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Rich in life but poor in data: the known knowns and known unknowns of modelling how soil biology drives soil structure

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Soil biology has a fascinating capacity to manipulate pore structure by altering or overcoming hydrological and mechanical properties of soil. Many have postulated, quite rightly, that this capacity of soil biology to 'engineer' its habitat drives its diversity, improves competitiveness and increases resilience to external stresses. A large body of observational research has quantified pore structure evolution accompanied by the growth of organisms in soil. Specific compounds that are exuded by organisms or the biological structures they create have been isolated and found to correlate well with observed changes to pore structure or soil stability.

This presentation will provide an overview of basic mechanical and hydrological properties of soil that are affected by biology, and consider missing data that are essential to model how they impact soil structure evolution. Major knowledge gaps that prevent progress will be identified and suggestions will be made of how research in this area should progress. We call for more research to gain a process based understanding of structure formation by biology, to complement observational studies of soil structure before and after imposed biological activity.

Significant advancement has already been made in modelling soil stabilisation by plant roots, by combining data on root biomechanics, root-soil interactions and soil mechanical properties. Approaches for this work were developed from earlier materials science and geotechnical engineering research, and the same ethos should be adopted to model the impacts of other biological compounds. Fungal hyphae likely reinforce soils in a similar way to plant roots, with successful biomechanical measurements of these micron diameter structures achieved with micromechanical test frames. Extending root reinforcement models to fungi would not be a straightforward exercise, however, as interparticle bonding and changes to pore water caused by fungal exudates could have a major impact on structure formation and stability. Biological exudates from fungi, bacteria or roots have been found to decrease surface tension and increase viscosity of pore water, with observed impacts to soil strength and water retention.

Modelling approaches developed in granular mechanics and geotechnical engineering could be built upon to incorporate biological transformations of hydrological and mechanical properties of soil. With new testing approaches, adapted from materials science, pore scale hydromechanical impacts from biological exudates can be quantified. The research can be complemented with model organisms with differences in biological structures (e.g. root hair mutants), exudation or other properties. Coupled with technological advances that provide 4D imaging of soil structure at relatively rapid capture rates, the potential opportunities to disentangle and model how biology drives soil structure evolution and stability are vast. By quantifying basic soil hydrological and mechanical processes that are driven by soil biology, unknown unknowns may also emerge, providing new insight into how soils function.