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THE EFFECT OF SITE CONDITIONS AND HEATING ON SOIL WATER REPELLENCY IN AEOLIAN SANDS UNDER PINE FORESTS AT BORSKÁ NÍŽINA LOWLAND (SW SLOVAKIA)

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Abstract

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The effects of site conditions and thermal energy input on soil water repellency of dune-sand soils of the Borská nížina lowland (SW Slovakia) were evaluated. Composition of plant cover at three locations reflects soil genesis and moisture regimes. In investigated soil profiles, the severity of water repellency depends strongly on moisture regime of soils. The maximum Water Drop Penetration Time (WDPT) values exceeded 12 h in Dystric Regosol. In Arenic Umbrisol WDPT values did not exceed 60 s and Haplic Gleysol was wettable. Potential effect of wildfires on water repellency of the soils was investigated through laboratory experiments. Distinct increases in the persistence of water repellency were observed when the samples were heated for 20 minutes with maximas of WDPT observed at 150 and 200 °C. Water repellency disappeared after heating to 250 and 300 °C in the subsurface and topsoil horizons, respectively, due to organic matter decomposition. But it was necessary to repeat heating to 250 and 300 °C in order to eliminate water repellency in A horizons of selected soils.

Key words: soil water repellency, soil genesis, soil heating, pine forests

Introduction

Water repellency (hydrophobicity) has been of interest to soil scientists for well over a century and has received considerable attention because of its potentially serious implications for agriculture and forestry. It is particularly common in coarse textured soils because sandy soils have a low surface area, which can be more readily coated with hydrophobic organics. In areas affected by fire, water repellency can be induced by heating or burning of soil organic matter and above-ground biomass. The effect of heating on soil water repellency has long been recognized (e.g. Krammes, DeBano, 1965; Nakaya, 1982).

Occurrence of soil water repellency has far-reaching consequences for water and solute movement through soil profiles, soil moisture distribution, soil aggregate stability (Mataix-Solera, Doerr, 2004) and for plant growth (see review by Doerr et al., 2000). Soil water repellency can contribute to land degradation (Shakesby et al., 2003). For example it can cause delayed germination of pastures and crops leaving soil bare for longer and prone to wind erosion. Yields are reduced by the patchy growth and the delay in germination reduces the effective growing seasons (McKissock et al., 2000). Water repellency of the topsoil reduces the infiltration capacity of the soil matrix, which can lead to enhanced overland flow and associated soil erosion (Shakesby et al., 2003) and nutrient washout (Lennartz et al., 1997).

Water repellent properties of soils have been described in many countries in the World (DeBano, 2003). Little information exists on the occurrence of soil water repellency in C Europe and only a little attention had been dedicated to this phenomenon in Slovakia. As far as we know, Dlapa et al. (2004) and Lichner, Dlapa (2004) were among the first who reported the occurrence of water repellency formed under natural conditions in soils of Slovakia.

Because there is no systematic information on the development of water repellent properties and on the susceptibility to water repellency of Slovakian soils, our research is focussed on the field conditions under which water repellency occurs in sandy soils of Borská nížina lowland (SW Slovakia). Parameters, which were investigated in relation to soil water repellency include soil genesis (soil type), soil texture, soil organic matter content, and plant cover. In addition, as forest fires in Slovakia are not infrequent (Osvald et al., 2005), potential effects of heating on water repellency in different soils horizons were investigated in the laboratory to simulate possible effects of wildfires or hot dry summer periods.

Materials and methods

The study area is located in the northern part of the Borská nížina lowland, which represents the largest aeolian sand area in Slovak Republic. The soils used in this study are developed from Pleistocene dune sands and belong to Dystric Regosol (RGdy), Arenic Umbrisol (UMar) and Haplic Gleysol (GLha) groups according to WRB (FAO, 1998).

