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Water repellency of clay, sand and organic soils in Finland

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Water repellency (WR) delays soil wetting process, increases preferential flow and may give rise to surface runoff and consequent erosion. WR is commonly recognized in the soils of warm and temperate climates. To explore the occurrence of WR in soils in Finland, soil R index was studied on 12 sites of different soil types. The effects of soil management practice, vegetation age, soil moisture and drying temperature on WR were studied by a mini-infiltrometer with samples from depths of 0-5 and 5-10 cm.

All studied sites exhibited WR (R index >1.95) at the time of sampling. WR increased as follows: sand (R = 1.8-5.0) < clay (R = 2.4-10.3) < organic (R = 7.9-undefined). At clay and sand, WR was generally higher at the soil surface and at the older sites (14 yr.), where organic matter is accumulated. Below 41 vol. % water content these mineral soils were water repellent whereas organic soil exhibited WR even at saturation. These results show that soil WR also reduces water infiltration at the prevalent field moisture regime in the soils of boreal climate. The ageing of vegetation increases WR and on the other hand, cultivation reduces or hinders the development of WR.

Key-words: Water repellency, hydrophobicity, infiltrometer, ethanol, clay soil, sand soil, organic soil, Finland, boreal climate zone

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Introduction

Soil hydrological properties which affect water movement and erosion are time dependent. Processes altering the soil pore network continuity include variations in soil moisture, plant root density, the shrink-swell phenomenon, the impact of soil fauna and human action. Further, soil water repellency (WR) has an impact on water infiltration into the soil. Delayed soil wetting due to WR increases preferential flow and results in an uneven wetting pattern (Dekker and Ritsema 1996) or may expose soil to surface runoff and consequent erosion (Osborn et al. 1964). On the other hand, WR enhances aggregate stability (Giovannini et al. 1983). WR however, increases soil water kinetic energy (decrease of friction between soil and water) and reduces the contact area between water and soil matrix, thereby weakening the ability of the topsoil to retain nutrients and agrochemicals.

Soil WR is commonly related to soil organic matter although the total amount of soil carbon does not directly allow satisfactory prediction of soil hydrophobic properties (Harper et al. 2000). Organic matter inducing WR occurs on the surface of soil particles (coating) or as an intrinsic particulate organic matter (Ma'shum and Farmer 1985, Franco et al. 1995). Micro biota is associated with WR either via decomposition or generation of organic substances (Hallett and Young 1999) involved in WR.

Decrease in soil moisture content usually tends to increase the degree of WR. This relationship, however, is inconsistent (Dekker et al. 2001). Therefore the critical soil water content limit, or transition zone, which divides soils into water repellent and wettable (Dekker and Ritsema 1994, Dekker et al. 2001, Doerr et al. 2006) gives relevant information about the WR phenomenon. WR is shown to reduce bulk soil wetting rate. In soils of the UK (Doerr et al. 2006) severe to extremely WR markedly reduced water uptake through matrix suction for 7 day period compared to wettable samples. This finding indicates that the effect of WR on soil hydrology may be long-lasting.

Predicting the influence of WR on transport processes in soil is rather difficult and no appropriate method has been introduced in the literature (Shakesby et al. 2000). One difficulty is to separate the impact of hydrophobicity from the other soil moisture related phenomena, such as shrink-swell properties and transient hydraulic conductivity, which occur simultaneously. Further, the high spatial variation of the WR complicates extrapolation of measured data and makes it difficult to include WR in hydrological simulation models. Despite uncertainty in the origin and consequences of the WR phenomenon, studies on soil hydrophobicity have remarkably increased.

At the outset of WR studies most attention was paid to the coarse soils in warm and dry climates while later on the phenomenon has been recognized also in soils of humid climates (Colombia and UK, Jaramillo et al. 2000, Doerr et al. 2006). Finnish soils commonly have a rather high content of organic matter, which usually promotes hydrophobicity. Therefore these soils also may have a potential to be hydrophobic, even though they are in the boreal climate zone. However, snow cover during the winter (around 75 days), the wet spring and autumn periods and rather dry periods in summer suggest high fluctuations on soil WR. Annual mean precipitation is up to 650 mm and annual evaporation is about 400-500 mm. Summer time (May-August) mean precipitation is 190 mm and temperature + 16 °C (climate data from 1971-2000 in Southern Finland given by the Finnish meteorological Institute).

