Model of water drop infiltration in amphiphilic porous media

Florian Cajot*[1], Annette Bérard[1], Claude Doussan[1], and Philippe Beltrame[1]

[1]UMR1114 EMMAH – INRAE, Avignon Université, UMR EMMAH, F-84000, Avignon, France – France

Résumé

Under the current climate change, assessing water transfer and infiltration in soil, considered as complex porous medium, is a crucial point for estimating consequences of either heavy rain on runoff or of drought on plant water uptake. In both cases, variations in soil wettability due to amphiphilic materials is an overlooked point, but can greatly affect the infiltration and water transfer, such as water repellency in soil (1, 2, 3). A macroscopic model of the infiltration of a water drop into a porous medium is developed and applied to a soil containing amphiphilic molecules such as Exopolysaccharides (EPS) found in soil near plant roots (4). These molecules present a hydrophobic or hydrophilic property depending on the water content in soil. Experiments found in literature (5, 6) or performed in our laboratory show two main behaviors :

i) When the soil is sufficiently moist, imbibition is immediate and rapid as in hydrophilic soils.

ii) In contrast, for a dry soil, the drop does not infiltrate immediately and the subsequent imbibition is slower and depending on the soil hydrophobicity, the drop may never infiltrate. Models based on Richards Equation (7) in the soil and its variants (8, 9) can only reproduce the rapid infiltration of regime i). We propose here to derive new equations describing the hydrophilic and hydrophobic interactions both in the soil and on the soil surface in contact with the water drop to describe all water infiltration regimes. In place of a contact angle to characterize the wettability of the soil surface, we introduce a free energy term which includes attractive and repulsive interactions, derived from the modeling of drop dynamics on a substrate (10) and include the dependence of the surface wettability on the water saturation in the porous matrix (1). Concerning the soil, we recently developed a water-dependent hydrophobicity model (11) which has been extended to the case of amphiphilic molecules.

In order to reproduce to interactions between water at soil surface and in the soil volume, and to be consistent with thermodynamic principles, we show that it is necessary to add a term inside the porous matrix that depends on both the saturation and the film height at the surface. The resulting equation system is a fourth order PDE system similar to the lubrication model with wettability. To our knowledge, it is the first time that wettability, both in the soil and on the soil surface, is accounted for to represent water infiltration. The numerical simulation of developed coupled equations is in agreement with the experiments of the infiltration of a drop on a thin layer of sand containing EPS. We retrieve the dependence of the Water Drop Penetration Time (WDPT) test with the concentration of amphiphilic molecules and soil moisture. Moreover, we are able to reproduce the two regimes of the infiltration dynamics: instantaneous infiltration and progressive and slow infiltration depending on the initial water saturation of the soil.

*Intervenant