Soil samples (2–3 kg) were taken from soil profiles of RGdy (altitude 212 m, 48°38’06’’ N, 17°17’08’’ E), UMar (altitude 213 m, 48°39’11’’ N, 17°16’13’’ E) and GLha (altitude 218 m, 48°38’01’’ N, 17°17’40’’ E) at different genetic horizons. The samples were air-dried and ground to pass a 2 mm sieve before analysis. Gravel and plant residues were removed from the samples.

The determinations of soil pH, total organic carbon content, and particle size distribution were made by standard methods (Fiala, 1999). Particle size distribution was determined by measuring the amount of soil particles still in suspension after various settling time, the percentage of each size fraction was determined by the pipette method. Soil pH values were determined using a soil/solution ratio 1:2.5. Soil organic matter (SOM) content was determined by oxidation with $K_2Cr_2O_7$-H_2SO_4 and titration of non-reduced dichromate.

Phytocoenological relevés were made according to method of Zürich-Montpellier school (Moravec, 1994), with implementation of the Braun-Blanquet combined both abundance and dominance scales. Nomenclature of vascular plants, lichens and bryophytes taxons is according to Marhold, Hindák (1998). The area of reléves was 400 m^2, the syntaxons names were used on the base of the Šomšák (2000) and Šomšák et al. (2004).

For soil water repellency measurement, air-dried soil samples (10 g) were placed in the Petri dishes, and the persistence of water repellency was estimated with the widely used water drop penetration time (WDPT) test in all the samples. This test determines how long water repellency persists on a porous surface and is thought to be most indicative of the hydrological consequences of water repellency in soils as it relates to the time required for raindrops to infiltrate (Doerr, 1998).

The WDPT test involved placing three drops of distilled water from a medicinal dropper onto the sample surface and recording the actual time required for complete droplet infiltration. In subsequent processing, an average of three WDPT values was used.

The following classes of the persistence of water repellency were distinguished (Bisdom et al., 1993): hydrophilic <5 seconds, 5–60 slightly hydrophobic, 60–600 strongly hydrophobic, 600–3600 severely hydrophobic, and >3600 extremely hydrophobic.

Heat energy impulses at different maximum temperatures were applied to dry samples to simulate the effects of a forest fire on field soils. Samples in open Petri dishes were placed into an oven and heated to the selected temperature. Selected temperatures were applied with duration of 20 min, the heat source turned off, and samples cooled down to 25 °C. The temperatures of 50, 100, 150, 200, 250, and 300 °C were used in this study. Examples of the temperature curves for heating/cooling cycles (100 and 250 °C) are given in Fig. 1.

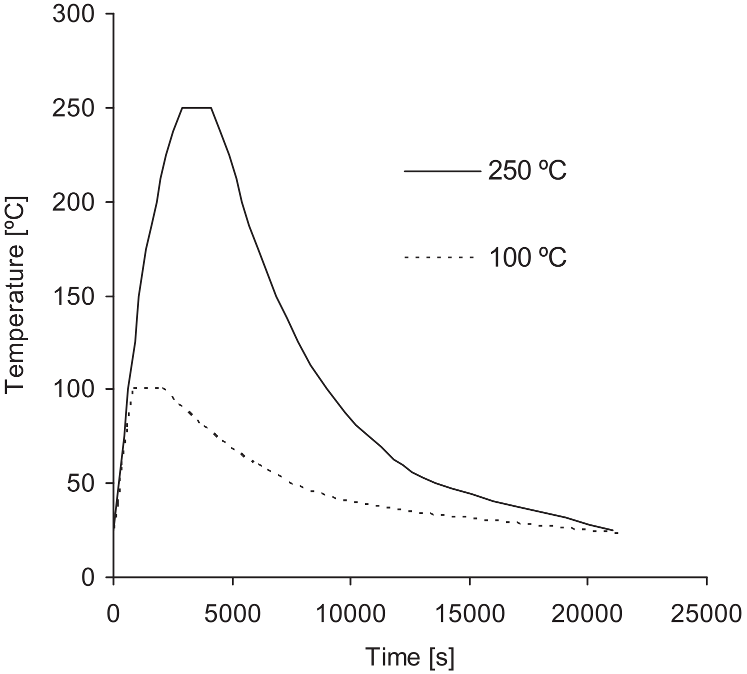

Fig. 1. Characteristic heating curves recorded during heating treatments of 100 and 250 °C.

