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Water repellency of post-boggy soils with a various content of organic matter

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Abstract: The objective of this study was to estimate the water repellency of post-boggy soils in north-eastern Poland. Potential water repellency was determined based on the water drop penetration time (WDPT) test and the molarity of an ethanol droplet (MED) test. A total of 276 soil samples with a varied organic carbon (OC) content, ranging from trace amounts in sandy subsoils to 44.4% in organic soils, were analyzed. The investigated material represents peat-muck soils (Eutri-Sapric Histsols) and muck-like soils (Arenic Gleysols, Areni-Humic Gleysols, Gleyic Arenosols). The mineral matter of the analyzed soils comprised loose sand. The obtained results indicate that peat soil formations are marked by higher potential water repellency than muck soil formations. The highest WDPT values (16 390 s) were reported in respect of an alder peat sample with 41.9% OC content, collected at a depth of 55–60 cm. In the group of muck soils, a sample with 36.7% OC content, collected at a depth of 15–20 cm, was marked by the highest water repellency (WDPT 10 492 s). The water repellency of the studied soils is dependent on organic matter content, and it is manifested only when organic matter content is higher than 20%. Soils with OC content of up to 12% show low water repellency or are hydrophilic. Organic soil formations (>12% OC) are characterized by a varied degree of water repellency, but WDPT values in excess of 2000 s are reported only in respect of soils containing more than 35% OC. A significant positive correlation between the content of organic matter, organic carbon, total nitrogen and water repellency was observed in the entire studied population (n = 276). A significant positive correlation was also found between WDPT values and the C:N ratio, while a significant negative correlation was reported in respect of pH_{H_2O}.

Key words: hydrophobicity; potential water repellency; post-boggy soils; MED-test; WDPT-test; soil organic matter

Introduction

Water repellency (hydrophobicity), i.e. a tendency of a surface not to absorb water, and wettability (hydrophilicity), a tendency to become wetted by surface water, are phenomena applicable to porous solid bodies, including soil. According to research findings, hydrophobic organic substance, found mostly in the surface layer of soil, is one of the main causes of the water repellency of soil (Wallis & Horne 1992; Bisdom et al. 1993; Horne & McIntosh 2000). This phenomenon leads to an unproductive movement of water along soil surface during precipitation, preferential flow and accelerated solution leaching. Water repellency impairs the soil's capacity to effectively retain water (Berglund & Persson 1996; Lichner et al. 2007). Hydrophobic soils are also susceptible to water and wind erosion. Water repellency is considered to be a negative soil property as it increases the risk of environmental degradation and reduces agricultural production (Doerr & Thomas 2000). Hydrophobicity affects soils in various climatic zones throughout the world (Jaramillo et al. 2000). Despite the fact that water repellency is affected by organic matter content, there are very few published sources investigating this phenomenon in organic soils (Wallis & Horne 1992; Berglund & Persson 1996; Sokołowska et al. 2005).

The persistence or stability of water repellency is evaluated by the water drop penetration time (WDPT) test which measures the time elapsed from the moment a drop is placed on soil surface until it is completely absorbed. Longer absorption time is indicative of higher persistence of water repellency of soil. The severity or degree of water repellency is examined using the molarity of an ethanol droplet (MED) test (Wallis & Horne 1992; Doerr 1998; Doerr et al. 2000).

The objective of this study was to determine the water repellency of post-boggy soils with a varied content of organic matter and the dependency between the investigated parameter and basic soil properties.

Material and methods

The experimental material consisted of 276 soil samples with a varied organic matter content. Soil samples were collected from an outwash area (Masurian Plain) in north-eastern Poland. The investigated soils are used as meadows and pastures, and soils with a lower organic matter content (3–20%) are also used as arable land. They consist of drained, post-boggy soil formations developed on fluvioglacial sand. The first drainage works were conducted in the investigated area in the late 19th century when a network of drainage ditches was dug. Drainage efforts were continued in the 1930s and after World War II. As a result, lowland valley bogs were transformed into grassland, while alder peat soils were transformed into muck soils. In view of the international soil classification (IUSS Working Group WRB 2006), the investigated soils covered units from peat-muck soils (Eutri-Sapric Histsols) to muck-like soils (Arenic Gleysols, Areni-Humic Gleysols, Gleyic Arenosols).