The main objective of this study was to determine whether WR exists in agricultural soils of Finland and to what extent it may be exhibited. The study areas were chosen to represent the main soil types of Finnish agricultural soils (2.3 million ha); 62% coarse mineral soils, 26% clay soils and 12% organic soils (Viljavuuspalvelu, statistics for period 2001-2005). Secondly, the effects of vegetation age and management practices on WR were studied and the effect of water content on the development of WR was evaluated. Moreover, the effect of soil drying temperature on the degree of potential WR is considered. This study provides essential information about the WR phenomenon in Finland and enables the assessment of the relevancy of WR on soil hydrology in the boreal climate zone.

Material and methods

Experimental sites

For the evaluation of soil hydrophobic properties, soil samples were taken from three areas representing different soil types; clay soil (6 sites), sand soil (3 sites) and organic soil (2 sites). These areas were classified according to FAO (2006). The clay soil at Jokioinen Lintupaju in south-western Finland (60° 48' N, 23° 28' E) was a Vertic Stagnic Cambisol (Eutric), the sand at Maaninka, central Finland (63° 8' N, 27° 19' E) was a Haplic Regosol (Dystric, Oxyaquic), and the organic soil at Jokioinen Kuuma, south-western Finland (60° 54' N, 23° 31' E), was a Sapric Histosol (Dystric, Drainic). The general properties of the experimental sites are presented in Table 1. Soil texture was determined by a pipette method. Cation exchange capacity (CEC) was determined with 1 M ammonium acetate (pH 7) extraction, soil pH was measured in water suspension (soil:H_2O = 1:2.5 volume/volume) and organic carbon (C) was determined by dry combustion with the Leco CNS 1000 apparatus.

For the clay soil, the sampling was carried out in May 2005 on six experimental areas differing in management and vegetation. These were five vegetated sites used as buffer zones (former cultivated field) along a watercourse, and an adjacent cultivated field. The sampling was performed in spring under dry soil conditions, before substantial vegetative growth and sowing of field crops. The sites were:

- Cultivated field which had been ploughed in autumn and seed-bed preparation conducted in spring
- 14-year-old natural vegetation with grass species and scrubs at natural state
- 14-year-old annually harvested vegetation with grass species
- 3-year-old annually harvested vegetation with grass species
- 14-year-old vegetation with grass species mowed for 10 years and grazed by cattle for 4 years
- 3-year-old vegetations with grass species grazed by cattle

For the sand soil the sampling was carried out in early season after the emergence of the spring cereal in June 2005. The three sites were as follows, both vegetated sites are former cultivated fields:

- Cultivated field sown to spring cereal
- 3-year-old annually harvested forage grass
- 10-year-old natural vegetation with grass species used as a buffer zone use

On the organic soil the sampling was carried out in September 2006 after harvest. The sampled plots were as follows:

- Harvested field shown for spring cereal 4 months earlier. The sampling was carried out in stubble soil.
- 5-year-old annually harvested forage grass (former cultivated field)

Table 1. Chemical and physical soil properties.

Soil type	Depth cm	CEC* cmol(+) kg^{-1}	Base saturation %	Particle size distribution Clay %	Silt %	Sand %	C** %	pH
Clay	0-6	37.0	88	51	42	7	5.4	6.2
Sand	0-30	12.5	86	8	47	45	1.4	6.6
Organic	0-30	77.5	72	49	21	30	22	5.5

*cation exchange capacity, **organic carbon

Sampling and analyses

Six replicates of undisturbed 100 cm^3 soil cylinders were cored from each site from depths of 0-5 cm (dead plant material was removed) and 5-10 cm. The samples were stored in the cylinders with lids on at +4 °C until measurements. The WR measurements were carried out under various soil water contents: The first measurements were performed at the field moisture obtained at sampling. The second dataset was obtained after saturation. Thereafter samples were dried stepwise to obtain different moisture contents as follows: drying on the sand bed -30 hPa, -60 hPa, -100 hPa, drying on the ceramic plate -150 hPa, -300 hPa, and -500 hPa and drying in the oven at +40 °C, +70 °C, +105 °C. For the organic soil the suctions of -150 hPa and -500 hPa were replaced by a -1000 hPa suction. For the clay and sand volume change, i.e. shrinkage resulting from soil drying, was detected by vernier caliper at 9 defined locations and soil volume was calculated at each moisture contents expecting isotropic shrinkage (Bronswijk 1990). The WR results are related to volumetric water content (W v/v) in Figure 2. For the organic soil volumetric water contents were calculated using the cylinder volume, resulting in a slight error in volumetric water contents in Figure 2.

