Plant roots growing against or around mechanical obstacles

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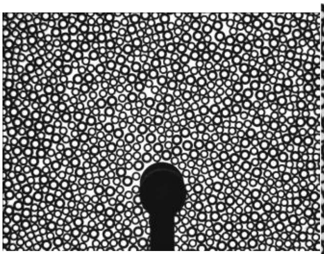
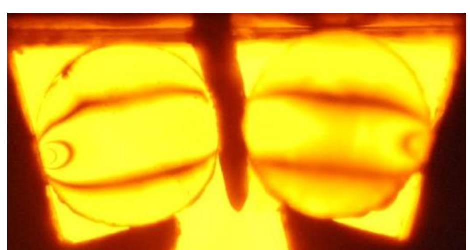
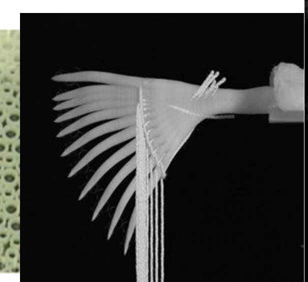
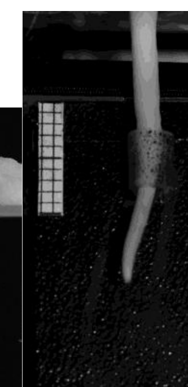
V. Legué (PIAF, Clermont)
L. Dupuy (James Hutton Institute)
Jonathan Barès (S. Mora, LMGC, Montpellier)



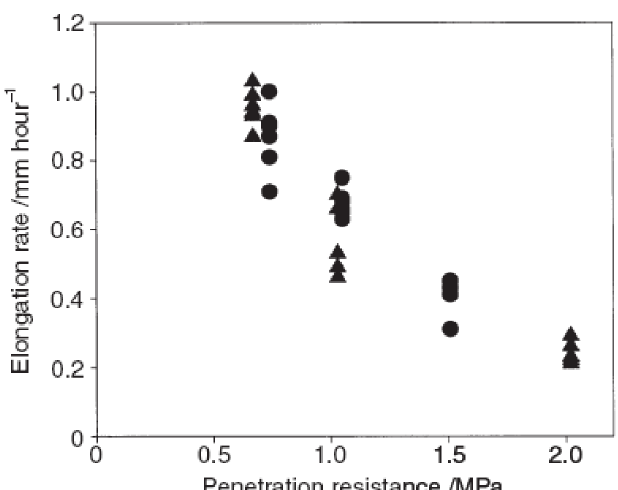


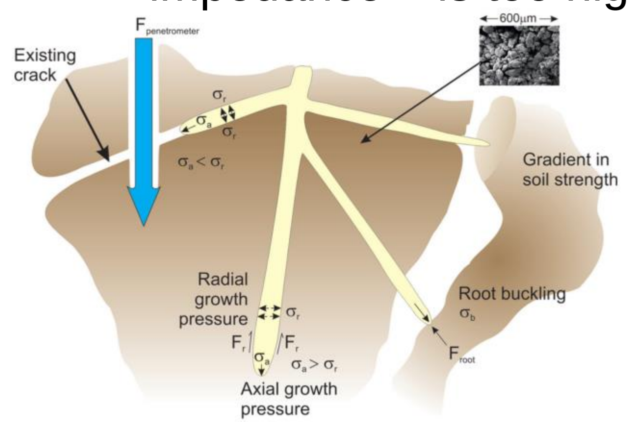
Mechanical stresses on growing roots in soils

After ARS- USDA,Soil and Water Cons. Div.

- In homogeneous soils, it is observed :



- root growth velocity decays
- stops when the « soil mechanical impedance » is too high



Jin et al. J.Exp.Botany 2013

- In heterogeneous soils ?

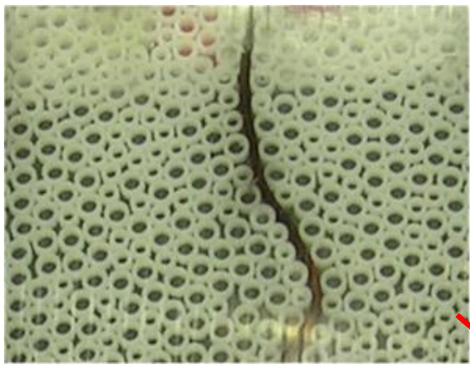
Main objective of our work: characterize the mechanical and biological responses of a root facing mechanical obstacles (or complementary pores) in simplified experimental substrates