Results and discussion

Characteristics of the vegetation

The Dystric Regosol stand was classified into the association *Pyrollo umbelatae-Pinetum* (Libb. 1933) Schmidt 1936. This community includes the secondary (oak-) pine forests. Its occurrence is limited mostly on the sand dunes, which have very poor stands with the dominance of moss layer, matching the subassociation *typicum.* In the tree layer the planted *Pinus sylvestris* dominates, interspersed with the native *Quercus robur*. A solitaire of the *Pinus sylvestris* species is in the shrub layer only. The herb layer is also very poor in biomass. Except for *Pinus sylvestris* and *Quercus robur* seedlings, only few individuals of the hemi-heliophytic species *Calamagrostis epigeios* and *Festuca ovina* occur. In accordance with the acid pine litter, the moss layer is well developed and dominated by acidophilous mesophyte bryophytes *Dicranum scoparium, Pleurozium schreberi* and *Hypnum cupressiforme.* Epixylic *Lophozia ascendens* also occurs.

The Arenic Umbrisol stand belongs to the association *Molinio arundinaceae-Quercetum* Samek 1962, which are the acidophilous birch-oak forests growing mostly in the moderate depressions and represent the transition community from the bog moss alder to climazonal forests. As the tree layer is dominated by *Pinus sylvestris,* the accumulation of acid and decomposition resistant pine litter has affected the herb and moss layers. On this basis, the stand was classified into the subassociation *Pleurozietosum schreberi* Neuhäsl et Neuhäslová–Novotná 1967. The herb layer contains only a small number of species. As a consequence of the good lighting conditions in the stand, the species *Calamagrostis epigeios* predominates. The characteristic species of this association, the hygrophilous grass *Molinia arundinacea*, is abundant and just a few individuals represent other species here. With the exception of the *Pinus sylvestris* and *Quercus robur* woods, the *Frangula alnus* and *Padus racemosa* shrubs grow here *Carex ericetorum* and *Dryopteris carthusiana*. The moss layer is developed markedly and it is created by the acidophilous bryophytes – mesophyte *Pleurozium schreberi, Dicranum scoparium* and xerophyte *Leucobryum glaucum.*

The Haplic Gleysol stand most probably presents a degraded community of *Carici elongatae-Alnetum,* subassociation *betuletosum pubescentis*. In the tree layer the planted *Pinus sylvestris* and *Quercus petraea* agg. dominate, which are interspersed by the native *Betula pubescens.* In the shrub layer only the hygrophilous plant *Frangula alnus* is found. The herb layer is quantitatively very rich and it is characterized by the prevalence of hydro- and hygrophilous plants. Most of them are nitrophilous or demand a high amount of nutrients in soil. Dominant is *Carex acutiformis,* from the other typical alder-forest species growing here *Calamagrostis canescens, Iris pseudacorus, I. sibirica, Juncus effusus, Lysimachia vulgaris, Scutellaria galericulata, Sanguisorba officinalis, Molinia arundinacea* and *Galium palustris.* The mesophyte species *Briza media, Melica nutans, Dryopteris carthusiana* and *Rubus fruticosus* document the man-made, partly changed habitat conditions. In the moss layer one species of bog moss, *Sphagnum palustre*, occurs.

Table 1. Physical and chemical properties of the samples taken from different horizons of Dystric Regosol (RGdy), Arenic Umbrisol (UMar) and Haplic Gleysol (GLha).

