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The influence of vegetation on soil water repellency-markers and soil hydrophobicity

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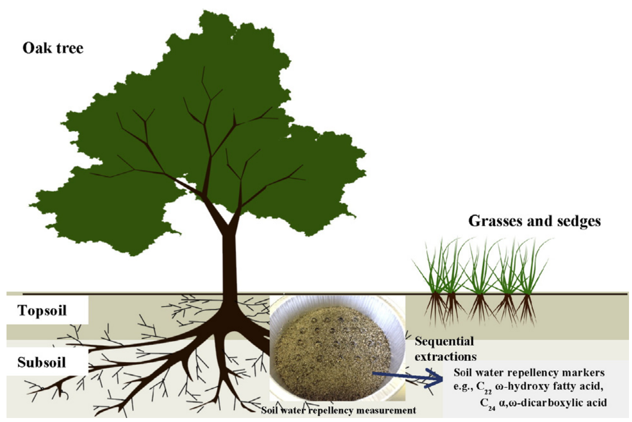
HIGHLIGHTS

- Covering plant species primarily influences soil water repellency and its markers.
- Single long-chain soil water repellency (SWR)-markers positively correlate to SWR.
- Root-derived ω-hydroxy fatty acids and α,ω-dicarboxylic acids predict SWR well.
- The corresponding biomarkers of the SWR predictors are abundant in grass roots.
- Grass roots mainly contribute to the organic matter in topsoils leading to strong SWR.

GRAPHICAL ABSTRACT



Graphical abstract shows that in an ecosystem with oak, grasses and sedges, the roots of various plant species distribute differently in the top- and subsoils. The soil water repellency was measured using water drop penetration time test. The soils were extracted sequentially and soil water repellency markers, e.g., C_{22} ω-hydroxy fatty acid and C_{24} α,ω-dicarboxylic acid, were observed mainly derived from plants.

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ABSTRACT

Soil water repellency (SWR) markers are defined as hydrophobic compounds in soil causing SWR and are mainly derived from plants. Previous studies have shown the types and abundance of SWR-markers in soils. However, how these SWR-markers are exactly related to SWR and their origin is poorly understood. This study aims to understand the relationship between SWR-markers, vegetation type and cover and SWR for a simple sandy soil ecosystem, consisting of oaks with sedge and six grass species. All the soil (at different depth) and vegetation samples were collected in the field along a 6 m transect, starting from an oak tree. Further along the transect grasses and sedges became more abundant. Free and ester-bound lipids from soils and plant leaves/roots were obtained using a sequential extraction method and identified by gas chromatography–mass spectrometry. Significant linear correlations were found between the main soil characteristics, such as total organic carbon content, and SWR. Single long-chain ($>C_{20}$) SWR-markers derived from both plant leaf waxes and roots positively related to SWR. Both ester-bound ω-hydroxy fatty acids and C_{22} and C_{24} α,ω-dicarboxylic acids were predominantly present in the grass roots, but to a lesser extent in the roots of oak and sedge. These suberin-derived ω-hydroxy fatty acids and α,ω-dicarboxylic acids characteristic of roots could well predict the SWR. Additionally, the SWR

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predictors abundantly present in the soils matched well with high concentrations of the corresponding biomarkers in the dominant vegetation species that covered the soils. Our analyses demonstrated that grass roots influenced SWR more due to their more substantial contribution of organic matter to the topsoils than oak roots. This led to a stronger SWR of the soils covered with grass than those covered with oak vegetation.

1. Introduction

As one of the common and important soil properties, soil water repellency (SWR) can limit water flow in soils and potentially trigger soil erosion (DeBano, 1981, 2000; Jungerius and De Jong, 1989; Ritsema et al., 1993; Dekker and Ritsema, 1994; Doerr et al., 2000, 2007; Zavala et al., 2009, 2014). This phenomenon occurs in different types of soils at various depths under a wide range of vegetation species, including mosses (Lichner et al., 2007), herbs (Llewellyn et al., 2004; Doerr et al., 2005), grasses (Dekker and Ritsema, 1996; Ritsema and Dekker, 1998), shrubs (Verheijen and Cammeraat, 2007) and trees (Franco et al., 1995, 2000; Mataix-Solera et al., 2007; Rodríguez-Alleres et al., 2007; Hansel et al., 2008; Atanassova and Doerr, 2010; de Blas et al., 2013). It is well known that SWR is caused by hydrophobic organic compounds in soil, which are predominantly derived from vegetation (Bisdom et al., 1993; DeBano, 2000; Horne and McIntosh, 2000; Hansel et al., 2008; de Blas et al., 2010, 2013) and to a small extent from microbes (Wallis and Horne, 1992; Rillig, 2005) and those were accordingly defined as SWR-markers by Mao et al. (2014). SWR can also be caused by amphiphilic organic compounds (cf. Doerr et al., 2000), and by the actual state of the soil ranging from water repellent to wettable which is a result of the meteorological history.

