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How severe and subcritical water repellency determines the seasonal infiltration in natural and cultivated sandy soils

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ABSTRACT

Infiltration into meadow and fallow (cultivated) sandy soils was evaluated after several prolonged rainy and dry spells during the years 2005–2011. Both soils evolved on fluvio-eluvial sandy sediments planted with pine forest, were originally strongly water repellent, but their management after deforestation was different. The fallow soil was intensively cultivated since 1950 while the other was left for natural grassland succession. For comparison, the perfectly wettable bare sediment of similar origin and texture was taken as reference material.

We focused on soil porosity, hydraulic conductivity ($k_{(-20\ \mathrm{mm})}$) and sorptivity (S) estimated by mini-disc infiltrometer, water drop penetration time (WDPT), and water repellency index (R).

The results indicate that cultivation (mainly liming) the fallow soil alleviated the water repellency to its subcritical level, what is also the main explanation for different water repellency persistence levels in fallow versus meadow soil. Notwithstanding, cultivation has not substantially increased water infiltration properties confirming the hypothesis that subcritical water repellency may still retard water infiltration. Some stability of wetting patterns observed in the meadow and fallow soils resulted in only insignificant increase of $k_{(-20\ \mathrm{mm})}$ during the rainy periods.

Long dry spells enhanced the infiltration capacity in wettable reference material because of sorptivity increase. Sorptivities of water repellent meadow and fallow soils, however, remained restrained during both, the rainy and dry spells due to higher water content (when wet) and to stronger water repellency (when dry). As a result, only small seasonal variability in infiltration rates was observed in both water repellent soils.

1. Introduction

Extreme weather events such as droughts are likely to occur more frequently at different spatial and time scales in the future (IPCC, 2001; Farkas et al., 2009), and these droughts are reported to lead to soil aridisation in the Central European region (Leuzinger et al., 2005; Eitzinger, 2009; Šiška, 2009; Takáč, 2009; Trnka, 2009; Mihailović, 2009; Vučetić, 2009). Prolonged dry periods resulting from global climate change may enhance surface runoff and soil erosion (Imeson et al., 1992; Shakesby et al., 1993), create irregular infiltration patterns and preferential flow in agricultural (Dekker and Ritsema, 1994; Ritsema and Dekker, 1998) and forest soils (Ehwald et al., 1961; Burcar et al., 1994), or create irregular, patchy growth of pasture and meadow vegetation (DeBano, 1981; Moore et al., 2010). The above mentioned effects are generally perceived as negative and are often explained as a result of reduced infiltration due to decreased soil wettability or so called soil water repellency (SWR). Soil water repellency is a reduction in the rate of wetting and retention of water in soil caused by the presence of hydrophobic organic coatings on soil particles and interstitial particulate organic matter (Moore et al., 2010; Franco et al., 1995). Soil water repellency changes the redistribution of precipitation towards enhanced runoff and evaporation and thus may reduce water infiltration, soil water storage, leading to water stress in vegetation. Conversely, developing a water repellent surface layer could also reduce subsequent drying of deeper soil layers by preventing evaporation and upward capillary movement of water (Imeson et al., 1992; Bachmann et al., 2001).

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Jackson and Gillingham (1985) suggested that lime applied to the soil through fertilization increased soil moisture by alleviating SWR. Jiayou et al. (1993) reported that liming soils increased soil moisture compared to a control, and attributed the effect to an improvement of soil structure and SWR alleviation. However, soil wetting and infiltration processes can be affected by lower levels of SWR, as well. For example, Wallis et al. (1991) reported that many soils exhibit subcritical water repellency, in which these soils appear to infiltrate and redistribute water, but at a reduced rate (Bachmann et al., 2007).

Water repellency is particularly common in coarse-textured soils because sandy soils have a low surface area, which can be more readily coated with organic materials. Mineral particles can be easily coated by fulvic acids (Miller and Wilkinson, 1977), waxes (Kung, 1990; Franco et al., 2000), or lignin-type organic polymers (Sharma et al., 1993). SWR generally increases during dry weather, while it is reduced or completely eliminated after prolonged and/or heavy precipitation (Doerr et al., 2000). It is suggested, therefore, that particularly sandy soils will be susceptible to SWR development after prolonged dry periods and elevated temperatures (e.g., heat waves) that could occur more often from climate change. The question is whether soil hydrological processes (e.g., Goebel et al., 2011) are more affected by severity and spatial variability of SWR (e.g., Jungerius and de Jong, 1989).