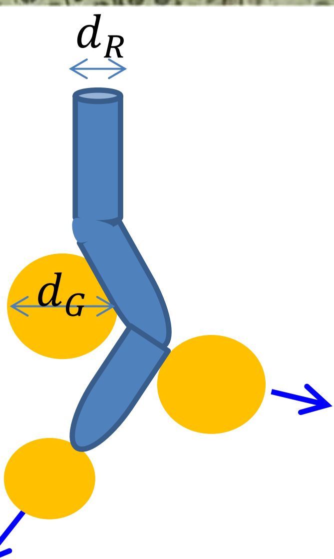
Simplified root/soil interaction

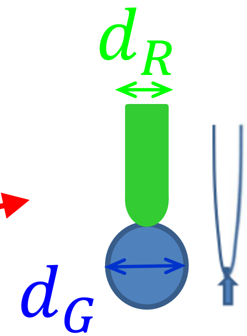
Case $d_R \sim d_G$ with non-cohesive grains

Coupling between root and soil

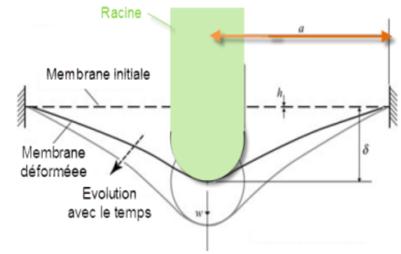
(reorganisable granular material)

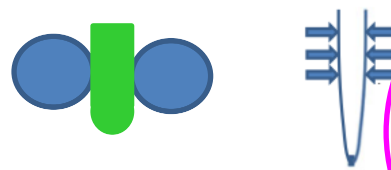




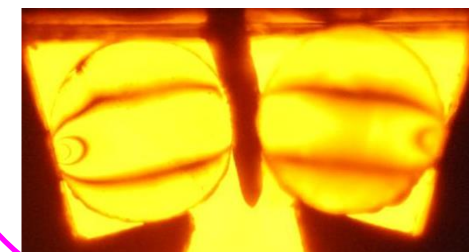


Axial stress

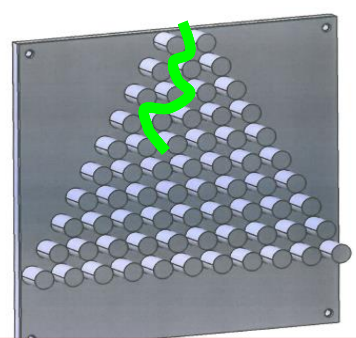




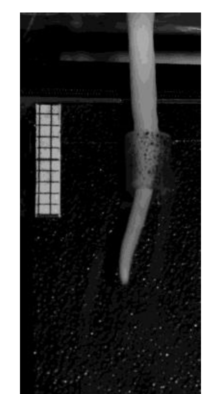
Radial stress (2D)



Repeated stresses
(assembly of fixed obstacles)



Radial stress (3D)

