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► **To cite this version:**

Mahmoud Fakh, Jean-Yves Delenne, Farhang Radjai, Thierry Fourcaud. Analysis of the mechanical interaction between a growing root and a granular substrate using the Discrete Element Method. Plant Biomechanics International Conference PBM8, Nov 2015, Nagoya, Japan. 2015. hal-01837330

**HAL Id: hal-01837330**

**<https://hal.science/hal-01837330>**

Submitted on 3 Jun 2020

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# **Analysis of the mechanical interaction between a growing root and a granular substrate using the Discrete Element Method**

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## **Introduction**

Among numerous factors that explain the variability of root architecture, including genetics, environment and developmental instability (Forde, 2009), the mechanical interaction between growing roots and the soil substrate has often been under-estimated. We hypothesize that the heterogeneous structure of soil at the particle scale, evidenced by the broad distribution of forces, can significantly influence root growth trajectories and its ramification system. We use discrete-element numerical simulations to investigate, as a first step, the growth of a single root inside a granular material.

## **Objectives**

The objectives are 1) to understand and quantify root-soil mechanical interactions at both the grain and plant scales, and 2) to develop a general biophysical law of root-soil interactions that can be used in Functional Structural Plant Models (FSPM) (Fourcaud et al., 2008).

## **Numerical Modeling**

For this purpose we developed a numerical model of root-soil system based on the Discrete Element Method (DEM) (Radjai & Dubois, 2011). This approach is suited for the investigation of the effect of soil disorder on root variability at the particle scale. The simulations allow us to characterize the reorganization of grains under the action of a growing root. By return, the forces experienced by the root during its growth can be estimated numerically. These interactions are analysed using methods and tools provided by the physics of granular media.

The root is 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 meristem, which is constantly replicated at a given rate and pushed forward under the action of elastic forces. As a result, the root grows as 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 determined by the dynamics of the whole root under the action of its internal elastic forces and reaction forces exerted by the grains. Since the model is two-dimensional and the pore space is not open, we use two different diameters for the particles: a large diameter for the interactions between particles and a smaller diameter for the interactions between particles and root. The difference between the two diameters corresponds to the width of a gap at contact points through which the roots can pass. The ratio  $r$  of this gap to the root diameter is an essential model parameter.

## **Parametric Study**

Several parameters being involved in the mechanical behaviour of the root-grains system, we first carried out a parametric study of their influence on forces at the root tip and the overall root trajectories. The major parameters affecting root trajectories and reaction forces were identified to be the root stiffness and gap ratio  $r$ , as discussed above. Our first results exhibit 3 different growth regimes:  $r \ll 1$ ,  $r \sim 1$  and  $r \gg 1$ . By analysing the evolution of reaction forces

exerted by grains on the root tip, we find that for all regimes, the mean force during the growth increases with root stiffness as a power law. For all values of root stiffness tested in each regime, we find a broad distribution of the forces experienced by the root apex. The distribution has the same functional form when the forces are normalized by the mean force for each stiffness. It is characterized by a decreasing power law for forces below the mean and an exponential fall-off for forces above the mean. This distribution seems thus to reflect the broad distribution of forces inside the granular material. It is also interesting to note that, since the forces scale with the mean force, the standard deviation of forces also scales with the mean force.

### Perspective

The modelling approach developed in this work will be applied to characterize the shape of the roots and the influence of soil properties, such as size polydispersity and cohesion between grains, on their development. The numerical results will be compared to experimental data from the Rhizoscope genotypic platform developed at CIRAD, which allow observing real plant roots growing in ballotini (Ahmadi et al., 2014).

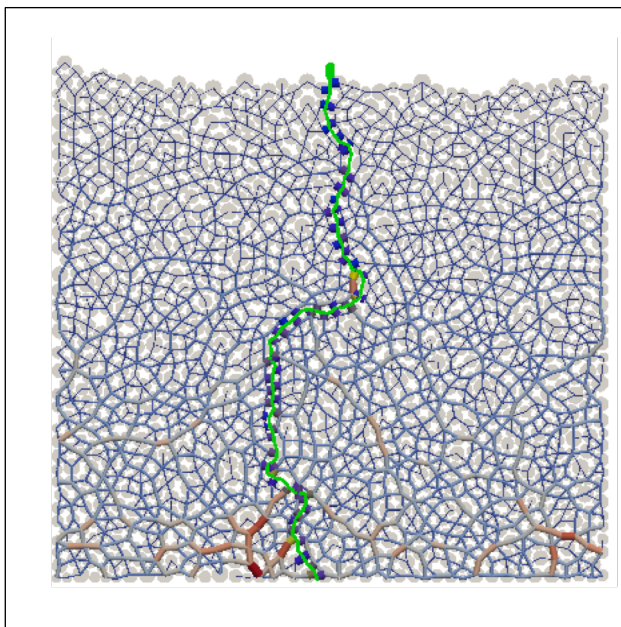


Fig. 1 : DEM simulation of root growth and a map of force chains in the granular bed.

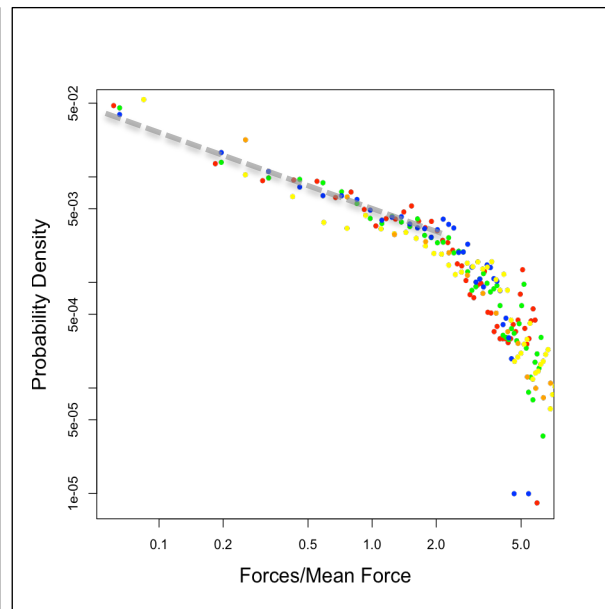


Fig. 2 :Probability density function of forces for several root trajectories

### Acknowledgement

This project is supported by Agropolis Fondation under the reference ID 1202-073 through the “Investissements d’avenir” program (Labex Agro: ANR-10-LABX-001-01).

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