average value of the initial infiltration rate decreased in the both SL and CL soils with increasing the severity of the repellency from degree 0 to 1. Little difference was observed for the average value of the initial infiltration rate and final infiltration rate between the WR soil and wettable soil column with upper WR layer. Presence of WR in the lower layer of the wettable soil led to the perversion in cumulative infiltration curve after the certain time of experiment beginning. It was also observed that the presence and placement of water repellent layer could significantly affect the water infiltration and its rate.

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