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Hydration induced motility and diffusion constraints enhance diversity of microbial communities growing on rough surfaces

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Biodiversity serves as biological insurance for ecosystem functioning and microbial community dynamics in soils. We study effects of hydration induced motility and diffusion constraints on microbial growth, and quantify the magnitude of these influences on community dynamics at soil pore scales. We propose a Coexistence Index (C.I.) that analytically links ranges of motility, diffusion, and hydraulically connected liquid cluster sizes and defines a composite criterion for microbial species coexistence under partial saturations. The analytical C.I. index was tested using a hybrid model that combines individual based and diffusion-reaction elements and explicitly estimates effects of hydration on motility and diffusion affecting microbial growth and species interactions on rough surfaces. Hydration of soil rough surfaces defines micro-habitats for microbial life and controls nutrient diffusion, microbial growth rates and dispersal. The range of microbial motility is drastically reduced with minute changes in surface hydration and reflects a more severe constraint that concurrent changes in nutrient diffusion fluxes and connectivity of liquid filled elements. For mildly dry conditions (high values of matric potential) nutrient diffusion range is smaller than microbial motility and water cluster sizes (C.I. > 1), creating conditions for species coexistence. In contrast, coexistence is jeopardized and lost below critical threshold (C.I. < 1), in which hydration enabled diffusion range exceeding motility and connectivity ranges, confers biological advantages to competitive species, resulting in competitive exclusion. These biophysical models provide insights regarding the surprisingly narrow range of hydration conditions supporting motility and promoting coexistence of competing species, and contribute to understanding fundamental mechanisms of biodiversity maintenance in unsaturated soils.