SOIL-ROOT INTERACTIONS

LBRES2106

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ABOUT THE COURSE

- Course **material** is online:
  - 🔗 http://bit.ly/LBRES2106
- Collaborative **summary**
  - everybody can take notes in a Google Doc
  - I will correct the summary after each course
  - 🔗 http://bit.ly/LBRES2106-summary
- Course **evaluation**:
  - 🔗 http://bit.ly/LBRES2106-eval

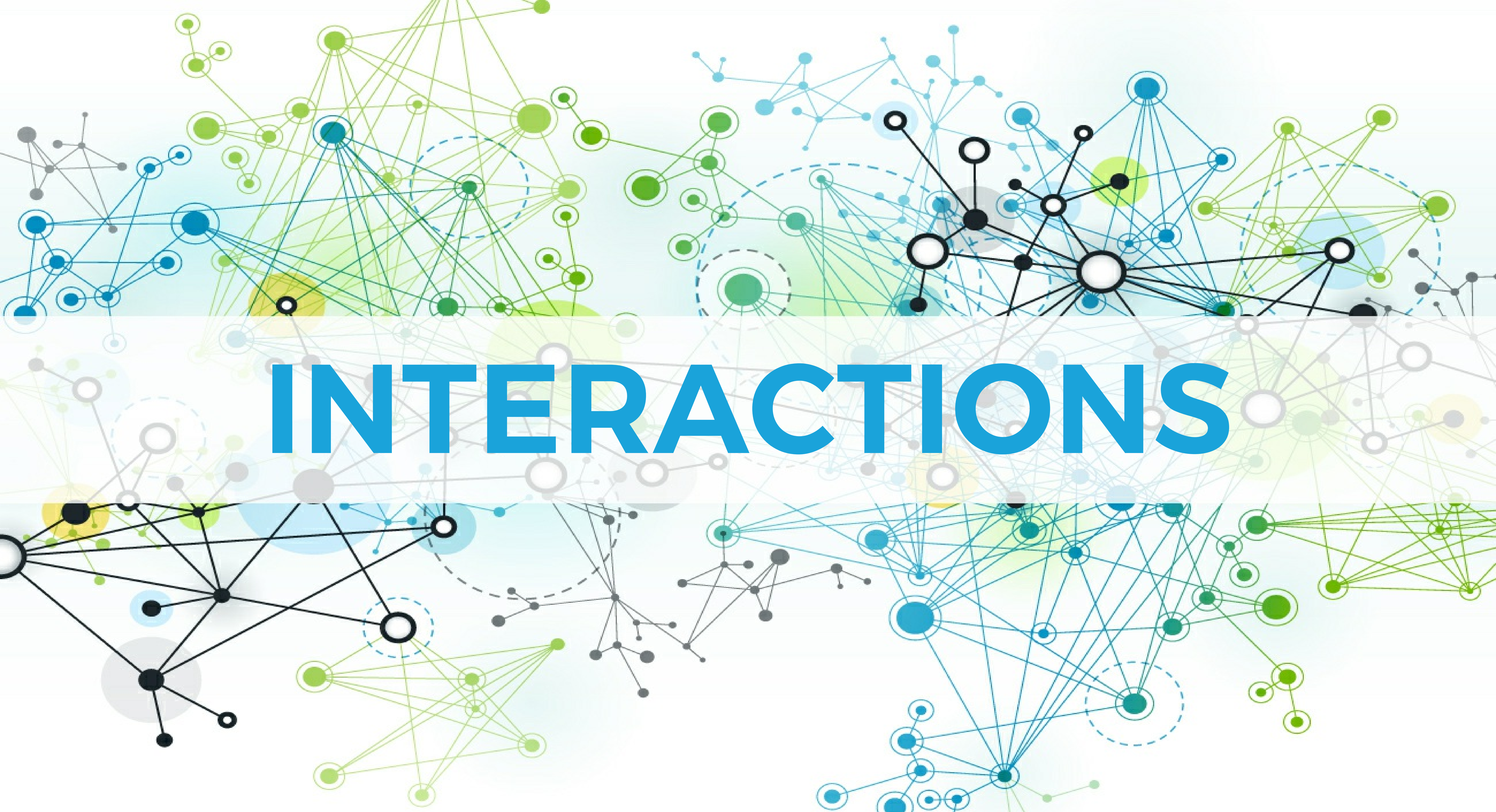
COURSE OVERVIEW

- Introduction
  - Interactions
  - Plants vs animals
  - Some basics about the soil
- Root systems architecture
- Roots and water uptake
  - How do root architecture shape the water uptake?
  - How do the water content shape the root architecture?