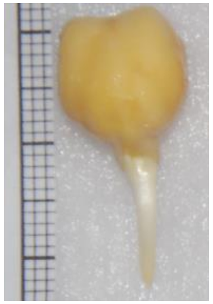


Kolb, Legué, Bogeat-Triboulot
Phys.Biol. 2017

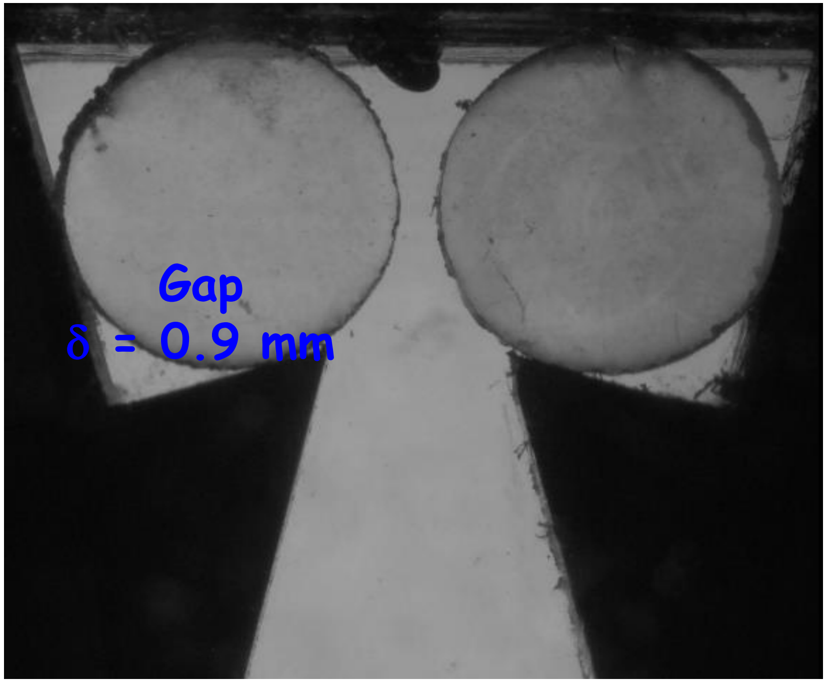
Growing root in a single pore

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**

$<\sigma> = 0.30 \pm 0.15$ MPa

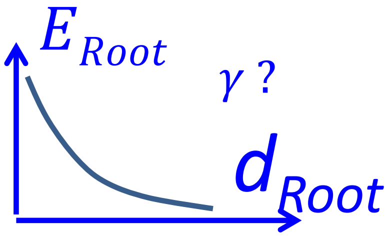
Kolb, Hartmann, Genet, ***Plant Soil 2012***

Root's mechanics

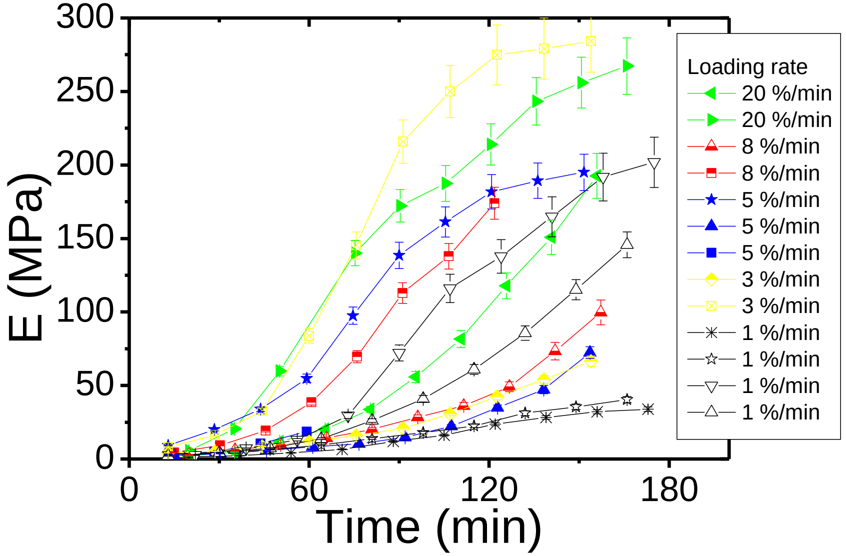
→ Need of the mechanical characterization of a root in compression

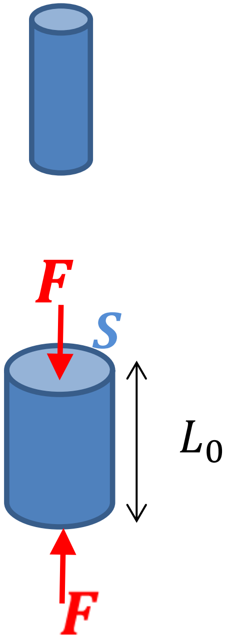
→ What is usually described in articles:

$$E_{Root} \propto d_{Root}^{\;-\gamma}$$



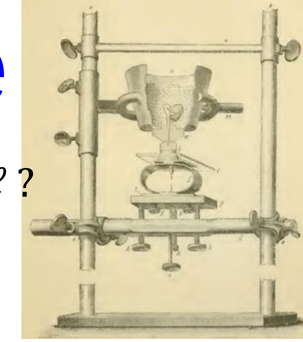
→ Our measurements: Cycles of compression tests in air separated by waiting times





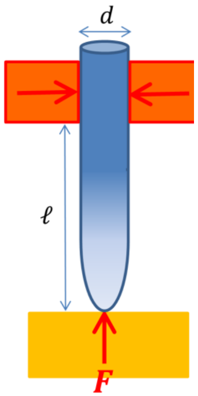
Initially thinner roots have faster drying process and rigigify faster

Root facing a single obstacle



Pfeffer, 1893

Problematics : What limits growth in heterogeneous soils with pore sizes of length ℓ ?