Soil samples were divided into groups based on their organic matter content and depth in soil profile. Surface layers containing more than 12% OC (> 20% LOI) were described as muck soil formations, while surface layers with 1.3–12% OC content – as muck-like soil formations (humose sands) (Okruszko & Ilnicki 2003). As regards morphological features, muck-like soils resemble muck soils which have a similar origin but contain less organic matter and more sand. Organic soil formations in soil profiles deeper than 20 cm comprise lowland alder peat, usually under muck-forming process, and strongly decomposed alder peat in deeper layers. Another group of investigated samples consisted of mineral soil formations (<1.3% OC) underlying muck soils and muck-like soils. Soil samples collected at a depth of 0–20 cm were described as surface formations, while samples obtained from deeper layers (20–100 cm) – as subsurface formations.

Samples were air-dried, visible plant remnants were removed by hand picking and the material was passed through a 2.0 mm mesh sieve. Thirty samples representative of all investigated soil types were subjected to a granulometric analysis. The content of Ø 2000–50 μm (sand), 50–2 μm (silt) and < 2 μm (clay) fractions was determined using a laser analyzer (Mastersizer 2000) after organic matter removal by oxidation with 30% H_2O_2. Loss on ignition (LOI) at a temperature of 550 °C was determined in soil samples as an estimated measure of organic matter content. The content of organic carbon was determined spectrophotometrically after oxidation with a potassium dichromate solution (ISO 14235, 1998), and total nitrogen (TN) content was measured by Kjeldahl's method. pH was determined by potentiometry (van Reeuwijk 2002). The resulting content was converted into soil dry matter (dried at 105 °C).

The water drop penetration time (WDPT) test and the molarity of an ethanol droplet (MED) test were carried out to determine the water repellency of soil samples, and every soil formation was classified into the relevant hydrophobic category (Doerr 1998). Tests were performed at a temperature of 20 °C. In the WDPT test, a standard medical syringe was used to place 15 drops of distilled water on homogenized and smoothed soil surface, and the arithmetic mean (WDPT-mn) and the median (WDPT-med.) were calculated. In the MED test the following volumetric concentrations of ethanol were applied: 0%, 3%, 5%, 8.5%, 13%, 24%, 36%, according to Doerr's method (1998), to produce water drop penetration time of 3 seconds. Since the investigated samples were air-dried, the results indicate potential (and not actual) water repellency (Dekker & Ritsema 1994). This degree of water repellency may be observed in surface soil samples after a long period of draught.

Results and discussion

The investigated samples vary with regard to organic matter content, ranging from trace amounts in sandy subsurface layers to 83.0% LOI (40.5% OC) in organic surface formations. The highest content of organic matter in organic subsurface layers was determined in the peat sample (90.1% LOI; 44.4% OC). The mineral matter of the studied soils comprises loose sand with the following fractions: sand – 93.7%, silt – 5.1% and clay – 1.2%.

The majority (60.9%) of the 276 investigated soil samples were hydrophilic, with water drop penetration time below 5 seconds. Based on the above results, the samples were classified into the first water repellency category (Table 1).

The remaining samples showed different degrees of water repellency. Ten samples were classified into category 9, and 23 – into category 10, implying a very high degree of water repellency. The samples were divided into groups to verify the hypothesis that water repellency is dependent on organic matter content. Water repellency characteristics were evenly distributed in

Table 1. Frequency distribution of WDPT categories for 276 investigated soil samples.

WDPT determination		All samples studied		>12% OC Depth				1.3–12% OC Depth				0–1.3% OC Depth	
				0–20 cm		20–100 cm		0–20 cm		20–100 cm		0–100 cm	
Cat.	Time (s)	n	%	n	%	n	%	n	%	n	%	n	%
1	<5	168	60.9	12	21.8	0	0.0	92	74.8	38	77.6	26	89.7
2	5–10	20	7.2	0	0.0	0	0.0	15	12.2	4	8.2	1	3.4
3	10–30	17	6.2	6	10.9	2	10.0	6	4.9	1	2.0	2	6.9
4	30–60	9	3.3	3	5.5	0	0.0	4	3.3	2	4.1	0	0.0
5	60–180	10	3.6	5	9.1	0	0.0	3	2.4	2	4.1	0	0.0
6	180–300	9	3.3	7	12.7	0	0.0	2	1.6	0	0.0	0	0.0
7	300–600	5	1.8	2	3.6	1	5.0	1	0.8	1	2.0	0	0.0
8	600–900	5	1.8	3	5.5	2	10.0	0	0.0	0	0.0	0	0.0
9	900–3600	10	3.6	7	12.7	3	15.0	0	0.0	0	0.0	0	0.0
10	3600–18000	23	8.3	10	18.2	12	60.0	0	0.0	1	2.0	0	0.0
	Σ	276	100.0	55	100.0	20	100.0	123	100.0	49	100.0	29	100.0

Table 2. Correlation coefficients between soil properties and measure of hydrophobicity.

