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Water repellency under coniferous and deciduous forest — Experimental assessment and impact on overland flow

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ABSTRACT

Current climate change makes it necessary to gain a deeper understanding of the runoff generation processes in Central European forests. A changing climate might affect soil water repellency (SWR) which can be seen as an import trigger for overland flow generation in forested areas. In this study the differences between coniferous and deciduous forest concerning SWR and overland flow generation were investigated in a small catchment in the Hunsrück low mountain range, Rhineland-Palatinate, Germany.

To investigate the occurrence and persistence of SWR and its influence on overland flow generation, a combination of two experimental methods was applied: water drop penetration time (WDPT) test, and rainfall experiments. The field WDPT test results ranged from wettable (WDPT < 5 s) up to more than 900 second persistence of water repellency in both forest types. The median WDPT was 30 s for the coniferous forest and 1 s for the deciduous forest sites. On the deciduous forest soils, only the Of-horizon showed considerable water repellency. Rainfall experiments with 40 mm h^{-1} rainfall intensity yielded runoff coefficients between 0% and 63%. The lowest measured infiltration rate of the rainfall experiments was 11.6 mm h^{-1}. The highest runoff coefficients were measured on water repellent (WDPT > 300 s) coniferous forest sites. The overland flow starts significantly earlier with water repellent soil conditions. The median runoff rate for the wettable forest soils is 2.7%, whereas the water repellent sites show a median runoff coefficient of 11.4%.

The results suggest that the occurrence of SWR can lead to considerable overland flow generation under forest.

1. Introduction

Temperate humid forests are often regarded as water retention areas rather than sources for overland flow (Hümann et al., 2011; Wahren et al., 2012). Exceptions are compacted areas like harvester tracks or forest roads. Here, very high overland flow rates can be measured (Arnáez et al., 2004; Butzen et al., 2014; Eastaugh et al., 2008; Robichaud et al., 2010; Wagenbrenner et al., 2010). Nevertheless, the occurrence of soil water repellency (SWR) is another important factor influencing overland flow generation processes in forests (Bens et al., 2007; Buczko et al., 2007; Doerr et al., 2000; Hartmann et al., 2009; Lichner et al., 2013; Neris et al., 2012; Wahl et al., 2005; Wessolek et al., 2008). All these studies are located in Central Europe and emphasize that SWR is an important factor influencing the infiltration process even under a humid temperate climate.

According to Wessolek et al. (2008) the processes of water repellency in the different organic layers of forest soils have not been investigated extensively. Most of the studies were focused on the influence of forest fire (Arcenegui et al., 2007; Bodí et al., 2012; Cerdà and Doerr, 2008; Shakesby, 2011; Zavala et al., 2009) or on the water repellency of mineral soil horizons (Doerr et al., 2006; Woche et al., 2005). There are some experimental field studies in the Mediterranean showing that SWR can intensify overland flow generation after forest fires (Cerdà and Doerr, 2008; Imeson et al., 1992; León et al., 2013; Malvar et al., 2013). The influence of SWR on overland flow generation has been investigated for example by Gomi et al. (2008) and Miyata et al. (2009) on test plots under Cypress forest in Japan. Overland flow occurred on all plots even for storms of lower intensity (<10 mm h^{-1}) (Gomi et al., 2008). Nevertheless, there is still a lack of experimental data quantifying the impact of water repellency on overland flow generation for Central Europe. This paper offers experimental data from field rainfall simulations to close this gap.

According to Doerr et al. (2000), a surface shows hydrophobic behaviour if the surface tension of a water droplet (cohesion) is higher than the adhesive forces of the surface. Organic polymers or waxes can have lower forces of attraction. This leads to hydrophobic properties of a surface. The hydrophobic substances can be provided by living or dead plant material in different decomposition states or by fungi or micro-organisms in organic layers and mineral soil (Atanassova and

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Doerr, 2010, 2011; Chau et al., 2012; Doerr et al., 2000; Morley et al., 2005). Water repellency can also be a consequence of forest fires (Arcenegui et al., 2007; Bodí et al., 2012; Cerdà and Doerr, 2008; Robichaud and Hungerford, 2000; Rodríguez-Alleres et al., 2012; Shakesby et al., 2003; Zavala et al., 2009, 2010; Zehe et al., 2007).

Soil water repellency typically shows temporal variations, which are strongly related to the seasons (Buczko et al., 2007). During dry periods in the summer months, the soils are most frequently influenced by SWR (De Jonge et al., 1999; Orfánus et al., 2014; Zehe et al., 2007). Doerr et al. (2000) state that a hydrophobic soil becomes hydrophilic again if critical water content is exceeded. According to Dekker and Ritsema (1994) and Zehe and Sivapalan (2009), SWR can be regarded as a threshold process. It occurs if the soil moisture drops below a certain value and if certain organic compounds are present (Atanassova and Doerr, 2010; Morley et al., 2005; Neris et al., 2012). In the last 20 years, important progress has been made revealing the mechanisms that control occurrence and severity of water repellency effects (Doerr et al., 2000, 2009). In the last decade several studies on soil hydrophobicity in European temperate forests have been published (Bens et al., 2007; Buczko et al., 2005, 2006; Doerr et al., 2006; Greiffenhagen et al., 2006; Orfánus et al., 2014; Wahl et al., 2003). The investigated sites were situated in southern UK (Doerr et al., 2006), south-western Slovakia (Orfánus et al., 2008, 2014), eastern Germany (Wessolek et al., 2008) and north-eastern Germany (Bens et al., 2007; Buczko et al., 2005, 2007; Hartmann et al., 2009; Wahl et al., 2003). In the course of climate change, we expect that dry periods in late spring and summer will become more frequent (IPCC, 2007, 2013). This could lead to an increased influence of water repellency effects also in Central European forests particularly in conjunction with heavy summer rainstorm events. In 2010, 30.1% of the total area in Germany and even 42% of the total area in Rhineland-Palatinate was forested (German Federal Office of Statistics, 2012). Regarding this high proportion of forests, the importance of the forests as possible sources for overland flow becomes clear. Forests have a protective function; they can diminish flood peaks because the forest soils can absorb much water and release the infiltrated water with a long delay (Hausler and Scherer-Lorenzen, 2001).