Straight growth limited either by

- « Maximum growth pressure » of the root (growth arrest)

$$\sigma_{Max} \sim P$$

- or by Buckling stress

$$\sigma_B \sim \frac{F_B}{d^2} \sim \frac{EI}{\ell^2 d^2} \sim E\left(\frac{d}{\ell}\right)^2$$

F_B= buckling force for a root of diameter d
and of non-supported length ℓ

I = quadratic moment $I \sim d^4$

$$\sigma_{Max} \sim \sigma_B \text{ for } \ell_C \sim \sqrt{\frac{E}{P}}\, d \sim \sqrt{10}\, d \sim 3d$$

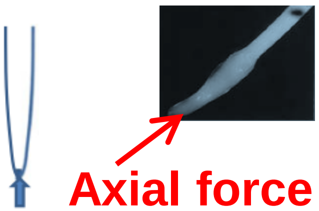
For d=1 mm, $\ell_C \sim$ 3 mm (critical pore size)
$\ell < \ell_C$ possibility of growth arrest
$\ell > \ell_C$ possibility of buckling
and reorientation of the growth axis

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

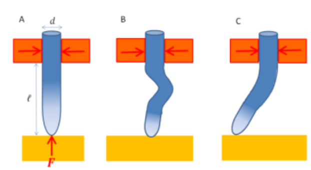
- sudden arrest of growth during a transient before the root resumes its growth?
- localized diameter increase ?
- what is the rate of force increase depending on the obstacle rigidity?
- what is the maximum pushing force ?



Kuzeja, J. Plant Physiol., 2001

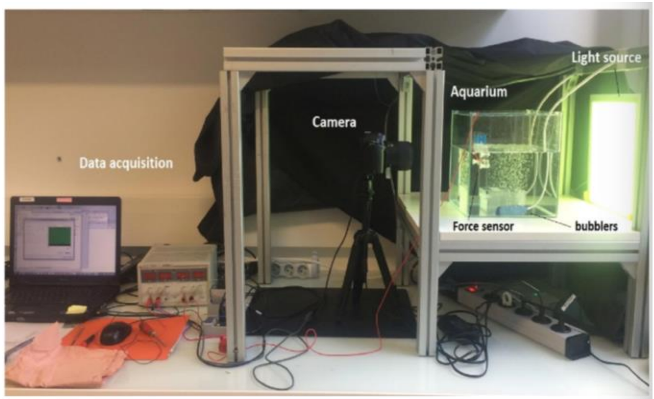
Scenario 2: Reorientation of the root growth

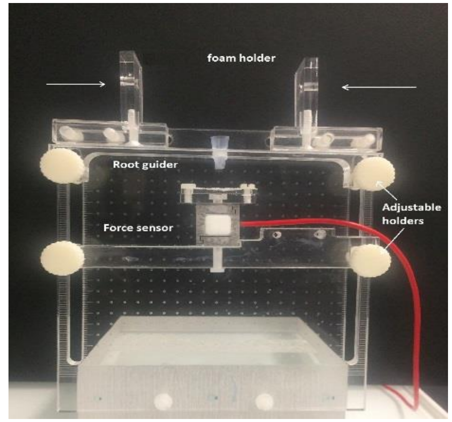
→ Mechanical reorientation due to buckling or bending and sliding ?
→ Biological reorientation due to differential growth
→ Mixed effects ?