The infiltration of water and ethanol (95%) at 20 °C was measured using the apparatus (Figure 1) described by Leeds-Harrison et al. (1994) and modified by Hallet and Young (1999). For clay and sand soils infiltration was detected manually within 75 s at 15 s intervals, whereas for organic soil data was collected automatically for 90 s using a computer connected to a balance. The sorptivity (S) of water (Sw) and Ethanol (Se) was calculated according to Leeds-Harrison et al. (1994) as presented in Equation 1.

$$S = (Q * f/4b * r)^{1/2} \qquad \text{(Equation 1)}$$

where Q is the stationary infiltration rate of liquid flow, f is the air-filled porosity and r is the radius of the infiltration tip: 1.5 mm. The Value for parameter b, which depends on soil-water diffusion function, is 0.55 (White and Sully 1987). A pressure head of -2 cm was used. According to Equation 2, the WR index (R) was calculated from Sw and Se (Tillman et al. 1989).

$$R = 1.95\ (Se/Sw) \qquad \text{(Equation 2)}$$

In the equation, the parameter 1.95 originates from differences of viscosity and surface tension of liquids (Hallett and Young 1999). According to Tillman et al (1989) an R index > 1.95 represents the transition from none repellent to a moderately (or subcritically) water repellent soil. For example, an R index of 6 represents a situation where water infiltration has decreased by a factor of 6 due to WR.

The results for the actual WR measured in field moist soil and potential WR measured after drying at +40 °C, +70 °C, +105 °C are presented with their standard errors of the means (SE) to enable reader to evaluate statistical significance. Further, analysis of variance was carried out for these results with

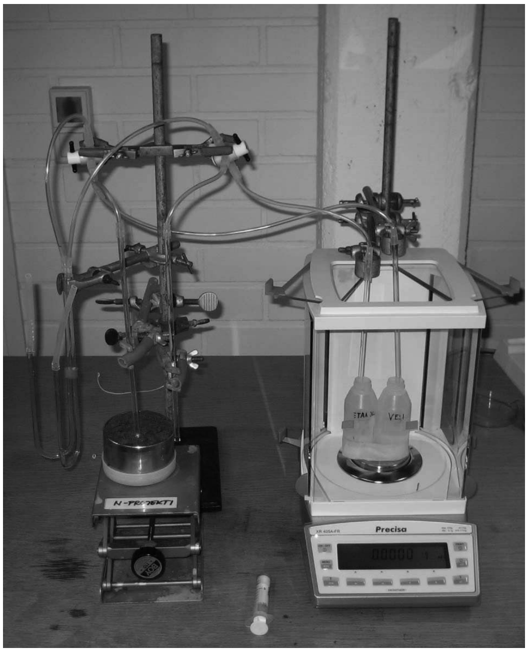

Figure 1. Mini-infiltrometer.

the SAS 9.1 program. When the differences between sites were statistically significant, Tukey´s test was conducted to localize these differences.

Results

Results for actual WR, initial volumetric water content, potential WR at +40 °C, +70 °C and +105 °C and soil carbon content (C%) at the soil surface and at a depth of 5 cm are presented in Table 2 and 3, respectively. All the sites regardless of soil type, depth, age of vegetation or management practice were water repellent at the time of sampling. Actual WR was greatest in the organic soil (R = 7.9-36.1) and it was higher in the clay (R = 2.6-9.7) than in the sand (R = 2.4-5.0). The same pattern was also obvious when WR was detected after drying at +40 °C, +70 °C or +105 °C (i.e. potential WR). Soil WR decreased with depth in the clay while in the organic soil there was an increase in WR with depth. Further, considering initial soil moisture at the time of sampling and measured actual WR, no inconsistent relationship was observed.

In the clay soil surface, the lowest soil moisture, carbon content, actual WR (R = 3.1) and potential WR (R = 2.4-3.1) were detected in the cultivated field. Actual WR was significantly higher in all vegetated plots except the 3-year-old harvested site, whereas the potential WR (+40 °C) was significantly higher only in the 14-year-old grazed and harvested sites. Further, the actual WR was higher in the grazed sites (R = 8.2 and 9.7) than in the harvested ones (R = 4.7 and 8.2); the 14-year-old sites exhibited higher repellency value than the 3-year-old sites. Also, the potential WR values were higher in the older sites, but the only statistically significant difference was observed between the old and the young harvested site after drying at +40 °C. The 14-year-old natural site had lower actual (R = 6.8) and potential (+40 °C, R = 5.9) WR, higher soil moisture and carbon content than the grazed (+40 °C, R = 7.9) or harvested (+40 °C,

Table 2. Actual WR (water repellency), initial soil moisture (W), potential WR of soil samples dried at +40, +70 and +105 °C and carbon content (C, %±SE., clay 0-2.5 cm) at the depth of 0-5 cm. The SE (when n=6) values for WR indexes (R) are presented in the column headlines, otherwise the values are next to R value (n=4-5). Means with the same letter do not differ significantly at p<0.05. The WR results of each soil type and columns were tested separately.

