Mechanical feedback between a growing root and a deformable granular medium: extracting physical laws from numerical simulations

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indicator on plant community performance and soil properties to offer the soil protection and reinforcement for the slope stability.

SBEE25 – Mechanical feedback between a growing root and a deformable granular medium: extracting physical laws from numerical simulations

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Plant roots play a key role in reinforcing soils against erosion and shallow landslides through different chemical (formation of soil aggregate) and physical processes (mechanical reinforcement, water infiltration and water suction). Managing vegetated slopes on a longterm perspective to avoid soil loss necessitates understanding and quantifying the dynamics of root-soil interaction.

Soil resistance to penetration is a major component that can significantly affect root growth. The impact of soil properties on root growth has been largely studied at the root, plant and vegetation scales, mainly reducing soil properties to a single input variable representing soil impedance. However the mechanical feedback between growing roots and a deformable soil, is still largely unknown. The underlying questions are how the grains are reorganizing under the action of growing roots, and in return how the resulting forces acting on the growing root tips modify its development, including root elongation rate, root shape and ramification.

We started answering these questions in a theoretical way, developing a numerical model of root growth in a granular medium. The model is based on the discrete-element method (DEM). Single roots are modelled using chains of connected spheroline elements. The growth is initiated from a circular element placed at the free surface of a granular bed prepared by random pluviation. This circle plays the role of a meristem, which is constantly replicated at a given rate and pushed forward under the action of elastic forces, generating a line of fixed thickness equal to the diameter of the circle and with prescribed stiffness and bending moment. The orientation of the meristem at every growth step is driven by the dynamics of the whole root under the action of its internal elastic forces and reaction forces exerted by the grains. The preliminary model is two-dimensional, which not allows the pore space to be opened as in a 3D situation, consequently limiting root the penetration. To overcome this limitation, we introduce two different diameters for the grains, i.e. a “real” diameter that is considered to calculate grain-grain mechanical interactions, and a smaller “virtual” diameter to take into account root-grains interactions. The difference between the two diameters corresponds to the width of a gap at contact points through which the roots can pass. The ratio of this gap to the root diameter is considered as a model parameter.

Parametric studies showed the influence of granular structure and root mechanical properties on root trajectories. The analysis of the evolution of reaction forces exerted by grains on the root tip exhibited a broad distribution of the forces experienced by the root apex during a given growth period. This distribution has the same functional form for each root stiffness when forces are normalized by the mean force. It is characterized by a decreasing power law for forces below the mean force, and by an exponential fall-off for forces above the mean force, thus reflecting the broad distribution of forces inside the granular material.

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