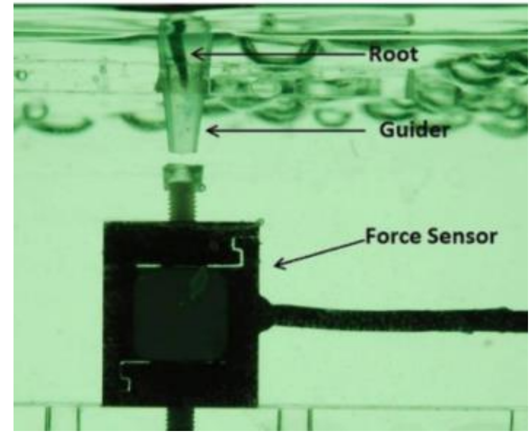


Root’s pushing force measurement

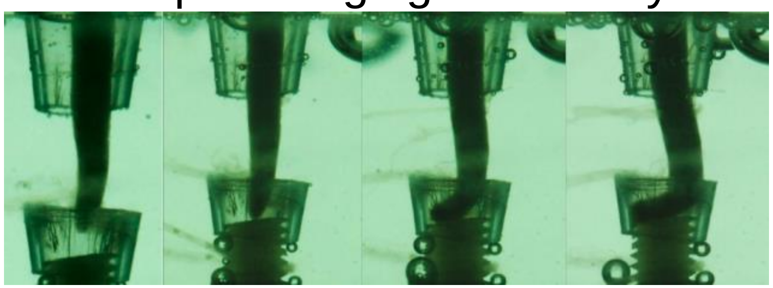
Experimental setup



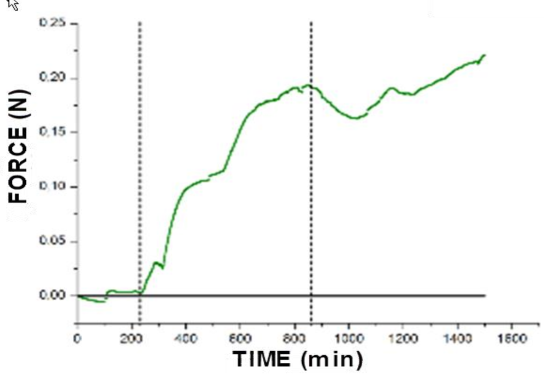




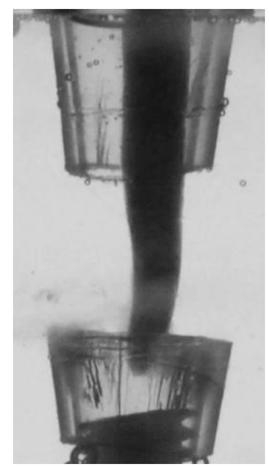
→ Time lapse imaging over 1 day or more

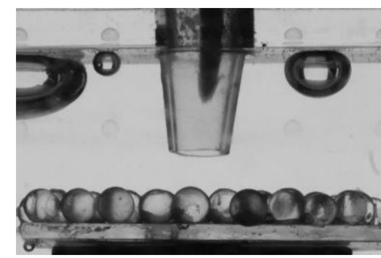


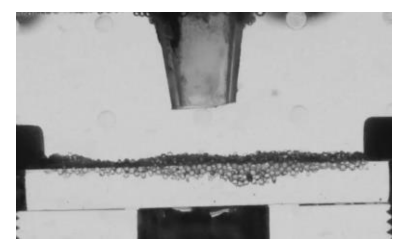
→ Evolution of pushing force with time



With different root tip’s boundary conditions



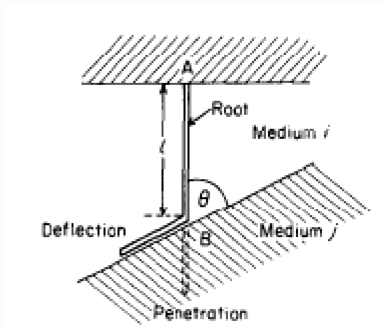




