MINISYMPOSIUM

PLANT MODELS (B): MODELLING LIFE IN SOIL

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Minisymposium Keywords: mathematical modelling, soil, bacteria, roots, fungi, earth worms

Plants have many unique attributes that distinguish them from other forms of life on earth. Unlike many other organisms, they rely directly on deep soil resources and this makes them immobile. To compensate, they develop strategies to explore, sense and respond rapidly to the environment and establish relationships with neighbouring biological organisms. They have rigid cell walls and tissues to allow for the growth of large mechanically stable structures and for the long distance transport of substances. But they also establish local relationships with close soil organisms to capture water and nutrient and survive in the most diverse environments. The beauty and diversity of plant growth and forms has stimulated the development of new approaches to describe and model plant systems and their environment.

The objective of this symposium is to showcase recent theories and tools to describe the physics of plant growth and their interactions with the soil environment. The symposium will have two part. The first part will focus on the development of forms and structures (Plant Models A - Plant development). The second part will focus on biological models in soil (Plant Models B - Modelling life in soil).

Invited speakers of this minisymposium are: Dani Or (Swiss Federal Institute of Technology Zurich ETH, Switzerland), Andrea Schnepf (Forschungszentrum Jülich, Germany), Matteo Ciantia (University of Dundee, UK), Siul Ruiz (Swiss Federal Institute of Technology Zurich ETH, Switzerland), Lionel Dupuy (the James Hutton Institute Dundee, UK)

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MICROBIAL LIFE IN SOIL AGGREGATES – FROM HOTSPOTS TO SOIL BIOGEOCHEMICAL FLUXES

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Joint work with Robin Tecon, Hannah Kleyer, Benedict Bore

Keywords: Soil, Bacteria, Pore network, Self organisation.

The highly dynamic and often fragmented aquatic habitats of unsaturated soil impose constraints on dispersion (rates and spatial extent) of microbial cells. The persistent state of spatial isolation, punctured by infrequent and short-lived wetting events, promotes spatial diversity yet it forces intense interactions among spatially confined microbial species. To gain quantitative insights into these interactions, we developed an individual based mechanistic modeling framework that represents key biophysical processes within physical domains mimicking unsaturated soil to study factors that shape interactions among multispecies microbial communities. Results illustrate interplay of trophic dependencies and cell-level interactions in patchy diffusion fields that give rise to collective spatial self-organization. We illustrate these interactions considering microbial processes within 3D pore networks (soil aggregates and other "hot spots") where hydration conditions affect gas diffusion and thus the sizes and spatial arrangement of aerobic and anaerobic bacterial communities responsible for important biogeochemical soil functions. Experiments based on direct observations of tagged aerobic and anaerobic bacteria in glass-etched pore networks under oxygen and carbon cross-gradients confirm salient features of such important hot spots. We will present column experiments using soil aggregates of prescribed sizes and carbon architecture and the resulting soil greenhouse gases produced under different hydration conditions. A new modeling strategy for upscaling biogeochemcially-produced GHG fluxes from the single aggregate, to populations of aggregates in soil profiles and landscapes composed of different soil types and biomes will be presented

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A SPH MODEL FOR GROWTH OF PLANT ROOTS

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Keywords: Plant root growth, Smoothed Particle Hydrodynamics method, Plant cell dynamics.

The root system stores and transports water and nutrients in a plant, essential for plant growth and development. However, the in situ observation of the structure of plant roots and their interactions with soil is extremely limited by the opaque nature of the soil and an easy experimental monitoring of the growth processes in the soil is often not possible (e.g. [1]). Mathematical modelling allows us to reconstruct the information about growth processes and to visualize and predict the behaviour of plant roots. In this work, we propose a model for a plant root growth using the Smoothed Particle Hydrodynamics method (SPH). We identify the cellular elongation and division as principal drivers of the root growth. The framework of visco-poroelasticity is considered to incorporate the porous nature of a plant root tissue and the dynamics of nutrient concentrations. The turgor pressure and the cell division depend on the distribution of nutrients in a plant tissue and division is localized at the tip of the root, corresponding to the region of the plant root meristem. Once divided, the cells are moving away from the meristem and growth is dominated by elongation. Using the similarity of the SPH particles with the root cells, the SPH model allows us to incorporate the cell-to-cell interactions and dynamics in a plant root.

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MECHANICAL AND BIOPHYSICAL CONSTRAINTS AFFECTING SOIL BIOTURBATION BY EARTHWORMS AND PLANT ROOTS

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Joint work with Dani Or

Keywords: Earthworms, Root, Soil, Mechanics, Biophysics.

Earthworms and decaying plant roots form networks of soil biopores that affect soil hydrological and ecological functioning. We developed quantitative platform for modeling the mechanical stresses and energetic costs of burrowing into soil that consider different rates (200 and 0.2 μms^{-1}) and limiting pressures (200 kPa and 1 MPa) for earthworms and plant roots respectively. These biophysical differences impose strict windows of activity defined by soil mechanical properties that are linked to hydration status. Our modeling results delineate activity windows and energetic costs defined by regional climatic conditions where earthworm burrowing becomes mechanically prohibitive while root growth remain unaffected. We discuss ecological ramifications of such constraints under present and future climatic scenarios and NPP on soil structure generation, carbon consumption, and subterranean biophysical activity

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THE RANDOM WALKS OF ROOTS IN A GRANULAR MEDIA

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Keywords: Root, Granular media, Particle interaction, Mechanics, Biophysics.

Root growth through soil is challenging, yet trees are known to overcome the resistance from soils at depth exceeding 15 meters. This study investigates the factors limiting growth under high levels of mechanical resistance from a granular medium. We developed experimental system to capture root growth and particle forces perceived by plants. We extract descriptions of growth trajectories at high resolution and developed new signal processing tools to mine for patterns in growth trajectories. Finally, we propose a stochastic mechanics theory, termed T-SWITCH, to analyse root responses to interactions with the surrounding set of particles. Results show roots grow through a finite set of viscoelastic micro-deflections of the tip but helical patterns are conserved at all levels of soil pressure. This study reveals fundamental mechanisms of root development in soil that could be used to promote storage of deep soil carbon, increase nutrient use efficiency and drought resistance of crops.

References

[1] A.L. Smit, A.G. Bengough, C. Engels, M. van Noordwijk, S. Pellerin, S.C. van de Geijn. (2013). *Root methods: a Handbook*, Springer Science & Business Media.