	Actual WR		Potential WR			
		W(v/v)	+40 °C	+70 °C	+105 °C	C
Site	R±0.8	%±stdev	R±1.0	R±1.2	R±1.3	%±0.6
Clay, 14 yr. natural	6.8^{b}	42±1	5.9^{abc}	5.0^{ab}	6.2	7.0
Clay, 3 yr. harvested	4.7^{ab}	31±5	3.6 ± 1.1^{ab}	4.3 ± 1.3^{ab}	2.4±1.4	3.2
Clay, 14 yr. harvested	8.2^{b}	36±1	10.3^{c}	9.4^{b}	4.6	4.9
Clay, 3 yr. grazed	8.2 ± 0.9^{b}	29±3	6.1^{abc}	5.0^{ab}	3.1	2.8
Clay, 14 yr. grazed	9.7^{b}	31±1	7.9 ± 1.1^{bc}	5.5 ± 1.3^{ab}	5.8±1.4	4.6
Clay, cultivated field	3.1^{a}	14±4	3.1^{a}	3.0^{a}	2.4	1.8
Site	R±0.4	W(v/v)	R±0.4	R±0.2	R±0.1	%±0.1
Sand, 10 yr. natural	4.3	33±3	3.8^{b}	2.8^{b}	2.9^{b}	5.5
Sand, 3 yr. harvested	2.7±0.5	37±3	2.5^{ab}	2.2 ± 0.2^{ab}	2.1 ± 0.1^{a}	2.1
Sand, cultivated field	3.7	32±1	2.0^{a}	1.9^{a}	1.8^{a}	1.8
Site	R±1.5	W(g/g)	R±1.4	*R/no inf.	*R/no inf.	%±0.3
Organic, 5 yr. harvested	7.9^{a}	74±8	15.3^{a}	*59.3/3	*23.6/2	27.2
Organic, 4 month, harvested	16.3^{b}	34±7	20.5^{b}	*37.8/1	*69.3/2	21.9

*Lowest measured R index and number of replicates indicating no water infiltration.

R = 10.3) site with the same age. At depth of 5-10 cm WR was generally lower than at soil surface and there were few significant differences between treatments. However, cultivated field had again the lowest actual WR.

In the sand soil the plot covered with 10-year-old natural vegetation had the highest actual and potential WR at both depths. At the surface of the site potential WR (R = 2.8-3.8) was significantly higher than at the cultivated field (R = 1.8-2.0). Organic carbon contents for these sites were 5.5% and 1.8%, respectively. At depth of 5-10 cm the actual WR (R = 5.0) was significantly higher at the more dry (28% v/v) 10-year-old natural site than at the cultivated field (R = 3.1, 32% v/v).

In the organic soil, the soil samples taken from the surface of the 4-month-old harvested site had significantly higher actual (R = 16.3) and potential (+40 °C, R = 20.5) WR than the 5-year-old harvested site (R = 7.9 and 15.3, respectively). Some replicates indicated no water infiltration during the measurement period (90s.) after drying at elevated temperatures which resulted in undefined R-values (see Eq. 2). In Tables 2 and 3, the lowest R index that was measured and the number of replicates indicating zero water infiltration are presented for these populations.

Potential WR, measured after drying the samples at +40 °C, resulted in equal moisture contents in clay (3-7% volumetric water content, v/v) and sand (1-2% v/v). Moreover, potential WR was generally highest in samples dried at +40 °C. Only 4 out of 18 measurements had higher R indexes after drying at +70 °C and 2 out of 18 measurements after drying at +105 °C than WR detected after drying at +40 °C. In the organic soil equal soil moisture was achieved only after drying at +105 °C (0 g g^{-1}, gravimetric water content), while after drying at 70 °C moisture varied still substantially (4 month old 0.02-0.12 g g^{-1} and 5-year-old. 0.03-0.24 g g^{-1}). Regardless rather high water content after drying at +40 °C (4 month old 0.33-0.56 g g^{-1} and 5-year-old. 0.74-0.81 g g^{-1}), 4 replicates out of 6 indicated no water infiltration at all at depth of 5-10 cm. It is notable that actual WR was mostly higher than the potential value in clay and sand while in

Table 3. Actual WR (water repellency), initial soil moisture (W), potential WR of soil samples dried at +40, +70 and +105 °C and carbon content (C, %±SE.) at the depth of 5-10 cm. The SE (when n=6) values for WR indexes (R) are presented in the column headlines, otherwise values are stated next to R value (n=4-5). Means with the same letter do not differ significantly at p<0.05. The WR results of each soil type and columns were tested separately.