σ_{max} = 0.16 MPa
≈ Turgor pressure

Taini Chitimbo, Manon Quiros

Root growth in an array of inclined rectangular plates

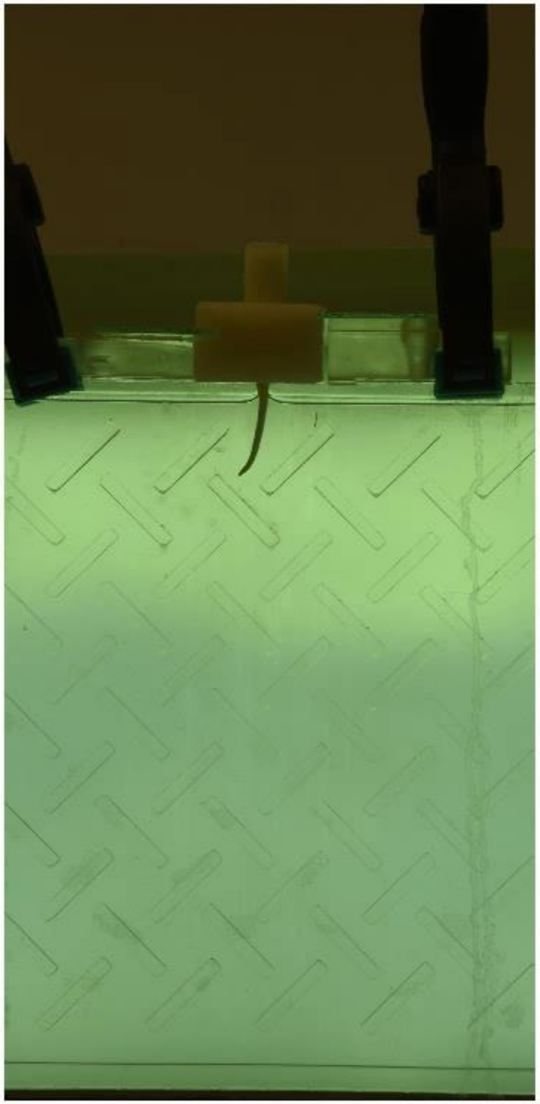


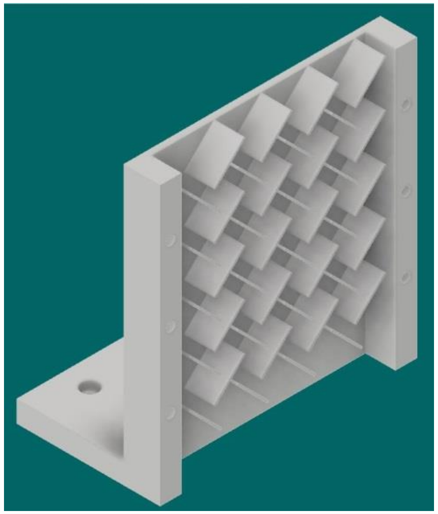
Dexter, Hewitt,
J. Agr. Engng Res 1978

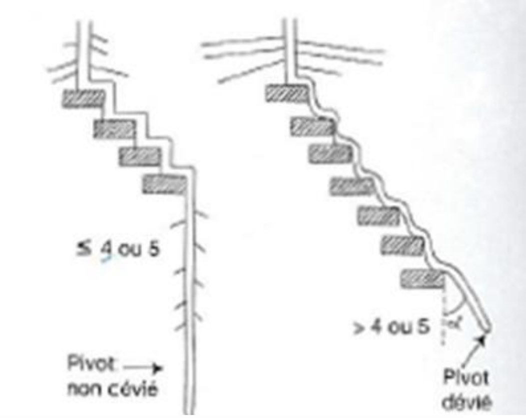
-Competition
thigmotropism/
gravitropism ?

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

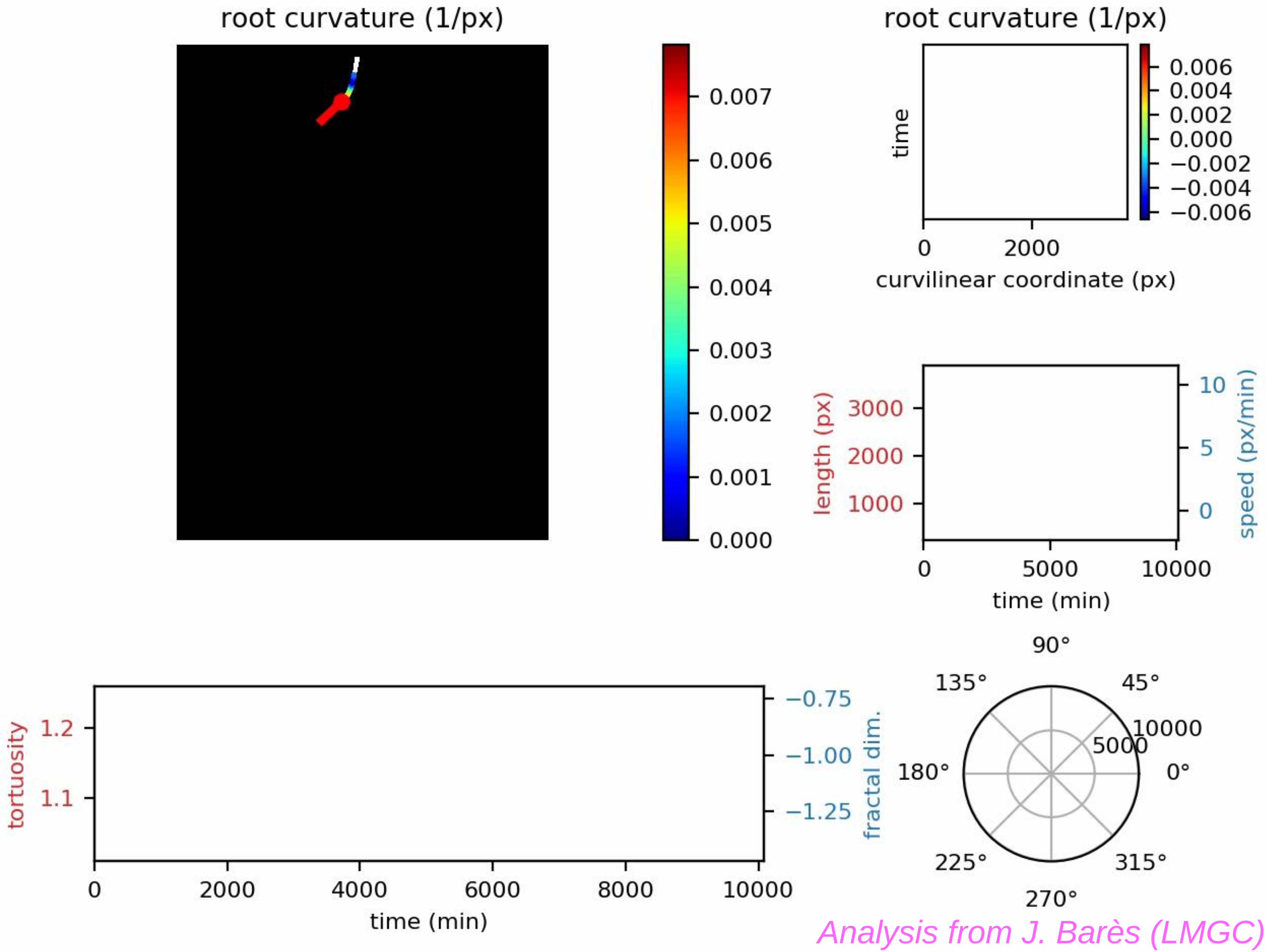
00days 00hours







Institut
pour le développement Forestier (Nancy)

