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Effect of Soil Water Repellency on Energy Partitioning Between Soil and Atmosphere: A Conceptual Approach[*1]

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ABSTRACT

Water repellency (WR) is a phenomenon known from many soils around the world and can occur in arid as well as in humid climates; few studies, however, have examined the effect of soil WR on the soil-plant-atmosphere energy balance. The aim of our study was to estimate the effects of soil WR on the calculated soil-atmosphere energy balance, using a solely model-based approach. We made out evapotranspiration to have the largest influence on the energy balance; therefore the effect of WR on actual evapotranspiration was assessed. To achieve this we used climate data and measured soil hydraulic properties of a potentially water-repellent sandy soil from a site near Berlin, Germany. A numerical 1D soil water balance model in which WR was incorporated in a straightforward way was applied, using the effective cross section concept. Simulations were carried out with vegetated soil and bare soil. The simulation results showed a reduction in evapotranspiration of 30–300 mm year^{-1} (9%–76%) at different degrees of WR compared to completely wettable soil, depending on the severity degree of soil WR. The energy that is not being transported away by water vapor (*i.e.*, due to reduced evapotranspiration) had to be transformed into other parts of the energy balance and thus would influence the local climate.

Key Words: climate, effective cross section, evapotranspiration, soil-atmosphere energy balance, soil hydraulic property, water balance

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INTRODUCTION

The term water repellency (WR) is used to describe inhibited wetting behavior of surfaces. If the solid-water contact angle is greater than 90°, a surface is defined as water repellent or hydrophobic. Water repellency and hydrophobicity are used synonymously in soil science (Müller and Deurer, 2011), whereas WR is used more often (DeBano, 2000 and Doerr *et al.*, 2000). In other fields, other definitions for WR exist. Reyssat *et al.* (2010) define WR as the bouncing back of a drop of water from a surface after impact; this definition is neither used in soil science nor by us. As WR is more commonly used, we do not use the term hydrophobicity from here on.

Water repellency is a phenomenon known from many soils in the world. It is widespread and can occur in humid climates as well as in arid climates (Doerr *et al.*, 2000). The WR under field conditions is a function of soil water content, quantity and quality of soil organic matter and other, not yet fully understood, factors (Ellerbrock *et al.*, 2005; Hardie *et al.*, 2012). The hydrological implications of water-repellent soils such as surface runoff, water erosion and preferential flow have been studied relatively well up to date.

In many regions global warming will lead to drier land surfaces and thus increase the likeliness of WR for soils. We postulate that global warming can not only lead to an increase in WR of soils, but WR has an impact on the local energy balance between soil and atmosphere and thus, will lead to a feedback on global warming. The postulated mechanism is as follows. Water repellency leads to preferential flow (Wessolek *et al.*, 2008); therefore less water is available in the upper soil horizons and less evapotranspiration does occur. The additional amount of energy that under wettable conditions vaporizes water has to appear in other parts of the energy balance. The parts of the soil-atmosphere energy balance that can be influenced are the sensible heat flux, longwave radiation emitted by the soil, reflected short wave radiation and the ground heat flux.

To our knowledge the effects of WR on the soil-atmosphere energy balance have not been studied yet. Müller and Deurer (2011) pointed out that changes of

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evaporation on water-repellent and surfactant-treated former water-repellent soils pose interesting questions for investigation. If enough water is available, *e.g.*, in Central European climate, the main energy flow away from the soil surface is contributed by the latent heat flux (Hillel, 1998; Foken, 2008). Therefore, we expect the major contribution to the changes in the energy balance to originate from the reduction of evapotranspiration.

The aim of this study was to undertake a model-based estimation of differences in evapotranspiration between wettable and water-repellent soils with otherwise identical properties. To achieve our aim we used an established numerical water transport model to simulate actual evapotranspiration for a non-repellent soil as reference. We incorporate WR into the model assuming parts of the soil to be inactive for water transport due to WR.