Measure of hydrophobicity	LOI (%)	OC (%)	TN (%)	OC: TN	pH H_2O	pH KCl
All samples studied, $n = 276$						
WDPT-mn	0.710*	0.681*	0.591*	0.181*	–0.177*	–0.010
WDPT-med.	0.718*	0.686*	0.601*	0.183*	–0.179*	–0.008
MED (%)	0.807	0.796*	0.784*	0.063	–0.114	0.066
Organic surface samples, $n = 55$						
WDPT-mn	0.662*	0.561*	0.319*	0.356*	–0.373*	–0.277*
WDPT-med.	0.664*	0.569*	0.327*	0.363*	–0.390*	–0.290*
MED (%)	0.804*	0.778*	0.717*	–0.063	–0.339*	–0.190
Organic subsurface samples, $n = 20$						
WDPT-mn	0.779*	0.830*	0.678*	0.162	–0.751*	–0.678*
WDPT-med.	0.792*	0.823*	0.699*	0.156	–0.752*	–0.669*
MED (%)	0.502*	0.497*	0.526*	–0.074	–0.754*	–0.772*
Humose surface samples, $n = 123$						
WDPT-mn	0.007	0.036	0.001	0.037	0.016	–0.016
WDPT-med.	0.006	0.035	0.000	0.035	0.019	–0.013
MED (%)	–0.094	–0.064	–0.056	–0.093	0.079	0.005
Humose subsurface samples, $n = 49$						
WDPT-mn	0.325*	0.339*	0.460*	–0.079	–0.003	0.068
WDPT-med.	0.324*	0.337*	0.459*	–0.079	–0.003	0.068
MED (%)	0.475*	0.528*	0.587*	–0.092	–0.017	0.109
Mineral samples, mostly subsurface, $n = 29$						
WDPT-mn	0.550*	0.408*	0.622*	–0.299	–0.366	–0.358
WDPT-med.	0.548*	0.407*	0.620*	–0.297	–0.362	–0.352
MED (%)	0.598*	0.411*	0.685*	–0.306	–0.404*	–0.535*

*Significant correlation coefficients at $\alpha = 0.05$

the group of surface organic formations (mucks) where 21.8% of samples were classified into category 1, and 18.2% samples – into category 10. The majority of organic soil samples collected at depths greater than 20 cm (decomposing alder peat) proved to be strongly hydrophobic. A total of 85% samples were classified into categories 8, 9 and 10.

Based on the above, it can be concluded that the potential water repellency of organic formations is not determined by the depth of their deposition in the soil profile. Peat soils have a higher potential water repellency than muck soils. Both formation types have a similar organic matter content which is slightly lower in mucks (by 3% OC on average) due to the mineralization of organic matter which is characteristic of dewatered surface formations. The water repellency of the investigated organic formations was similar to that of farmed low peatlands in Sweden (Berglund & Persson 1996).

Humus-rich surface soil formations with OC content of 1.3% to 12% were mostly hydrophilic, and 74.8% of samples were classified into category 1 (Table 1). Similar results were noted in respect of subsurface formations with an identical OC content, where 77.6% of the corresponding samples were classified into category 1. Mineral formations containing less than 1.3% OC proved to be hydrophilic and 89.7% of the samples were classified into category 1. This group of formations did not contain samples with water drop penetration time longer than 30 seconds.

None of the investigated samples was characterized by water drop penetration time longer than 18 000 seconds (>5 hours), which permits their classification into the highest water repellency category (11) according to Doerr (1998). In the muck soils formations, the highest degree of hydrophobicity (WDPT-mn 10 492 s) was determined in a sample with 36.7% OC content and pH_{H_2O} of 6.1, collected at a depth of 15–20 cm. In the group of subsurface organic formations, an alder peat sample collected at a depth of 55–60 cm with 41.9% OC content and pH_{H_2O} of 5.1 exhibited the highest WDPT-nm values (16 390 s).