This study was conducted in the Holzbach area which is situated in the Hunsrück low mountain range, Rhineland-Palatinate, Germany. The spatial distribution and temporal distribution of overland flow generation were investigated.

The presented work aims at answering the following research questions: i: to what extent is water repellency present in the study area (Central European temperate forest)?; ii: are there differences between coniferous and deciduous forests?; iii: which of the studied humus and mineral soil horizons are the most water repellent?; iv: how does water repellency influence overland flow generation in the studied forests?; and v: does soil moisture influence water repellency?

2. Study area

The study area Holzbach (Fig. 1) covers an area of 2.3 km^2 and is situated in the Hunsrück low mountain range in Germany. At the climate station "Weiskirchen/Saar" (N 49° 33′ 02″ E 6° 49′ 03″) situated at the gauge of the Holzbach River, the mean annual rainfall amount is about 1186 mm, and the mean temperature is 9.4 °C (German Meteorological Service, 2012: climate data from the 1st of January 1982 to the 31st of December 2011). The Holzbach area belongs to the south-western part of the Rhenish Slate Mountains. The bedrock is a quartzite belonging to the lower Devonian and the soils are mainly acidic Cambisols, Podsols and stagnic Cambisols with soil textures ranging from sand to sandy loam (Ad-hoc-Arbeitsgruppe Boden, 1996). The study area is almost completely covered by forest. Coniferous forest (mainly spruce/*Picea abies*) covers 50.2% of the area, 25.4% is deciduous forest (mainly beech/*Fagus sylvatica*), 10.5% is mixed forest (e.g. *P. abies* and *F. sylvatica*), 13.7% is a 10–15-year-old afforestation area and 0.2% is covered by grassland.

Within the study area, drained wetland was equipped with small dams to cut the artificial runoff paths in order to rewet peat areas. These land-management measures were carried out in the course of the EU-INTERREG IIIB NWE project WaReLa (Water Retention by Land-Use) in order to enhance water retention (Gallus et al., 2007; Segatz et al., 2009).

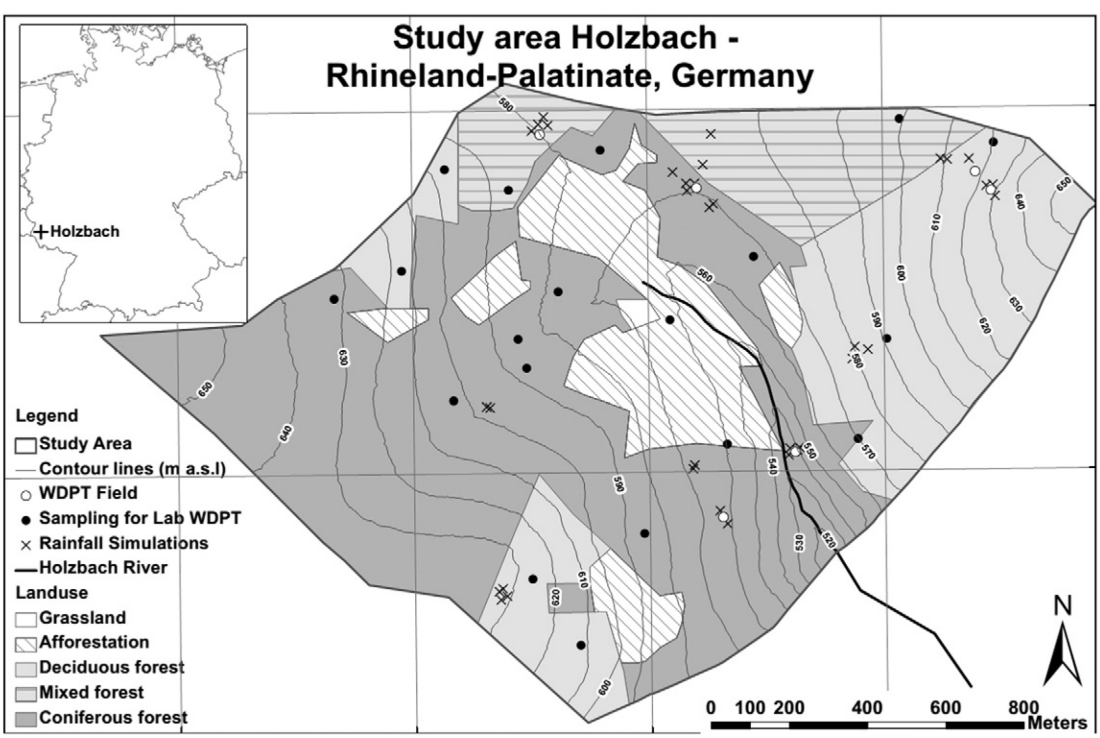

Fig. 1. Map of the study area Holzbach with the locations of WDPT-field-sampling sites (white dots), the sample sites for the laboratory measurements of WDPT (black dots), and the sites of the rainfall experiments (black crosses). (WDPT: water drop penetration time [seconds]).