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Soil water repellency and chemical soil properties in a beech forest soil — Spatial variability and interrelations

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ABSTRACT

Higher solute input due to stemflow infiltration causes enhanced soil acidification near the tree base. Infiltration-driven alteration of chemical soil properties like pH, and carbon to nitrogen ratio (C/N) and particle surface properties like oxygen to carbon ratio (O/C), may also affect soil wettability with a trend to increased soil water repellency (SWR) with increased acidity. Our study provides a link between chemical soil quality and physical behavior with respect to soil water infiltration and SWR, respectively in a beech forest soil.

The spatial variability of soil properties was analyzed within a grid ($\Delta = 1$ m, $5\text{ m} \times 8\text{ m} = 40\text{ m}^2$) and, to reveal direct effects of stemflow influence on soil properties, we sampled along a tree row ($\Delta z = 0.8$ m, $l = 46.60$ m) with varying sampling points to tree distances. All samples were taken in a beech (*Fagus sylvatica* L.) forest Bws/Bw-horizon in 0.1–0.2 m depth (dystric cambisol).

Analysis of spatial variability by standard statistics and geostatistical methods revealed no substantial differences between grid and transect samples for pH and sulfate, Al, and Fe (aluminum and iron oxalic acid extractable) concentration and SWR in terms of contact angle (CA, sessile drop method) measured for bulk soil samples. According to standard statistics, the total variance of chemical soil properties and SWR was independent of stemflow infiltration pattern. Results of spectral variance analysis showed that the spatial variability of acidification (pH, Al content) as well as SWR was strongly affected by the pattern of patches with and without stemflow infiltration or the distribution of beech trees, respectively. In a more or less regularly planted beech forest this caused a cyclic variation of soil acidification and SWR with a strong trend to increased SWR (CA ranges 17°–72°) with increased soil acidity. Specific chemical surface properties, analyzed via X-ray photoelectron spectroscopy, like O/C ratio ($r^2 = 0.782$) and the amount of nonpolar C species ($r^2 = 0.768$) as well as surface Al concentration ($r^2 = 0.867$) clearly showed a strong relation to CAs. Hence, SWR was strongly affected by stemflow infiltration patterns into soil. For C/N, sulfate, and Fe content no significant relations to SWR or soil acidity were found.

1. Introduction

The effect of soil water repellency (SWR) on water infiltration patterns causes water not to penetrate into the top- and subsoil through the entire cross section (Buczko et al., 2002; Bundt et al., 2001a) and is an important factor for overland flow generation and, as a consequence, for enhanced soil erosion (Butzen et al., 2015). SWR supports non-homogeneous water content distribution in the soil and promotes due to enlarged spatial variability of soil moisture preferential flow pathways (Bauters et al., 2000; Dekker et al., 2001; Dekker and Ritsema, 1994). For a spruce–beech forest soil preferential flow pathways can persist for decades. Along these pathways, soil organic carbon (SOC) and nitrogen (N) concentrations and microbacterial activity were found to be higher than in the surrounding soil matrix due to a better nutrient supply (Bundt et al., 2001a, 2001b). Thereby the risk of groundwater contamination increases due to rapid water flow which reduced the filter function of the soil as well as available water for plants. SWR occurs in different soil types, under different vegetations, land use and various environmental conditions such as climate (e.g. seasonal variation, temperature), water content, pH and time (Buczko et al., 2005; DeBano, 2000; Doerr et al., 2000). Drying of forest soils according to seasonal variations enhances SWR (Buczko et al., 2005; Krammes and DeBano, 1965) which directly affects local soil hydraulic processes like surface runoff, infiltration behavior and sorptivity (Clothier et al., 2000) which might affect significantly site hydrology from local to catchment scale (Doerr et al., 2003). Predicted larger frequencies of extended droughts due to the climatic change suggest for some locations' higher relevance for the occurrence of SWR (Goebel et al., 2011; Schwen et al., 2015) in forest soils with direct consequences for water and nutrient availability. Generally, water repellency in the field is affected by the potential SWR (maximum; i.e. in the dry state like air-dry) and the actual SWR, which is additionally affected by soil moisture. During drought periods, the water content should be reduced, hence the actual SWR should be higher. Stemflow that infiltrates into the soil around the base of a tree has been postulated to be an important mechanism by

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Table 1
Data of the typical soil horizons of a dystric cambisol soil profile in the near vicinity of the sampling locations.

Horizon	AE	Bsw	Bw	BwC	C	2C	2Cg	3C
Depth (cm)	0–2	2–12	12–36	36–65	65–125	125–150	150–180	180+
pH ($CaCl_2$)	3.3	3.4	4.4	4.5	4.4	4.1	4.2	4.2
SOC (g kg^{-1})	27	17	7	3	0.4	0.1	0.8	<0.1
Sand (%)	70	65	67	73	95	81	72	95
Silt (%)	26	30	29	24	4	11	19	4
Clay (%)	4	5	4	3	1	8	9	1

which trees are able to withstand drought (Martinez-Meza and Whitford, 1996; Schwärzel et al., 2012).