Site	Horizon	Depth	pH_{act}	pH_{exch}	% SOM	Granulometric composition (% weight)			WDPT
		cm	H_2O	1M KCl	%	2–0.05 mm	0.05–0.002 mm	< 0.002mm	s
RGdy	O	0+3	4.09	2.87	58.63	n.d.	n.d.	n.d.	n.d.
	A	0–5	4.17	3.38	3.79	84.1	3.0	12.9	> 43 200
	A/C	8–15	4.74	3.85	0.97	86.0	8.4	5.5	15 880
	C	20–30	5.07	4.33	0.40	89.1	0.7	10.2	733
UMar	O	0+4	3.69	2.78	60.84	n.d.	n.d.	n.d.	n.d.
	A	0–15	3.96	2.83	4.14	78.3	11.0	10.7	59
	C	50–60	4.94	3.77	0.26	96.0	0.4	3.6	28
GLha	O	0+6	4.97	4.18	59.21	n.d.	n.d.	n.d.	n.d.
	A	0–10	5.37	4.27	1.64	85.8	6.5	7.7	1
	Cg	50–60	5.94	4.97	0.09	90.3	0.3	9.4	< 1

Notes: pH_{act} – active pH; pH_{exch} – exchangeable pH; SOM – soil organic matter; WDPT – water drop penetration time; n.d. – not determined

Soil properties

Soil chemical properties and particle size distribution are listed in Table 1. The soils are developed from aeolian sands mostly consisting of fine sand with <15% silt and clay. Aeolian sands of the Borská nížina lowland contain 87–89% of quartz, up to 10% of feldspars and 1–3% of heavy minerals (Pelíšek, 1963). The study sites are under pine forests, which were seeded here several decades ago. Organic matter contents of 3.79, 4.14 and 1.64% were established in A-horizons (topsoils) of Dystric Regosol (RGdy), Arenic Umbrisol (UMar) and Haplic Gleysol (GLha), respectively. In subsurface horizons, organic matter contents decrease to 0.40, 0.26 and 0.09% in RGdy, UMar and GLha, respectively. As supported by phytocoenological results, the presence of hydro- and hygrophilous plant species gives evidence on distinct differences in soil moisture regimes of three selected soils. Relatively dry conditions occur in the whole profile of Dystric Regosol. The opposite is the case for the moist profile of Haplic Gleysol, which is saturated due to the shallow ground water table. For the Arenic Umbrisol relatively thick humus horizon, affected with ground water in the past, is typical. The change of soil moisture type from groundwater-determined to infiltration type initiates change of soil moisture regime and decrease in soil pH. According to the composition of vegetation cover, actual moisture regime and history, this soil falls between the relatively dry Dystric Regosol and the wet Haplic Gleysol.

Soil hydrophobicity measurements

WDPT values in A horizons varied from < 5 s to >12 h for air dried sieved samples as shown in Table 1. The initial persistence of dry soil sample water repellency decreases in