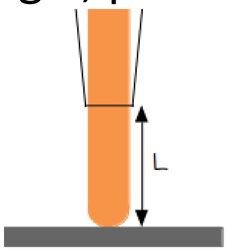

root curvature (1/px)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
root curvature (1/px)
time
0
2000
curvilinear coordinate (px)
0.006
0.004
0.002
0.000
−0.002
−0.004
−0.006
length (px)
3000
2000
1000
10
5
0
speed (px/min)
0
5000
10000
time (min)
tortuosity
1.2
1.1
−0.75
−1.00
−1.25
fractal dim.
0
2000
4000
6000
8000
10000
time (min)
90°
135°
45°
180°
0°
225°
315°
270°
5000
10000
Analysis from J. Barès (LMGC)

Perspectives

- Measurement of maximal axial forces exerted by the root

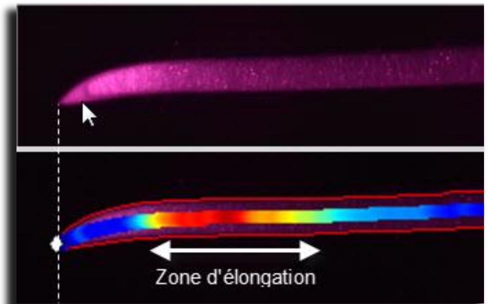
for a variation of the anchorage conditions, lateral confinement (tube, gel, plaster …) and free length of the root

(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

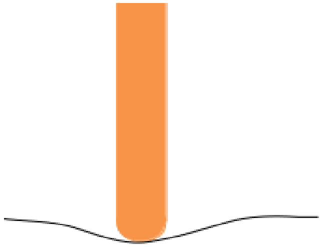
to identify the elongation zone

(see talk from M.B. Bogeat-Triboulot, INRA de Nancy)

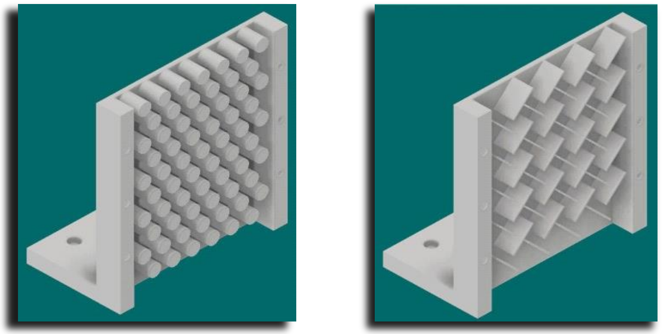
- Variation of the rigidity of the force captor

↳ Measurement of the force thanks to the deflexion of a membrane

(collaboration with L. Dupuy, the James Hutton Institute, Scotland)



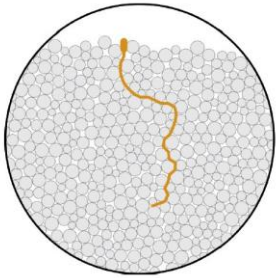
Perspective



- Control parameters

↳ Obstacle geometry (shape, length, spacing between obstacles)

↳ Obstacle mechanics (roughness, rigidity)