	Actual WR		Potential WR			
		W(v/v)	+40 °C	+70 °C	+105 °C	C
Site	R±0.9	%±stdev	R±0.5	R±0.6	R±0.3	%±0.2
Clay, 14 yr. natural	3.8	39±2	3.5±0.6	4.2±0.7	2.5±0.3^{ab}	2.7
Clay, 3 yr. harvested	4.3	32±5	3.7±0.5	3.2±0.6	3.1±0.3^{ab}	2.8
Clay, 14 yr. harvested	5.7	36±1	3.9	3.5	3.6^{b}	2.3
Clay, 3 yr. grazed	4.7	29±3	3.8	2.9	3.1^{ab}	2.1
Clay, 14 yr. grazed	4.7	31±2	2.7	3.0	2.3^{a}	2.1
Clay, cultivated field	2.6	32±7	2.9	2.6	2.6^{ab}	2.0
Site	R±0.5	W(v/v)	R±0.2	R±0.2	R±0.2	%±0.1
Sand, 10 yr. natural	5.0^{b}	28±4	2.9±0.2	2.9±0.3	2.7±0.2^{b}	1.7
Sand, 3 yr. harvested	2.4^{a}	37±2	2.4	2.5	1.8^{a}	1.4
Sand, cultivated field	3.1^{a}	32±2	2.3	2.3	1.8^{a}	2.0
Site	R±9.2	W(g/g)	*R/no inf.	*R/no inf.	*R/no inf.	%±0.2
Organic, 5 yr. harvested	26.4	81±5	*49.5/4	*39.8/4	*42.6/2	27.3
Organic, 4 month, harvested	36.1	56±5	*28.4/4	*77.6/3	*66.5/2	21.6

*Lowest measured R index and number of replicates indicating no water infiltration.