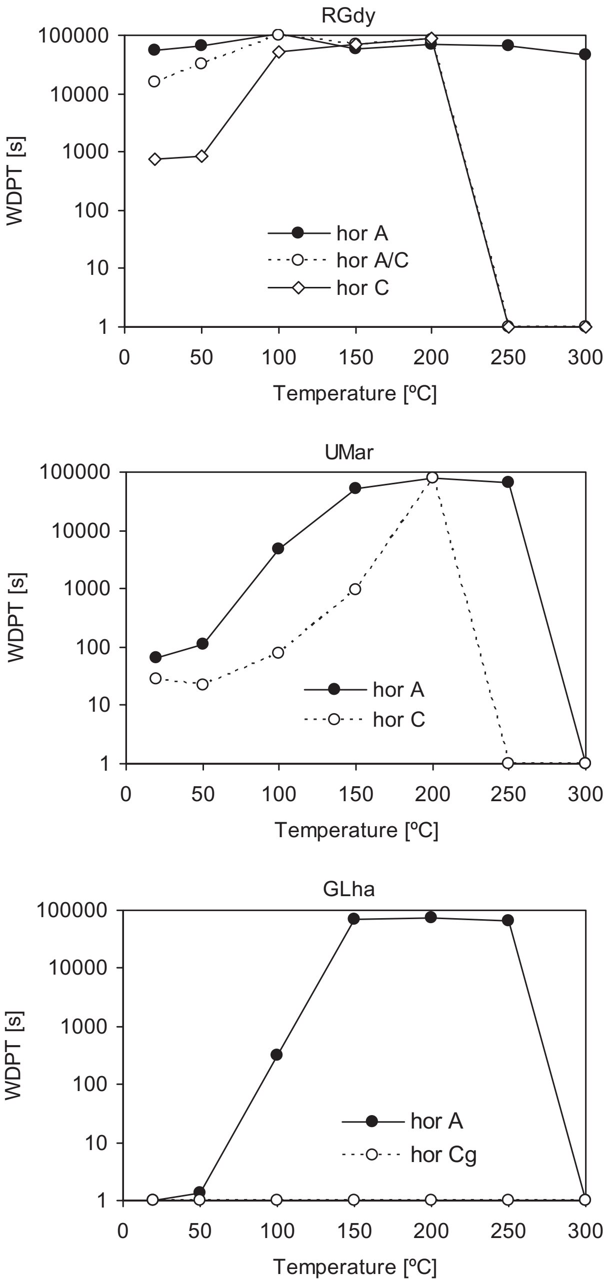

Fig. 2. Effect of heating for 20 minutes on the water drop penetration time (WDPT) values for soil samples from individual soil horizons of Dystric Regosol (RGdy, top), Arenic Umbrisol (UMar, middle) and Haplic Gleysol (GLha, bottom).

the sequence Dystric Regosol > Arenic Umbrisol > Haplic Gleysol, which suggests that water repellency depends on the moisture regime of the soils. A decrease in severity of water repellency occurred in the subsurface B and C horizons. However, samples from originally moist or wet horizons were hydrophilic (WDPT <5 s) or only slightly hydrophobic (5–60 s). Thus, water repellency amongst the soils investigated is variable and appears to correspond with soil moisture regime. The most hydrophobic Dystric Regosol had the highest WDPT value (Table 3) in the A horizon (>43200 s), decreasing in the B (15880 s) and C (733 s) horizons together with a decrease in SOM content (Table 1). Similarly in the Arenic Umbrisol, WDPT in the A horizon (59 s) is higher than in the C horizon (28 s). However, for the Dystric Regosol, WDPT in the A horizon was much lower than for B and C horizons irrespective of SOM content. This inconsistency may be the result of differences between past and current moisture regimes. Also the composition of vegetation cover now and in the past was different and may have led to the accumulation of different types of organic matter in the soils. The samples from Haplic Gleysol were wettable with WDPT values below 5 s.

The observed behaviour agrees with the theory that organic substances responsible for soil water repellency (so called amphiphilic or amphipatic compounds) may change orientation. In the wettable context, these compounds are likely to have their polar (i.e. wettable) end pointing outwards. If, for some reason, such as loss of water, a re-configuration or re-orientation occurs, these substances may well present their hydrophobic (non-polar) end at the surface (Horne, McIntosh, 2003). Although there were large differences in WDPT of original water repellency at room temperature, there was a distinct increase in persistence with increasing temperature of heating, as shown in the diagrams of Fig. 2.

Little decrease or increase in WDPT was observed after heating samples to 50 °C. When heated to 105 °C an increase in WDPT values was noted in all soil samples, except for the Cg horizon of the Haplic Gleysol. The maximum WDPT values were observed after heating to 150 and 200 °C. Water repellency of these samples was 19-fold higher after heating at 200 °C.

However, large differences in the shape of the diagrams were found between the samples taken from different soil horizons. The most important difference occurs at temperature 250 °C. In the samples from subsurface soil horizons, water repellency completely disappears after heating to 250 °C, but for topsoil samples water repellency remains extremely high. Water repellency disappears in all the samples, except for the A horizon of Regosol, after heating to 300 °C.