Generally, water repellent soils contain more organic matter than non-water-repellent soils (Atanassova and Doerr, 2010; Mainwaring et al., 2004, 2013). The concentration of free lipids in soils under pine and eucalyptus extractable by petroleum ether had a significant positive relation with soil hydrophobicity, while those of bound lipids did not correlate with SWR (de Blas et al., 2013). Mao et al. (2015) suggested that the linear correlation between the absolute concentrations of SWR-markers and SWR most likely followed the tendency of total organic carbon (TOC) content. A higher absolute SWR-marker concentration correlates with a higher TOC, and an increase in TOC leads to a higher soil hydrophobicity. However, only little is known about the relationships between the relative abundance of SWR-markers and water repellency, as well as the vegetation origin of these SWR-markers. Although the relative amount of microbial hydrolysed suberin-derived alcohols positively related to SWR, the insignificant relation between other major hydrophobic compounds in soil and its SWR still need to be convincingly explained (Mao et al., 2015).

The degree and distribution of soil hydrophobicity under various vegetation cover and land use vary (Doerr et al., 2005, 2007; Zavala et al., 2009; Rodríguez-Alleres and Benito, 2011, 2012; Badía et al., 2013). Since vegetation is the dominant source of the input of SWR-markers into soils (van Bergen et al., 1997; Kögel-Knabner, 2002), investigating the influence of vegetation on those compounds and SWR is essential. For instance, Rodríguez-Alleres et al. (2007) found that vegetation had more influence on the persistence of SWR under eucalyptus and pine forest than under grassland and maize crops. According to Lozano et al. (2013), the stronger persistence of SWR was found under oak, while the soil under the shrub *Cistus* was non-repellent. Badía et al. (2013) compared the soils under woody plants (pine and oak) and meadow, of which the soil under pine was most repellent, while the lowest water repellent soil was found under meadow. These studies hinted at the association of vegetation types with either soil organic compounds or water repellency; however, none of them linked SWR to their vegetation origin at the molecular level.

In Mao et al. (2015) we have tested the hypothesis that it is feasible to predict SWR using vegetation cover. However, our previous research site was probably too diverse with regard to current and past vegetation composition, which led to no or only poor correlations between vegetation and SWR. It is desired to understand whether such a poor correlation is due to the ecosystem complexity or whether the link between vegetation biomarkers and those causing SWR does inherently not exist. Therefore, we focused here on a more simple system with less vegetation variety (oak, grasses and sedge) compared to the vegetation-mixed system (algae, mosses, grasses, shrubs, trees) studied previously (Mao et al., 2014, 2015) to test this hypothesis. Within the present simple ecosystem, our study aims to investigate the effects of vegetation cover on SWR in which we aim to link SWR to SWR-markers in the soil and to link these SWR-markers to their vegetation origin (leaves/roots and species). In this paper the objectives are: i) to explore at the plot scale the possible relations between the patterns of TOC and the biomass of the vegetation cover and SWR along an oak-grass-sedge transect; ii) to understand at the molecule scale the link between vegetation biomarkers and SWR-markers and to use vegetation biomarkers to predict SWR; iii) to explore the influence of vegetation origin on SWR-markers and SWR and to use vegetation cover to predict SWR. To this end we applied a sequential extraction procedure to both soils and leaves/roots of the plant cover to obtain different compound fractions and to compare the types and abundances of typical SWR-markers with vegetation biomarkers.

2. Materials and methods

2.1. Study area

The soils and vegetation sampling was conducted in the Zuid-Kennemerland National Park of the Netherlands (52°25′09″ N, 4°35′ 23″ E). The sampling site is scattered with common oaks (*Quercus robur*), covered by sedge (*Carex sp.*) and different grass species (Table 1). The soils were classified as Hydrophobic Arenosols (FAO, 2015). The mineral particles in the study site are of similar mineralogical composition and the texture is: clay (<2 μm) < 0.5%; silt (2–50 μm) < 3.5% and sand (>50 μm) > 96% (Eisma, 1968).

2.2. Sampling, experimental design and pre-treatment

2.2.1. Soils

To investigate a gradient of oak and the main grass species on SWR, a 6 m long transect was laid out at the aforementioned site starting from the stem of one single oak tree in the direction of a second oak tree under the tree crown. Along this transect the soils were collected at different depths with each soil sample representing one soil horizon on 23rd of August 2013 (Table 2). The soil horizons included mineral

Table 1
Vegetation distribution and sampling. Location refers to the distance to the oak tree at which the undergrowth predominantly grows and was taken for analysis.

Vegetation	Common name	Location (m)	Type of biomass	
Quercus robur	Common oak	0	Leaves	Roots
Festuca rubra	Red fescue	2	Leaves	Roots
Poa nemoralis	Wood bluegrass	4	Leaves	Roots
Phleum pratense	Timothy-grass	5	Leaves	
Agrostis stolonifera	Creeping bentgrass	2/6	Leaves	
Holcus lanatus	Tufted grass	2/4/5/6	Leaves	Roots
Carex sp.	Carex	4	Leaves	Roots