MATERIALS AND METHODS

Hydraulic implications of soil water repellency

Soil WR changes the water budget of the soil-plant-atmosphere system and thus also has an influence on evapotranspiration. For our model we assume that plants on water-repellent regions become physiologically inactive and do not transpire any more; we neglect any adaptations of root growth or water redistribution through the root network by the plants. Typically, these plants become yellow and stop growth. Thus, only vaporization due to interception takes place. On wettable areas, vaporization originates from both transpiration and interception (Fig. 1). Increased surface runoffs from water-repellent areas as well as preferential flow are well known phenomena (Doerr *et al.*; 2000). In this study we assume a plain soil surface, *i.e.*, no surface runoff.

Soil WR is dynamic; *i.e.*, it changes over the course of a year (Täumer, *et al.*, 2006). Water repellency causes fingered flow of water in soils (Ritsema and Dekker, 2000; Wessolek *et al.*, 2008). In order to describe the area of the soil that is contributing to water transport, *i.e.*, the cross section that is not affected by WR, Täumer *et al.* (2006) established the effective cross section (ECS) concept, which we used in this study. The flow regimes in temperate climate, *e.g.*, in Central Europe, for late summer, with a low ECS (Fig. 2a), and in early spring, with a high ECS (Fig. 2b), are schematically shown in Fig. 2. The ECS is described in more detail later on.

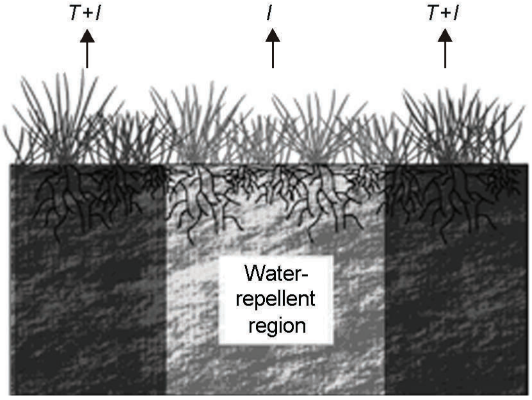

Fig. 1 Schematic illustration of the effect of soil water repellency on vaporization. Dark areas are the wettable part. T = transpiration; I = interception.

Conceptual model

The conceptual model is composed of four main parts: i) the core part of the modelling is the simulation of the water budget of the wettable fraction of the soil; ii) the upper boundary condition is given by meteorological data, collected at a site near Berlin, Germany, where precipitation and evapotranspiration are reduced by an interception model (Appendix A); iii) WR is taken into account by transforming infiltration data using the ECS concept of Täumer *et al.* (2006); and iv) at last the simulated evapotranspiration data is retransformed using ECS. Fig. 3 shows a schematic

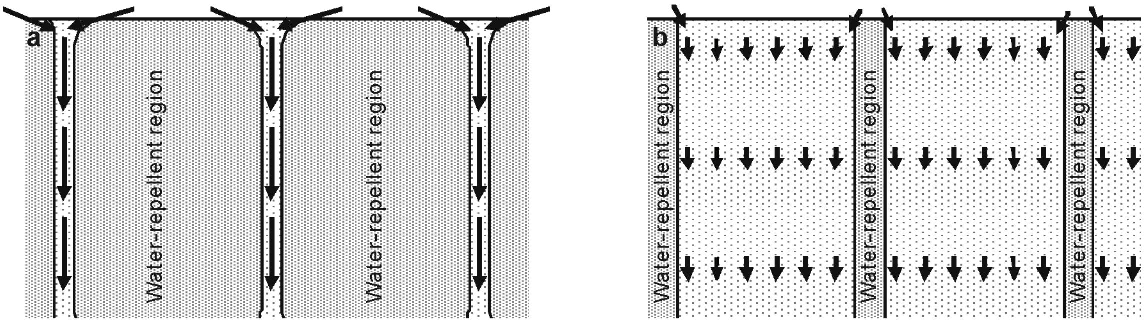

Fig. 2 Schematic illustration of flow regimes for two cases of water-repellent soil: effective cross section (ECS) of approximately 0.1 (a) and ECS of approximately 0.9 (b). Wettable flow fingers are brighter. Infiltrating water is indicated by black arrows; evapotranspiration is not indicated in the figure.