Because heating to above 200 °C causes thermal decomposition of soil organic matter, the overall effect of energy input will be a function of temperature, duration of pulse and organic matter content. It may be for these reasons that water repellency did not disappear in A horizons of all soil profiles after the first heating event at 250 °C (Table 2). The A horizon of Dystric Regosol remained extremely water repellent even after exposure to 300 °C heating. Only when a third thermal impulse was applied, water repellency disappeared in all the samples heated to 250 and 300 °C. In the samples exposed to three thermal impulses at 200 °C, water repellency remained extremely high, indicating that sufficient decomposition of crucial hydrophobic compounds did not occur at 200 °C.

Table 2. Water drop penetration time (WDPT) values (s) of soil samples from respective depths before and after the first, second and third heat treatment (20 minutes at the selected temperature).

Soil	Horizon	Temperature [°C]								
		----1st heat treatment----			----2nd heat treatment----			---3rd heat treatment---		
		200	250	300	200	250	300	200	250	300
RGdy	A	> 43 200	> 43 200	> 43 200	> 43 200	< 1	< 1	> 43 200	< 1	< 1
	A/C	> 43 200	< 1	< 1	> 43 200	< 1	< 1	> 43 200	< 1	< 1
	C	> 43 200	< 1	< 1	> 43 200	< 1	< 1	> 43 200	< 1	< 1
UMar	A	> 43 200	> 43 200	< 1	> 43 200	> 43 200	< 1	> 43 200	< 1	< 1
	C	> 43 200	< 1	< 1	> 43 200	< 1	< 1	> 43 200	<1	< 1
GLha	A	> 43 200	> 43 200	< 1	> 43 200	> 43 200	< 1	> 43 200	< 1	< 1
	Cg	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Notes: RGdy – Dystric Regosol; UMar – Arenic Umbrisol; GLha – Haplic Gleysol

The temperature thresholds at which soil water repellency disappeared were evaluated from controlled laboratory experiments by Krammes, DeBano (1965), Nakaya (1982) and Doerr et al. (2005). The above mentioned results are in general agreement with results of Doerr et al. (2005) who examined soils from Canada, Portugal and the UK and found that exposure to temperatures below 200 °C tends to increase water repellency, followed by a decline in repellency for exposure to 250 °C and elimination for 300 °C. Our results slightly differ in the fact that repellency disappears after heating to 250 °C in the Slovakian soils investigated here. Also Krammes and DeBano (1965) and Nakaya (1982) reported the temperature threshold at which soil water repellency disappeared above 250 °C. This difference may be due to short duration of heating with respect to soil organic matter in their experiments or different composition and properties of the soil organic matter in soils under study.

Observed variability of water repellency persistence and its thermal dependencies appear to relate to differences in field moisture regime of the different soils. The shape of the WDPT-temperature curves is thought to be affected by changes with depth of the content and stability of hydrophobic organic compounds. The severity of water repellency in the soil profiles appears to generally decrease with depth and from dry to wet regime.

Conclusion

Water repellent soils were found under pine forests at Borská nížina lowland (SW Slovakia). In investigated soil profiles, the severity of water repellency differed with the respective moisture regimes of the soils. A shallow ground water table with gleyic processes and hydrophilous herb layer seem to prevent the development of soil water repellency. In contrast, relatively dry conditions and acidophilous plants may be conducive to extremely high water repellency. The indicated effects of soil genesis, moisture regime and plant cover on the persistence of water repellency are worthy of future rigorous study.

Wildfire effect simulations under laboratory conditions showed distinct differences in WDPT among the soil samples after the first heating impulse at temperatures up to 150 °C. For heating at 200 °C, effects did not differ between soils of different genesis and moisture regime, with all samples becoming extremely water repellent, except for the sample of gleyic Cg horizon, which has a very low organic matter content.

When heated above 200 °C, the thermal degradation of organic compounds resulted in a decrease in water repellency, varying with initial amount and composition of soil organic matter, and duration of heating and temperature. As a consequence of thermal decomposition, water repellency always disappeared at a temperature ≥250 °C, provided the duration of heating was sufficiently long.

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