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Simulating rhizosphere structure alterations using finite element calculations

Markus Berli (1), Siul A. Ruiz (1,2), Jazmin E. Aravena (3), Lilly Bolduc (1), Teamrat A. Ghezzehei (4,5), Daniel P. Cook (2), Manoj Menon (6,7), Scott W. Tyler (6), Michael H. Young (1,8)

(1) Division of Hydrologic Sciences, Desert Research Institute, Las Vegas, NV 89119, USA, (2) Department of Mechanical Engineering, University of Nevada, Las Vegas, NV 89154, USA, (3) Department of Civil and Environmental Engineering, University of Nevada, Reno, NV 89557, USA, (4) School of Natural Sciences, University of California, Merced, CA 95343, USA, (5) Earth Science Department, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA, (6) Department of Geological Sciences and Engineering, University of Nevada, Reno, NV 89557, USA, (7) School of Earth and Environment, University of Leeds, LS2 9JT, U.K., (8) Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, Austin, TX 78712, USA

The rhizosphere is the thin layer of soil that surrounds the roots playing a critical role as an environmental interface that controls water, nutrient and solute transport from the soil to the biosphere. Despite its importance, relatively little is known about the processes of mechanical rhizosphere formation and alteration as well as its impact on rhizosphere hydraulic properties in highly structured soils as for example seed beds. In this study, we used synchrotron X-ray microtomography (XMT) and finite element calculations to explore rhizosphere alterations due to a radially expanding root and its influence on rhizosphere hydraulic properties. XMT images from beds of aggregates containing plant roots were used as templates for creating finite element meshes of structured soil surrounding the root. Rhizosphere deformation was then simulated by virtual root growth, i.e. radial expansion of a cylindrical body within a bed of elasto-plastic aggregates. For various load steps, water flow through the deformed rhizosphere to the “root” surface was calculated. Finally, XMT observed structure alterations around real roots were compared to alterations simulated by finite element calculations. Mechanical simulations show that “root” expansion within a bed of aggregates can increase inter-aggregate contact area, whereas inter-aggregate porosity decreases. Hydraulic simulations show an increase in partially saturated hydraulic conductivity of the rhizosphere with increasing inter-aggregate contact area; however, in this case saturated hydraulic conductivity decreases because of a decrease in inter-aggregate pore space. For a loose initial aggregate packing, as used in this study, inter-aggregate contact area controls partially saturated hydraulic conductivity of the rhizosphere. With increasing degree of rhizosphere compaction, however, the influence of inter-aggregate contact area on partially saturated hydraulic conductivity decreased and the hydraulic conductivity of the aggregate matrix became increasingly important. In agreement with observations from XMT images, mechanical simulations also show that root-induced rhizosphere compaction occurs primarily within a shell around the root with a shell thickness of one to two root radii. Although mechanical and hydraulic simulations are limited to 2D at this point, they provide some quantitative insight of how plant roots mechanically alter the surrounding soil and in particular its hydraulic conductivity.