The water repellency of the studied soils is dependent on organic matter content and it is clearly manifested only when organic matter content exceeds 20% (Fig. 1A). For this reason, the dependency between

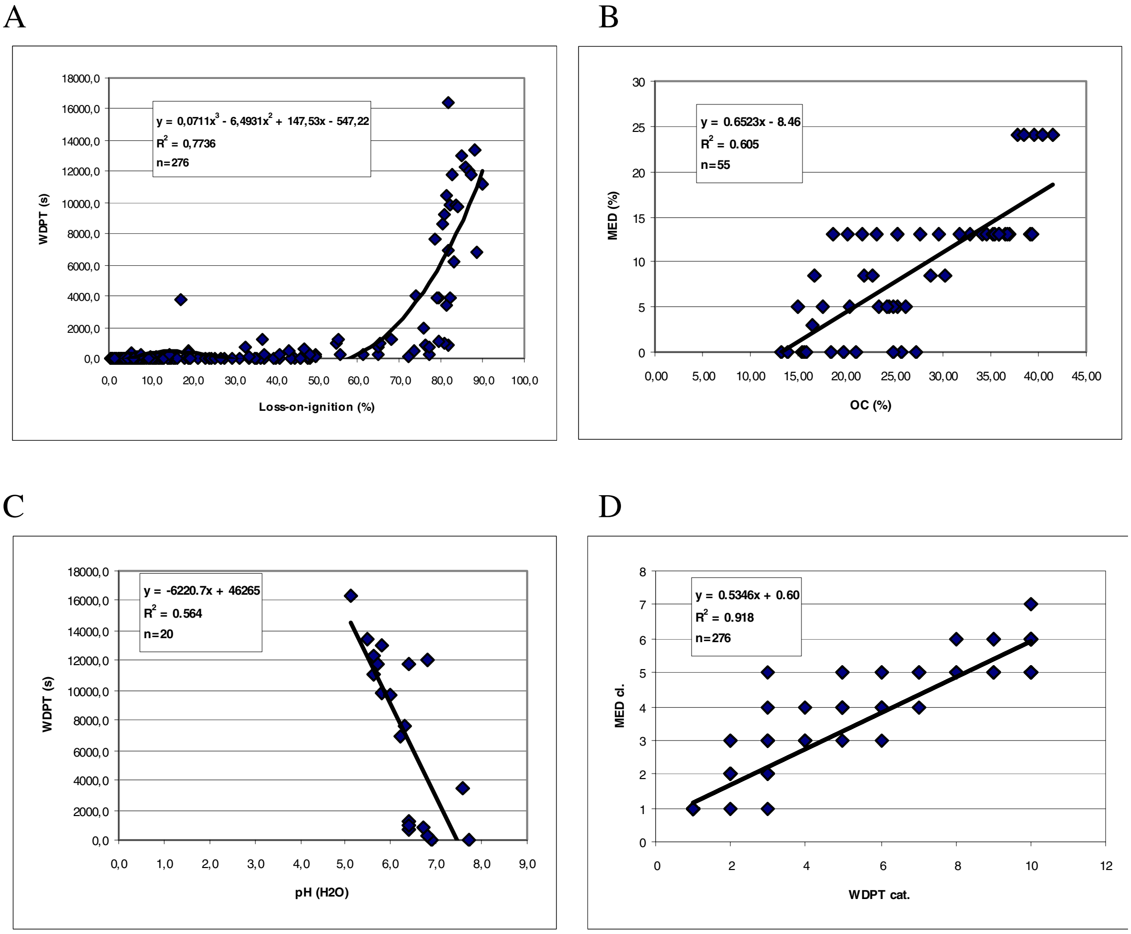

Fig. 1. Relationship between potential water repellency and some soil properties.

WDPT and LOI is curvilinear. It is believed that irreversible drying of organic matter is one of the main causes of water repellency of soil (Bisdom et al. 1993), which is of particular relevance in dewatered organic soils.