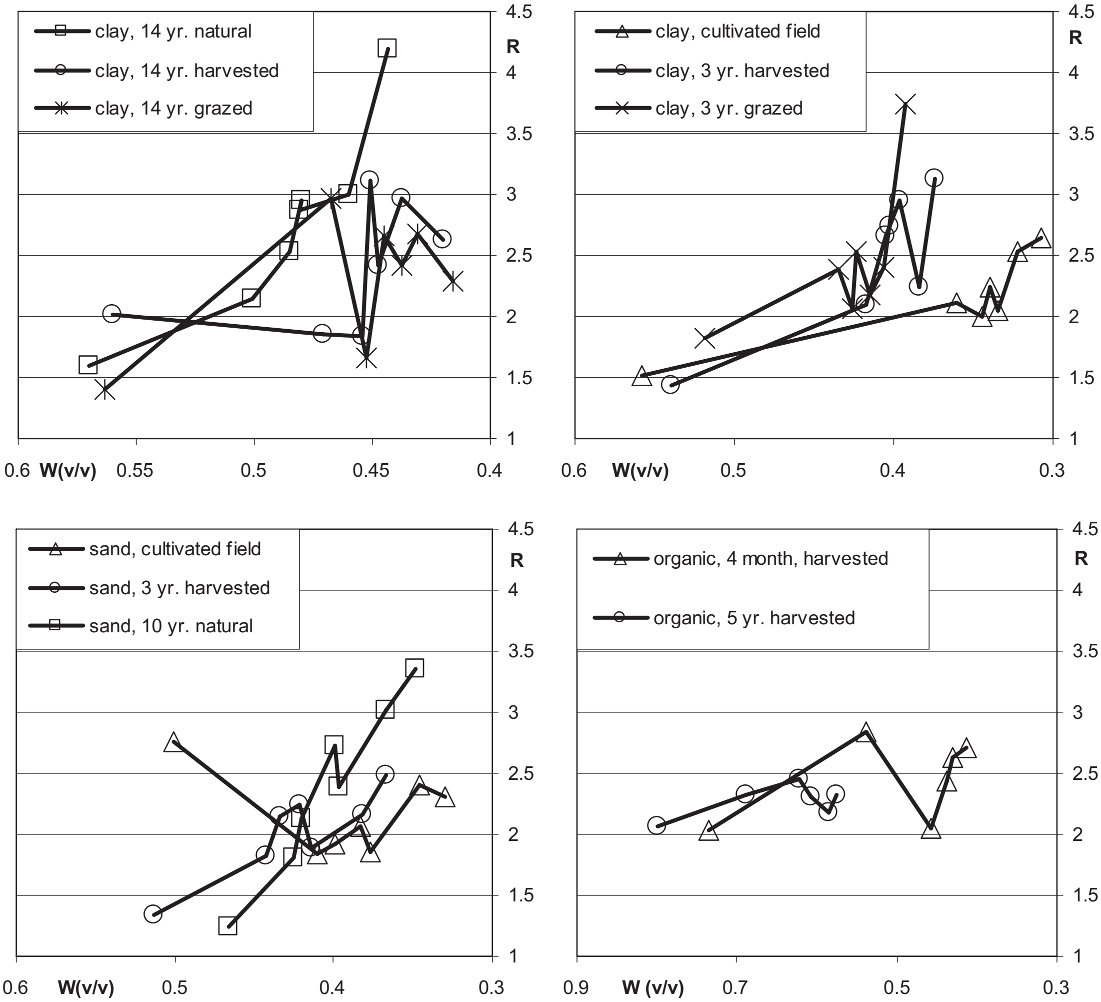

Figure 2. WR for soil surface samples (0-5 cm), measured at various soil volumetric moisture conditions.

the organic soil actual WR was lower than the potential one.

When the WR was detected at various soil moisture contents (Figure 2), seven sites indicated slight WR even at saturation. These sites were the 14-year-old harvested clay soil (R = 2 at 0-5 cm, R = 3.4 at 5-10 cm), the cultivated sand soil (2.8 at 0-5 cm) and all sites at organic soil (R = 2.0-2.8). When the volumetric water content was less than 41 vol. % all clay and sand soils resulted in mean R index >1.95, indicating hydrophobicity. In organic soil, no R indexes below 1.95 were detected. The slopes of linear regression between WR and soil water content were slightly negative for all except two treatments (Table 4), indicating increased WR when the soil dries. In organic soil this was more pronounced in the deeper soil layer. However, high fluctuation in successive measurements resulted in rather low r squared values and the y-intercepts, the point where the linear regression line crosses the y-axis, were mostly inconsistent with the measured potential WR values.

Table 4. The slope of linear regression line, R squared value and y-intercept for WR values measured at various soil water contents.

	0-5 cm			5-10 cm		
Site	Slope	R^2	y-intercept	Slope	R^2	y-intercept
Clay, 14 yr. natural	-18.0	0.80	11.5	-25.8	0.79	14.1
Clay, 3 yr. harvested	-8.7	0.70	6.1	-12.9	0.78	7.7
Clay, 14 yr. harvested	-5.7	0.24	5.0	17.1	0.57	-4.8
Clay, 3 yr. grazed	-9.7	0.41	6.6	-4.6	0.46	4.3
Clay, 14 yr. grazed	-7.1	0.37	5.6	-10.2	0.63	6.5
Clay, cultivated field	-3.7	0.72	3.5	-7.5	0.10	5.3
Sand, 10 yr. natural	-18.2	0.96	9.7	-7.1	0.40	5.2
Sand, 3 yr. harvested	-7.0	0.82	5.0	-5.8	0.88	4.4
Sand, cultivated field	2.4	0.15	1.2	-4.5	0.41	3.9
Organic, 5 yr. harvested	-0.9	0.34	2.9	-13.3	0.85	13.0
Organic, 4 month, harvested	-1.3	0.23	3.1	-18.3	0.65	15.4

Discussion

A soil is critically water repellent, when water does not enter into the soil. Tillman et al. (1989) called a soil sub-critically water repellent if the phenomenon was obvious but less severe, i.e. soil wetting is delayed because of hydrophobicity. Our results show that sub-critical WR (later only WR) is commonly exhibited in soils of the humid boreal climate of Finland. In principle, the results are in agreement with many earlier findings of WR measurements for various soil types (e.g. Dekker and Ritsema 1996, Jaramillo et al. 2000, Pietola et al. 2005, Doerr et al. 2006), although most WR studies have been carried out in warmer climate conditions. The most severe WR was detected in organic soil, this is consistent with Berglund and Persson (1996), who measured high WR in Swedish gyttja soils (mixture of organic and minerogenic material). Higher WR in clay than sand supports the statement of Doerr et al. (2006) that fine-textured soils are also prone to WR.

