Plant roots growing against or around mechanical obstacles

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Mechanical stresses on growing roots in soils

- In homogeneous soils, it is observed:
  - root growth velocity decays
  - stops when the « soil mechanical impedance » is too high

- In heterogeneous soils?

Main objective of our work: characterize the mechanical and biological responses of a root facing mechanical obstacles (or complementary pores) in simplified experimental substrates.
Simplified root/soil interaction

Case $d_R \sim d_G$ with non-cohesive grains
Coupling between root and soil
(reorganisable granular material)

Axial stress

Radial stress ($2D$)

Repeated stresses
(assembly of fixed obstacles)

Radial stress ($3D$)

Kolb, Legué, Bogeat-Triboulot
Phys. Biol. 2017
Growing root in a single pore

Seed: Chick-pea (*Cicer Arietinum* L.)
- pivot roots of millimetric size
  → simple root system with a large root diameter.
- gravitropic
- big seed with enough nutrients
  → not necessary to add nutrients to the water during growth

2D gap (between photoelastic disks)

3D gap (inside tube)

→ Lateral stress 2D ~ Turgor pressure
\[<\sigma> = 0.30 \pm 0.15 \text{ MPa}\]

Kolb, Hartmann, Genet, *Plant Soil* 2012
Root’s mechanics

→ Need of the mechanical characterization of a root in compression
→ What is usually described in articles:

\[ E_{\text{Root}} \propto d_{\text{Root}}^{-\gamma} \]

→ Our measurements: Cycles of compression tests in air separated by waiting times

Initially thinner roots have faster drying process and rigifify faster
**Root facing a single obstacle**

**Problematics**: What limits growth in heterogeneous soils with pore sizes of length \( \ell \) ?

Straight growth limited either by
- « Maximum growth pressure » of the root (growth arrest)
  \[ \sigma_{\text{Max}} \sim P \]
- or by Buckling stress
  \[ \sigma_B \sim \frac{F_B}{d^2} \sim \frac{E l}{d^2 d^2} \sim E \left( \frac{d}{l} \right)^2 \]
  \( F_B \) = buckling force for a root of diameter \( d \) and of non-supported length \( l \)
  \( I = \text{quadratic moment} \quad I \sim d^4 \)

\[ \sigma_{\text{Max}} \sim \sigma_B \text{ for } l_C \sim \sqrt{\frac{E}{P}} d \sim \sqrt{10} d \sim 3d \]

**Question**: What happens when a root pushes an obstacle of given rigidity?

**Scenario 1**: The root pushes the obstacle of given rigidity without bending
Characterization of the biological response visible at first at the macroscopic scale
- sudden arrest of growth during a transient before the root resumes its growth?
- localized diameter increase?
- what is the rate of force increase depending on the obstacle rigidity?
- what is the maximum pushing force?

**Scenario 2**: Reorientation of the root growth
  → Mechanical reorientation due to buckling or bending and sliding?
  → Biological reorientation due to differential growth
  → Mixed effects?

For \( d=1 \text{ mm}, l_C \sim 3 \text{ mm} (\text{critical pore size}) \)
\( l < l_C \) possibility of growth arrest
\( l > l_C \) possibility of buckling and reorientation of the growth axis

**Axial force**
Root’s pushing force measurement

Experimental setup

→ Time lapse imaging over 1 day or more

With different root tip’s boundary conditions

→ Evolution of pushing force with time

\[ \sigma_{\text{max}} = 0.16 \, \text{MPa} \approx \text{Turgor pressure} \]

Taini Chitimbo, Manon Quiros
Root growth in an array of inclined rectangular plates

Dexter, Hewitt,

- Competition
  - thigmotropism/
    - gravitropism?

- Roles of obstacles?
  - packing and density of obstacles
  - form
  - roughness
  - rigidity?

Institut pour le développement Forestier (Nancy)
Perspectives

• Measurement of maximal axial forces exerted by the root for a variation of the anchorage conditions, lateral confinement (tube, gel, plaster ...) and free length of the root
  (see talk from V. Legué, PIAF, Université Clermont-Auvergne)

• Retroaction on the sensor’s position to impose a constant force on the root for a given time

• Coupling with kinematic tracking by infrared imaging to identify the elongation zone
  (see talk from M.B. Bogeat-Triboulot, INRA de Nancy)

• Variation of the rigidity of the force captor
  Measurement of the force thanks to the deflexion of a membrane
  (collaboration with L. Dupuy, the James Hutton Institute, Scotland)
Perspective

- Control parameters
  - Obstacle geometry (shape, length, spacing between obstacles)
  - Obstacle mechanics (roughness, rigidity)

- Monitoring of the growth and the architecture of the root system
- Decoupling of mechanical and biological elementary processes of reorientation of the root tip
- Implementation of our results in numerical simulations in order to get more realistic behaviors of a root growing in a granular soil (see talk of F. Radjaï, LMGC Montpellier)

Fakih et al., PRE, 2019
From Daniel BERNARD

Inspired by roots moving around obstacles

IG: DanielBernardDCB (@dcbdraw)
GDR PhyP
(« Physics of Plants »)

Next meeting: interdisciplinary WORKSHOP
Biophysics of root-soil interaction
November 18-19, 2019, Clermont-Ferrand


INSCRIPTION BEFORE OCTOBER 25, 2019.

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