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Hydration conditions affect cell-to-cell bacterial interactions in porous media

Robin Tecon, Ali Ebrahimi, Hannah Kleyer, and Dani Or

Department of Environmental Systems Science, ETH Zürich, Zürich, Switzerland (robin.tecon@usys.ethz.ch)

Intra- and interspecific bacterial cell-to-cell interactions are key to many evolutionary and ecological processes in soil environments. Interactions are controlled by factors such as bacterial density, distribution, growth, motility, and dispersal. Importantly, biophysical constraints to cell-to-cell contact are different in terrestrial habitats (e.g. unsaturated soils) compared to aquatic habitats: soil bacteria inhabit pore spaces where the aqueous phase is often fragmented and limited to thin films that may trap cells in close proximity for prolonged periods or limit access to neighbors. Improved mechanistic understanding of factors that control cell-to-cell interactions is key to quantitative modeling and predictions of microbial community functioning in soil. We hypothesized that bacterial cell level interactions are affected by soil properties and hydration status both shaping the microscale conditions experienced by cells. We have used bacterial conjugation (i.e. the transfer of a plasmid that necessitates physical contact between a donor and a recipient cell) as a measure of cell interactions within a population of the soil bacterium Pseudomonas putida. A tagging system with fluorescent proteins allowed us to visually discriminate donors and transconjugants, while the frequency of transfer events was quantified by plating on selective media. Using hydration-controlled sand microcosms, we demonstrated that the frequency of cell-to-cell contacts during 20 hours under constant conditions slightly but significantly increased when water matric potential values were lowered from -1.2 kPa to -6.5 kPa. In addition, we have developed a mechanistic and spatially-explicit individual-based model that linked the macroscopic matric potential to microscopic distribution of liquid phase and bacteria in porous media. Results of the model simulations were in good agreement with experimental data, and they permitted us to systematically investigate the link between water potential, aqueous fragmentation and cell-to-cell contact, as well as the effects of cell density. These results demonstrate how mathematical modeling and experiments in artificial porous media help us tease out basic principles of bacterial organization and activity in soil, and highlight the role of biophysical processes in unsaturated environments.