Sorbonne Université/ China Scholarship Council program 2020

Thesis proposal

Title of the research project: **Structure of granular media and their effect on root growth**

Keywords: **Root growth, granular, mechanics, hydrogels**

Joint supervision: **yes (Lionel DUPUY)**

Joint PhD (cotutelle): **yes (IKERBASQUE & Neiker, Espagne)**

Thesis supervisor: **Evelyne Kolb**.

Email address of the thesis supervisor: evelyne.kolb@upmc.fr

Institution: Sorbonne Université

Doctoral school (N°+name): ED 564 Physique en Ile de France (EDPIF)

Research laboratory: PMMH (Physique et Mécanique des Milieux Hétérogènes), UMR7636

Address of the laboratory: Campus Sciences SORBONNE UNIVERSITE

Barre Cassan - Batiment A- 1er Etage

Case 18

7 Quai Saint Bernard

75005 Paris

Name of the laboratory director: Damien VANDEMBROUCQ

Email address of the laboratory director: damien.vandembroucq@espci.fr

Subject description (2 pages max):

1) Study context

Crop growth and food production rely heavily on processes taking place at the level of roots within the soil. A plant must acquire nutrients to develop and produce grains or tubers. Photosynthetic activity and production of carbohydrates depend heavily of the efficiency with which water is acquired from the soil (Daly et al., 2004). Finally, the mechanical resistance and physical properties of soils are known to affect growth (Kolb et al., 2017; Martins et al., 2019) and even contribute to the taste of products.

Knowledge on how soil heterogeneity controls many of these processes could drastically enhance our ability to optimise agricultural processes and crop production (Adamchuk et al., 2010). For example, intelligent ploughing could be developed to control aggregate size distribution for better crop establishment. Indoor farming could also rely on artificial media with optimised resistance to penetration. Unfortunately, current knowledge that could help address these questions is limited. Natural soils are difficult to visualize and control during a plant growth experiment (Zhu et al., 2006). Use of heavy techniques such as X-rays tomography combined with neutron tomography could depict successfully the inner physical structure of the wet granular soils (Zarebanadkouki et al., 2013;Kim et al., 2013), but until now they have failed to provide understanding of the biophysical process of growth. Finally, the physical structure of natural soil is so heterogeneous (Cattle et al., 1994) and stochastic, that to date, framework for optimisation of its physical properties has proved to be limited.

The objective of this study is to develop understanding of what physical properties of granular media can affect the development of the root system, for example the elongation rate, the tortuosity of growth trajectory, the thickening of the root diameter. To achieve this objective, the project will combine approaches derived from granular material physics and plant biology.

2) Details of the proposal

In a first step, the project will focus on the development of a model system for the study of root growth in an artificial substrate made of a controlled granular material (Downie et al., 2012; Verneuil and Durian, 2011). The objective of the model system is to provide a substrate for plant growth with the ability to control 4 of the main properties of granular materials, namely, (i) the size of the particles, (ii) the size distribution (polydispersity), (iii) the aspect ratio of the particle, and (iv) the packing fraction. The granular materials will be made of hard or soft particles which will be imaged by refractive index (RI) matching solution and tomographic 3D reconstruction. Hard grain systems will be made of thermoplastics, e.g. acrylic or PVC with refractive index matching liquid based on mineral oil, glycerol, or solutions of sugars. Deformable grain systems will be made of alginate hydrogels with water based RI matching solutions. The completed model system will be comprised of (i) fabrication approaches for the production of materials in sufficient volume (to grow plant in a few replicates) and with a range of structural properties; (ii) systems for data acquisition on the morphology and growth properties of the root; (iii) systems for the control of the environment sustaining healthy growth in the system.

In the second step, the project will focus on characterization of plant growth in a range of conditions. The objective is to understand how the structural characteristics of the media affect root growth properties and total biomass production. For example, can a given soil structure reduce resistance to penetration? The student will employ techniques such as live imaging (Downie et al., 2012; Yang et al., 2013) and growth kinematic (Basu et al., 2007) analyses to characterize the growth of the plant, the geometry of root trajectories, the magnitude and deflections of the root. Characterization of growth properties will be complemented with mechanical characterization of the substrate through for example shear tests and flexible penetrometer tests. Relationships will then be established between the nature of growth trajectories and the granular structure of the materials.

Finally the last part of the project will focus on utilizing the knowledge acquired in experiments to establish the principles that govern the response of roots to the mechanical and structural properties of the granular media. The student will propose mathematical models to describe the nature of the response of the root to soil particles, taking into account the mechanical properties of the root and those of the soil particles. For example, the student could exploit approaches recently developed in the laboratory considering minimization of mechanical energy induced by growth considering the statistical distribution of particle forces in a granular medium.

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3) References

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4) Profile of the Applicant (skills/diploma…)

The candidate must have a Master degree in biological or physical sciences. Ideally, the candidate should have experience of working with plants and granular materials. The candidate must demonstrate a basic knowledge of mathematics or computational techniques, for example the use of modeling or image analysis tools.

Contacts:

Thesis supervisor

Evelyne KOLB

Email address of the thesis supervisor: evelyne.kolb@upmc.fr