It is known that tree canopies affect rainfall infiltration patterns in forest stands and cause inhomogeneous distribution of water and nutrients in forest soil (e.g. Draaijers et al., 1992; Koch and Matzner, 1993, Böttcher et al., 1997, Chang and Matzner, 2000). Higher solute input in the vicinity of tree stems into the soil (Schimmack et al., 1993; Levia and Frost, 2003; Schwärzel et al., 2012) causes enhanced soil acidification, indicated by a lowered pH (Falkengren-Grerup, 1989; Koch and Matzner, 1993; Nikodem et al., 2010). Incident precipitation interacts chemically in the canopy with the leaves, branches, and trunk of the tree due to the concentration gradients between the precipitation and the tree, leading to a nutrient (Stachurski and Zimka, 2002; Adriaenssens et al., 2012) and dissolved organic carbon (DOC; Chang and Matzner, 2000; Levia et al., 2012) enriched stemflow fluxes compared to throughfall fluxes (Moore, 2003; Levia et al., 2012). Stemflow fluxes may be funneled at the tree base preferentially into top- and subsoil (Johnson and Lehmann, 2006; Schwärzel et al., 2012). Thus, the amount and the elemental composition of the soil organic matter (SOM) in the top- and subsoil around the beech trunk, i.e. bulk C content or C/N ratio, are also affected by the heterogeneous infiltration pattern due to stemflow (Chang and Matzner, 2000). Infiltration-driven alteration of chemical soil properties like pH and C/N ratios, around the base of the tree, may also affect the wettability of essential components of the organic material like humic and fulvic substances (Tschapek, 1984) and may have an effect on SWR.

Hallett et al. (2004) reported in one of the few studies dealing with geostatistical analysis of SWR, that reduced water infiltration may be linked to small-scale microbial and/or chemical processes that cause subcritical SWR. Sorptivity measurements at the millimeter-scale on the surface of a large undisturbed soil block (0.9 m wide, 1.3 m long,

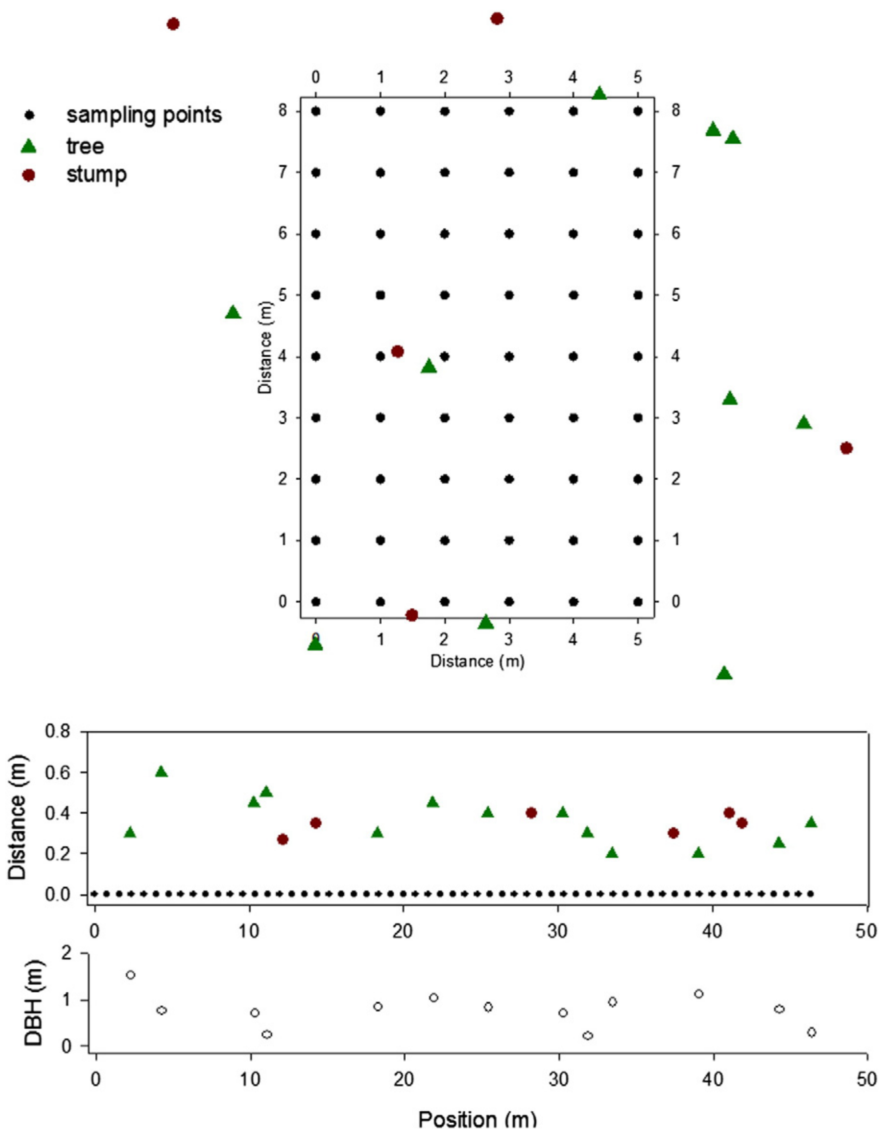

Fig. 1. Grid design and distribution of trees and stubs within and in the vicinity of the sampled grid (top). Distribution of beech trees and stubs along the sampled transect and distances to the sampling points (middle) and measured tree diameter at breast height (DBH, bottom).