Soil formations with OC content of up to 12% are slightly hydrophobic or hydrophilic. The only exception was a sample collected at a depth of 25–30 cm with OC content of 8.8% and pH_{H_2O} of 6.5 which exhibited WDPT-mn of 3 712 s. Organic formations (>12% OC) are characterized by varied degrees of water repellency, but WDPT values in excess of 2 000 s are demonstrated only by formations with OC content higher than 35% (Fig. 1A). The above is validated by the results of an analysis of simple correlation between water repellency values and basic soil properties (Table 2). In the entire studied population ($n = 276$) a significant positive correlation was determined between the content of organic matter, organic carbon, total nitrogen and all water repellency parameters. It should be noted that the coefficients of correlation are higher for water repellency expressed as MED (%) than for WDPT expressed as an arithmetic mean or median. In this group of soil formations, a significant positive correlation was also stated between WDPT and the C:N ratio, while a significant negative correlation was reported in respect of pH_{H_2O}. A relatively strong correlation between the degree of water repellency and organic matter content was also noted by other authors (Buczko et al. 2005). Dekker & Ritsema (1994) did not determine a correlation between organic matter content and WDPT values, but they observed a linear relationship between organic matter and MED values. Horne & McIntosh (2000) did not report a strong correlation between MED values and total organic carbon content.

An analysis of correlations between the investigated parameters in 5 groups of soil formations revealed a significant positive correlation between water repellency, LOI, OC and TN in all studied groups except for humose surface samples. Although this group contains the highest number of samples ($n = 123$), none of the investigated properties were significantly correlated. The above can be attributed to the relatively low organic matter content and the fact that pH and the C:N ratio in this group fall within a narrow range. Those formations are homogenized as they have been sampled from ploughed soil. As regards sandy soil formations, such as humose sands, the presence of plant debris at various stages of decomposition, soil aggregates and hydrophobic organic matter covering sand grains determine the degree of water repellency (Bisdom et al. 1993). For this reason, it is difficult to predict accurately soil's water repellency based solely on its organic matter content because the quality of soil, in particular the content

Table 3. Frequency distribution of MED classes for 276 investigated soil samples.

MED determination		All samples studied		>12% OC				1.3–12% OC				0–1.3% OC	
				Depth				Depth				Depth	
Cl.	Ethanol concentration (%vol.)			0–20 cm		20–100 cm		0–20 cm		20–100 cm		0–100 cm	
		n	%	n	%	n	%	n	%	n	%	n	%
1	0	170	61.6	12	21.8	1	5.0	92	74.8	38	77.6	27	93.1
2	3	23	8.3	1	1.8	0	0.0	16	13.0	5	10.2	1	3.4
3	5	20	7.2	9	16.4	1	5.0	8	6.5	2	4.1	0	0.0
4	8.5	14	5.1	5	9.1	1	5.0	5	4.1	2	4.1	1	3.4
5	13	36	13.0	23	41.8	10	50.0	2	1.6	1	2.0	0	0.0
6	24	12	4.3	5	9.1	6	30.0	0	0.0	1	2.0	0	0.0
7	36	1	0.4	0	0.0	1	5.0	0	0.0	0	0.0	0	0.0
	Σ	276	100.0	55	100.0	20	100.0	123	100.0	49	100.0	29	100.0

of organic substances that are directly responsible for water repellency should be taken under consideration (Bisdom et al. 1993; Dekker & Ritsema 1994; Horne & McIntosh 2000; Sokołowska et al. 2005).

The water repellency of mucks (organic surface samples), expressed as MED (%), shows a stronger correlation with LOI, OC and TN than expressed as WDPT (Fig. 1B). Such a relationship was not observed for peats (organic subsurface samples) (Table 2). It is believed that in strongly hydrophobic formations, an MED analysis may be more effective than a WDPT test because the long penetration time of an evaporating water drop is difficult to measure. Only one soil sample representing peats showed the MED value equals 36%, i.e. indicative of extreme hydrophobicity (Table 3).

The dependency between water repellency, expressed as WDPT, and the C:N ratio was significant for the entire population of the investigated soil formations (Table 2). In an analysis of soil formation groups, this relationship proved to be significant only for organic surface samples. As regards pH, a significant correlation between WDPT and pH_{H_2O} was determined for all studied formations. There was a strong negative correlation between water repellency and pH for surface as well as for subsurface organic formations (Fig. 1C). An increase in calcium ion concentrations and the accompanying rise in pH usually lead to a drop in water repellency (Wallis & Horne 1992). The results of the WDPT test, expressed as the hydrophobicity category, and of the MED test, expressed as the hydrophobicity class, were strongly correlated (Fig. 1D). It should be noted, however, that MED of class 5 corresponds to as many as 7 WDPT categories. The above is consistent with the findings of Doerr (1998).

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