To evaluate the influences of management practise and ageing of vegetation on soil WR, two different approaches were applied. First, the actual WR, measured at the initial soil moisture, allows the degree of WR *in situ* to be assessed. However, dissimilar plant cover and soil physical properties cause variations in soil moisture, which affect the degree of WR and complicate comparison between the sites. This difficulty was overcome by the second approach, through potential WR measurement, where samples were dried at elevated temperatures to simulate an extreme drying event (Hallett and Young 1999). However, there is no one widely accepted drying temperature to measure potential WR (see Dekker et al. 1998). Thus, the potential WR was detected after drying at +40, +70 and +105 °C. Our results support drying at + 40°C to be used at least for clay and sand because it provided close to equal moisture content and generally the samples dried at higher temperature resulted in lower WR values. Dekker et al. (1998) found that soil and hydrophobic coatings may be altered when dried at +85 °C as compared to drying at +25 °C. It is also possible that for the clay soil drying causes soil cracking, exposing a bare hydrophilic soil. Further, a temperature of around +40 °C may occasionally occur in summer at the soil surface even in Finland, while at the depth of 5 cm it is a slight over estimation (Heikinheimo and Foughstedt 1992). A drying temperature of + 40 °C approximately resembles a pF value of 5.5, which also may be the maximum drying intensity at the soil surface. Therefore soils dried at +40 °C may well resemble the soil surface subjected to thunderstorms in summer while WR measured in moister soil may better reflect the situation in other periods of the year.

The observation in clay and sand that WR values measured at the field moisture were even higher than the potential ones emphasizes the importance of determining the WR at various moistures to avoid erroneous interpretation of soil hydrophobicity, as stated by de Jonge et al. (1999). Decreasing WR upon drying is also observed in studies with UK soils (Doerr et al. 2006). On the other hand, the lowered potential R values may also be caused by saturation and step vice drying of samples, i.e. the drying cycle, which have been shown to decrease WR (Czarnes et al. 2000).

In the clay and sand cultivation reduced WR or at least retarded its development compared to vegetated sites, which is in agreement with earlier findings (Dekker and Ritsema 1996, Hallett et al. 2001). Further, there is strong indication that the ageing of vegetation increases soil WR. This is at least partly due to accumulation of organic matter on the soil surface at vegetated sites and on the other hand, decrease or dilution of soil organic matter content in cultivated fields (Harper et al. 2000). There is a slight indication that grazing results in more severe WR, because in the grazed plots rather high R values were measured regardless of the age of vegetation. Nutrients originating from cattle manure enhance microbial activity and production of hydrophobic exudates (Hallett and Young 1999). Pietola et al. (2005) also found that in a heavy clay soil of Finland a pasture with intense cattle trampling exhibited higher potential WR (air dry) as compared to pasture with no visible trampling. Moreover, soil was drier at the grazed sites than harvested ones which tend to increase actual WR.

Generally lower WR at depth of 5-10 cm in clay and sand is expected to result from smaller accumulation of organic matter than at the soil surface. Severe WR has also commonly been measured at the deeper soil horizons (e.g. Dekker and Ritsema 1996, Dekker et al. 2001, Doerr et al. 2006). Differences in surface soil R values were not reflected in the values at the deeper layer, which were rather constant. This raises the question whether core sampling is suitable for the assessment of WR below soil surface. According to Dekker and Ritsema (1996) aggregates inside the cores retain their orientation and are not disturbed. Sampling from deeper layers into the cores alters soil structure i.e. WR measurement takes place in the artificial fracture surfaces especially in structured clay soils. This may lead to underestimation of the degree of WR deeper in the soil.

Stepwise drying of soil revealed that WR starts to develop at rather high soil moisture content in clay and sand, whereas organic soil exhibited WR even at saturation. Clay and sand soils were water repellent below a soil moisture content of 41 vol. %. Dekker and Ritsema (1996) reviewed previous data sets of sprinkler irrigation studies on clay soils in the Netherlands. They concluded that low water uptake of irrigated clay cores at the initial water content range 34-42 vol. % was a result of hydrophobicity of the aggregates and prisms. This indicates that WR may affect soil hydrology for a rather wide soil moisture range.

For the organic soil, some replicates with no water infiltration were obtained already at the lowest drying temperature, indicating that the organic soil had a high potential for generating severe WR. In these cases, equation 2 results in an undefined R value. Like in clay and sand, in the organic soil carbon content was the highest at the older site. This site still resulted in lower WR probably due to the higher moisture content, although undefined R values and/or unequal moisture contents at the elevated temperatures do not allow firm conclusions to be made. The methodology of WR measurement in organic soil seems to be problematic and requires further studies. To achieve equal moisture content samples should be dried at a high temperature, which may alter the molecular conformation of organic substances as suggested by Dekker et al. (1998).