The objective of this study was to assess changes to hydraulic conductivity and sorptivity in sandy soils of the Pannonian Basin subjected to prolonged dry and wet periods. We focused specifically on different levels of SWR and their effect on soil properties that influence infiltration. After the deforestation in the half of the 20th century one soil was left for natural succession while the other was intensively cultivated and limed, so the role of calcite on soil hydrological processes in water repellent soils was evaluated here, as well.

2. Materials and methods

2.1. Locality Mlaky II (meadow soil and reference material)

The experimental site Mlaky II near Sekule is located in the Borská nížina lowland (Southwest Slovakia). This locality is at an elevation of 150 m above see level, the average annual air temperature is 9 °C, and the annual precipitation is 500–600 mm. The site is semiarid, where 95% of precipitation evaporates during the warm half year.

The soil is classified as Haplic Arenosol (WRB, 1994), evolved from fluvio-eluvial sandy sediments and has a sandy texture (Tables 1 and 2) too. The pine-forest (*Pinus sylvestris*) had been planted here since 17th century and managed by feudal monarchs until most forests were seized in the first half of the 20th century The actual vegetation consists mostly of grass species (*Poaceae* family). Among other species most frequent are *Achillea Millefolium*, *Acetosella vulgaris*, *Anthemis ruthenica*, *Convolvulus arvensis*, *Lepidium ruderale*, *Plantago lanceolata* and *Potentilla* sp. The moss *Brachythecium albicans* appears amply, as well.

The sandy material found at 50 cm depth in nearby unvegetated location was taken as reference material. This material is formed from aeolian silica sand that extends downward to the groundwater table at a depth of about 2 m. Visual assessment indicates that the material has been minimally influenced by vegetation or cultivation.

2.2. Locality Őrbottyán (fallow soil)

The second experimental site is located in the northern part of Hungary in the alluvium of Danube River. The site is at an elevation of 202 m above see level, the average annual air temperature is 10.3 °C, and the annual precipitation is 550–600 mm. This site is also semiarid, and is commonly dry from January through June. This soil evolved from the eolian sandy material deposited on fluvial sediments and has a sandy texture (Table 1), too. The relatively deep layer (with up to 1% humus content) that is characteristic of this site is a result of a subsoil fertilization experiment carried out in the 1950s. During this experiments large amount of organic fertilizer and carbonates were incorporated into the soil down to 40–50 cm depth to increase its organic matter content and water holding capacity (Köhler, 1984). According to Dvoracsek and Dvoracsek (1961) the humus content of the soil was less than 0.5% even in the topsoil, but its $CaCO_3$ content was 1%, 5%, 10% in the 0–30 cm, 30–60 cm, 60–100 cm layers, respectively. We found the carbonate content to range between 0.34 and 5% in the topsoil layer (Table 1). The soil was originally slightly acid (pH 6)

Table 1
Basic physical and chemical properties of studied soils.

Locality	Material description	Depth (mm)	No. of replicates	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	C_{org} (%)	pH (H_2O)	pH (KCl)
Őrbottyán (Hungary)	Fallow soil	0–50	5	86.3	8.3	5.4	0.34–5[a]	0.75	7.74	7.15
Mlaky II (Slovakia)	Meadow soil	0–50	3	91.3	2.8	5.9	<0.05	0.99	5.14	3.91
Mlaky II (Slovakia)	Reference material	500–550	3	94.9	1.7	3.4	<0.05	0.03	5.54	4.20

[a] The carbonates content varies over the research plot in this range.

Table 2
Physical characteristics of the studied soils; soil bulk density, porosity, field capacity (capillary porosity) and wilting point.

Material description	Bulk density ($g\,cm^{-3}$)	Characteristics of porous system		
		Porosity	Capillary porosity[a]	Wilting point[a]
Fallow soil	1.65	0.407	0.301	0.037
	1.66	0.395	0.295	0.038
	1.64	0.414	0.282	0.037
	1.67	0.411	0.268	0.038
	1.64	0.393	0.283	0.038
Meadow soil	1.40	0.390	0.144	0.035
	1.36	0.406	0.141	0.045
	1.38	0.425	0.192	0.056
Reference material	1.42	0.385	0.135	0.042
	1.47	0.397	0.210	0.085
	1.46	0.351	0.134	0.041

[a] The wilting point relates to the moisture content at pF = 4.18 (−15 bar) and capillary porosity relates to field capacity pF = 2 (h_w = −0.10 bar).