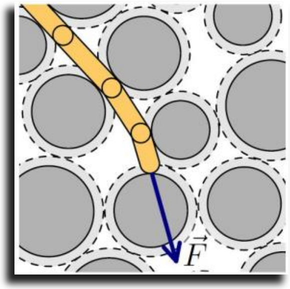


➪ Monitoring of the growth and the architecture of the root system

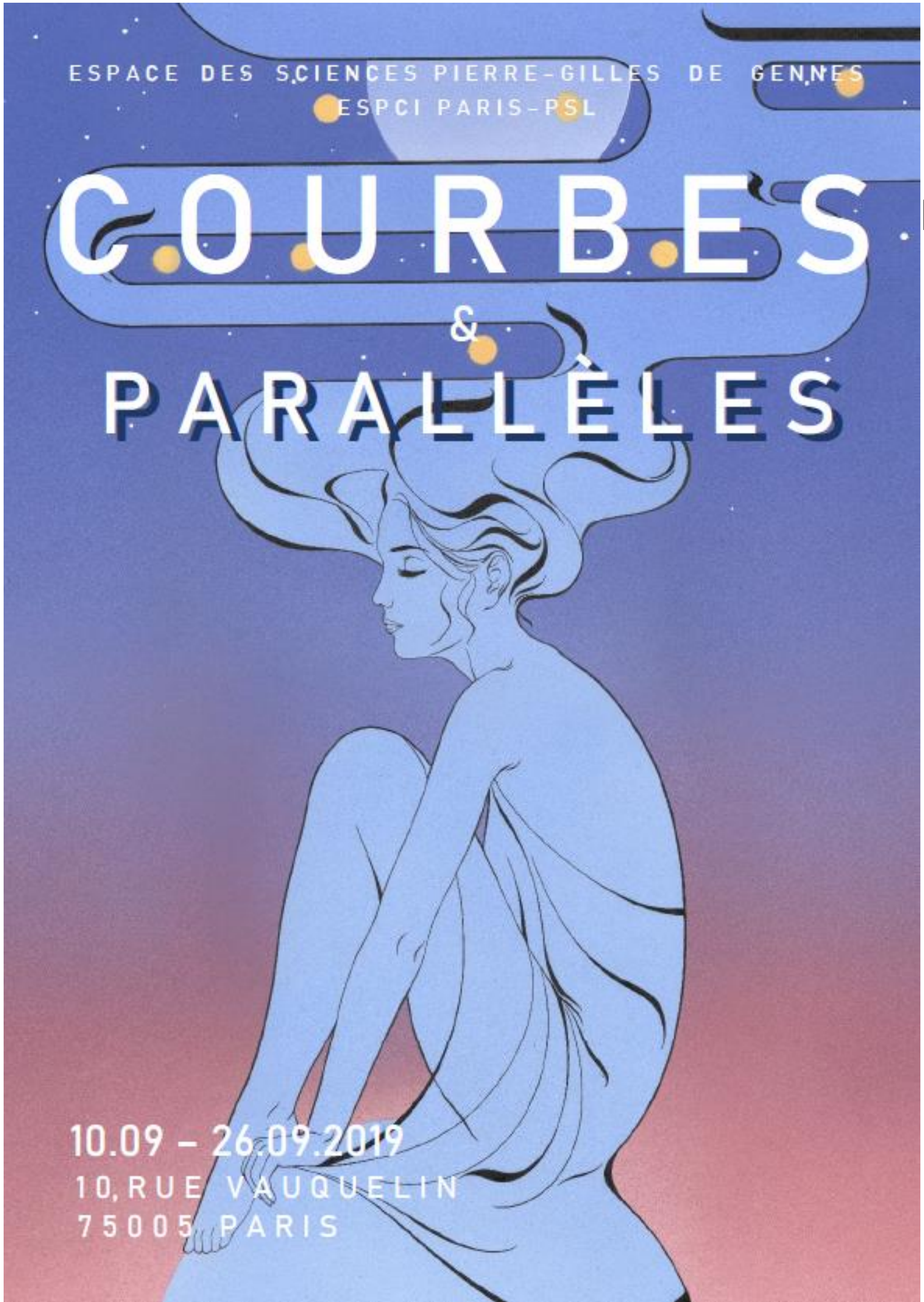
➪ Decoupling of mechanical and biological elementary processes of reorientation of the root tip

➪ 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)



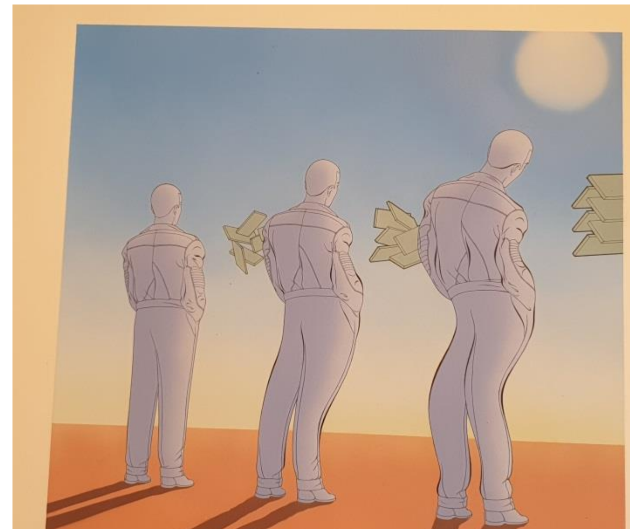
Fakih et al;, PRE, 2019



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

https://gdrphyp.wordpress.com/2019/07/13/workshop-biophysique-de-linteraction-racine-sol-18-19-nov-2019-clermont-ferrand/

INSCRIPTION BEFORE OCTOBER 25, 2019.

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