Soil WR has not been considered in previous soil science studies in Finland, although some results found in the literature suggest the existence of the phenomenon. For example, Turtola and Jaakkola (1995) studied the loss of phosphorus from heavy clay soil under a grass ley in Finland. They found high peak concentrations of dissolved phosphorus at sub-surface drainage water after broadcast of fertilization at summer, although only minor water flow was detected. This was thought to indicate fast preferential water flow through the soil. Our results suggest that in those conditions soil WR may have promoted preferential flow and consequent nutrient leaching, indicating importance of the WR studies also in soils of the humid boreal climate of Finland

Conclusions

WR proved to be common phenomenon in clay, sand and organic soils under boreal humid climate zone and it diminishes water infiltration substantially. Organic soil had a high potential to generate WR. In mineral soils, especially the soil surfaces of old vegetated sites were prone to WR. Water infiltration was diminished at these sites from four- to tenfold. The development of WR in rather moist soils indicates the importance of this phenomenon in soil hydrology in a wide moisture range. However, the development of WR could be hindered by cultivation. When soil WR is evaluated it proved to be crucial to undertake detections at various moisture contents, including measurements at field moisture (actual WR) and using samples dried at +40 °C (potential WR).

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SELOSTUS

Suomalaisten savi- ja hietamaiden sekä eloperäisen maan vedenhylkivyys

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Kun kuivaan, huokoiseen maahan tiputettu vesipisara ei imeydy välittömästi, maa on vettä hylkivää eli hydrofobista. Lämpimien ilmastoalueiden karkeilla mailla vedenhylkivyys on yleisesti havaittu ja tutkittu ominaisuus. Boreaalisella ilmastovyöhykkeellä ilmiötä on sen sijaan tutkittu vähän. Vedenhylkivyyden esiintyminen liitetään orgaaniseen ainekseen, vaikkakin on epäselvää, mitkä spesifit yhdisteet ilmiön synnyttävät. Vedenhylkivyys aiheuttaa veden imeytymisen heikkenemistä ja maan epätasaista kostumista. Nämä seikat puolestaan edistävät oiko- ja pintavirtauksien syntyä sekä eroosiota. Vedenhylkivyydelle on tyypillistä suuri ajallinen ja paikallinen vaihtelu.

Tässä tutkimuksessa maan vedenhylkivyysindeksi (R) määritettiin mini-infiltrometrillä käyttäen kolmesta suomalaisesta maalajista, savesta, hiedasta ja eloperäisestä maasta, 0–5 cm:n ja 5–10 cm:n syvyydeltä otettuja näytteitä. Tulosten perusteella arvioitiin kosteuden, kasvillisuuden iän ja viljelymuodon vaikutusta vedenhylkivyyden voimakkuuteen sekä tarkasteltiin määritysmenetelmän soveltuvuutta eri maalajeihin.

Tutkitut maanäytteet olivat näytteenottohetkellä vettä hylkiviä, ja ominaisuus lisääntyi maalajeittain järjestyksessä hieta < savi < eloperäinen maa. Kasvipeitteisillä alueilla veden imeytymisen maan pintaan todettiin heikentyneen hiedalla 3–4-kertaisesti ja savimaalla 4–10-kertaisesti vedenhylkivyyden takia. Näiden maalajien vedenhylkivyys lisääntyi kasvillisuuden ikääntyessä; vuosittain kynnetyllä pellolla se oli vähäisintä. Lisäksi vedenhylkivyys oli suurempaa maan pinnalla kuin syvemmässä kerroksessa. Tämä lienee seurausta pinnalle kertyvästä orgaanisesta aineksesta ja sen runsastumisesta, kun maata ei kynnetä.

Vedenhylkivyys lisääntyi maan kuivuessa. Kivennäismaat osoittautuivat vettä hylkiviksi, kun kosteus oli alle 41 tilavuusprosenttia. Eloperäinen maa taas oli lievästi vettä hylkivä jopa vedellä kyllästettynä. Kun määritettiin näytteiden potentiaalista vedenhylkivyyttä, savelle ja hiedalle sopivaksi kuivatuslämpötilaksi osoittautui +40 °C. Sen sijaan eloperäisen maan näytteiden esikäsittely potentiaalisen vedenhylkivyyden määrittämiseksi vaatii vielä lisätutkimuksia.

Tulokset osoittavat vedenhylkivyyttä esiintyvän myös boreaalisen ilmastovyöhykkeen maalajeilla, vaikka sitä ei aiemmissa maan veden liikkeitä käsittelevissä tutkimuksissa ole otettu huomioon. Ilmiön merkitys korostuu etenkin kuivissa olosuhteissa kasvipeitteisillä alueilla.