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Microbial Growth and Coexistence on Diffusion-limited Unsaturated Rough Surfaces

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Microbial activity in unsaturated soils plays an important role in biochemical nutrient cycling, bioremediation, and dispersal of pathogenic microorganisms. Quantitative description of microbial activity in unsaturated soils is hindered by complexity of pore space and hydration dynamics. Microbes in unsaturated soils live in an environment dominated by presence of numerous solid- and gas-liquid interfaces, where nutrient distribution and flux pathways are dynamically shaped by liquid configuration. We propose a model for considering effects of nutrient diffusive fluxes under various hydrations and pore space conditions on microbial growth and coexistence of two competing bacterial species. Simulation results show that hydration limitation to nutrient diffusive fluxes enhance microbial coexistence and are in good agreement with available experimental results. Effective nutrient diffusion coefficients on rough surfaces is significantly affected by liquid configuration and by connectivity (expressed as percolation probability) of the surface roughness network. The aqueous network is dynamically controlled by matric potential where effective diffusion coefficient varied from 0.46 mm^2/hr to 0 and percolation probability varied from 0.76 to 0.21 when matric potential varies from -0.01 to -5 kPa, respectively. For matric potential values of -2.0 kPa and lower, two competing microbial species coexisted indefinitely supported by limited nutrient flux and within fragmented liquid clusters with percolation probability 0.37. Coexistence was limited to 90 hrs at -1.2 kPa with increasing percolation probability to 0.52 (effective diffusion coefficient of 0.19 mm^2/hr). No coexistence was observed at matric potential of -0.01 kPa, the stronger species rapidly expanded and dominated the entire domain. Pore scale and roughness microhydrology may play an important role in the large microbial diversity found in soil.