INTRODUCTION

About interactions, soil and animals

Press down for details



INTERACTIONS

INTERACTION CAN MEAN DIFFERENT THINGS

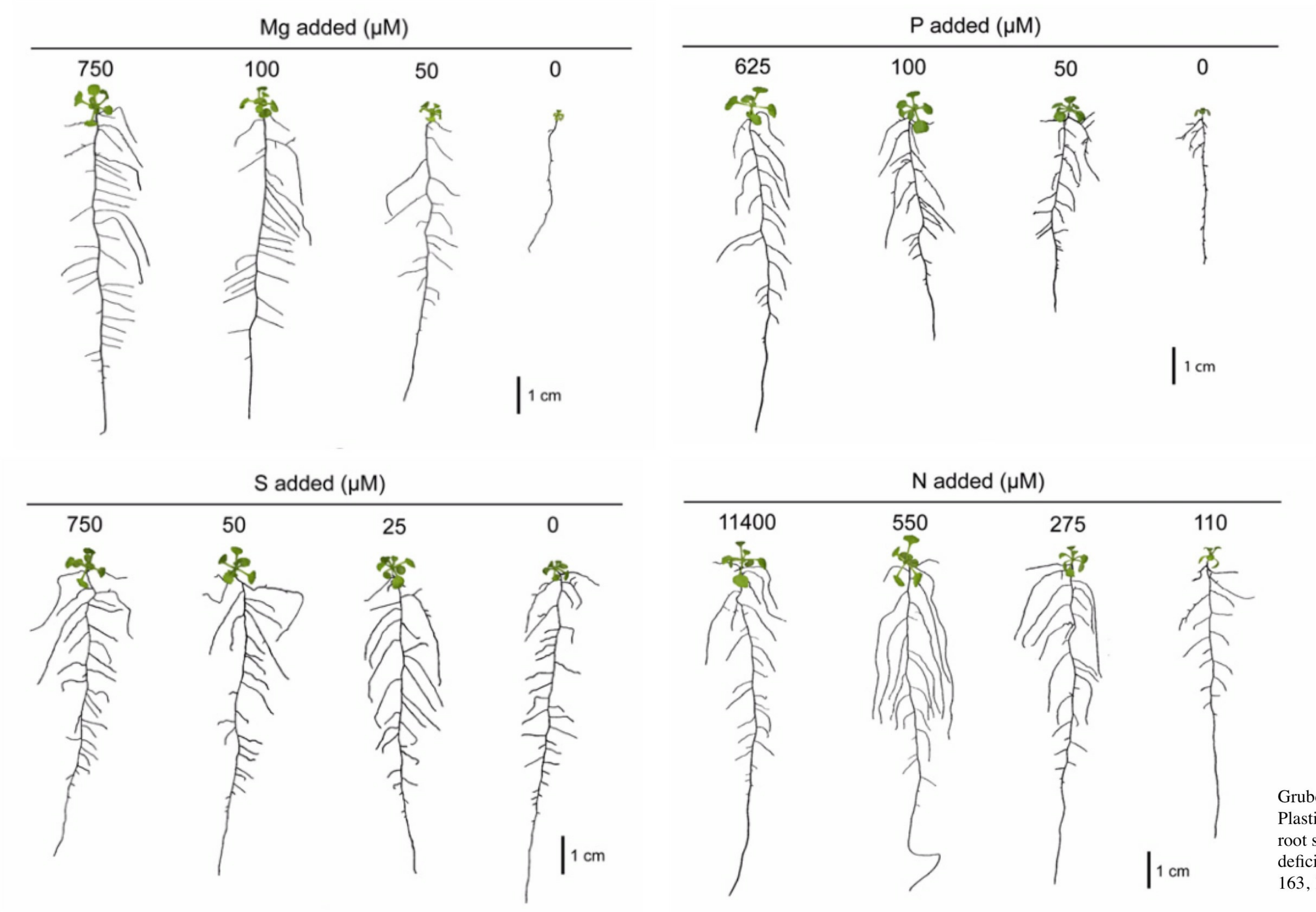
- Interactions between compartiments of the system

$$\text{Plant}_t = f(\text{Plant}_{t-1}, \text{Soil}_t, \ldots)$$

$$\text{Soil}_t = f(\text{Soil}_{t-1}, \text{Plant}_t, \ldots)$$

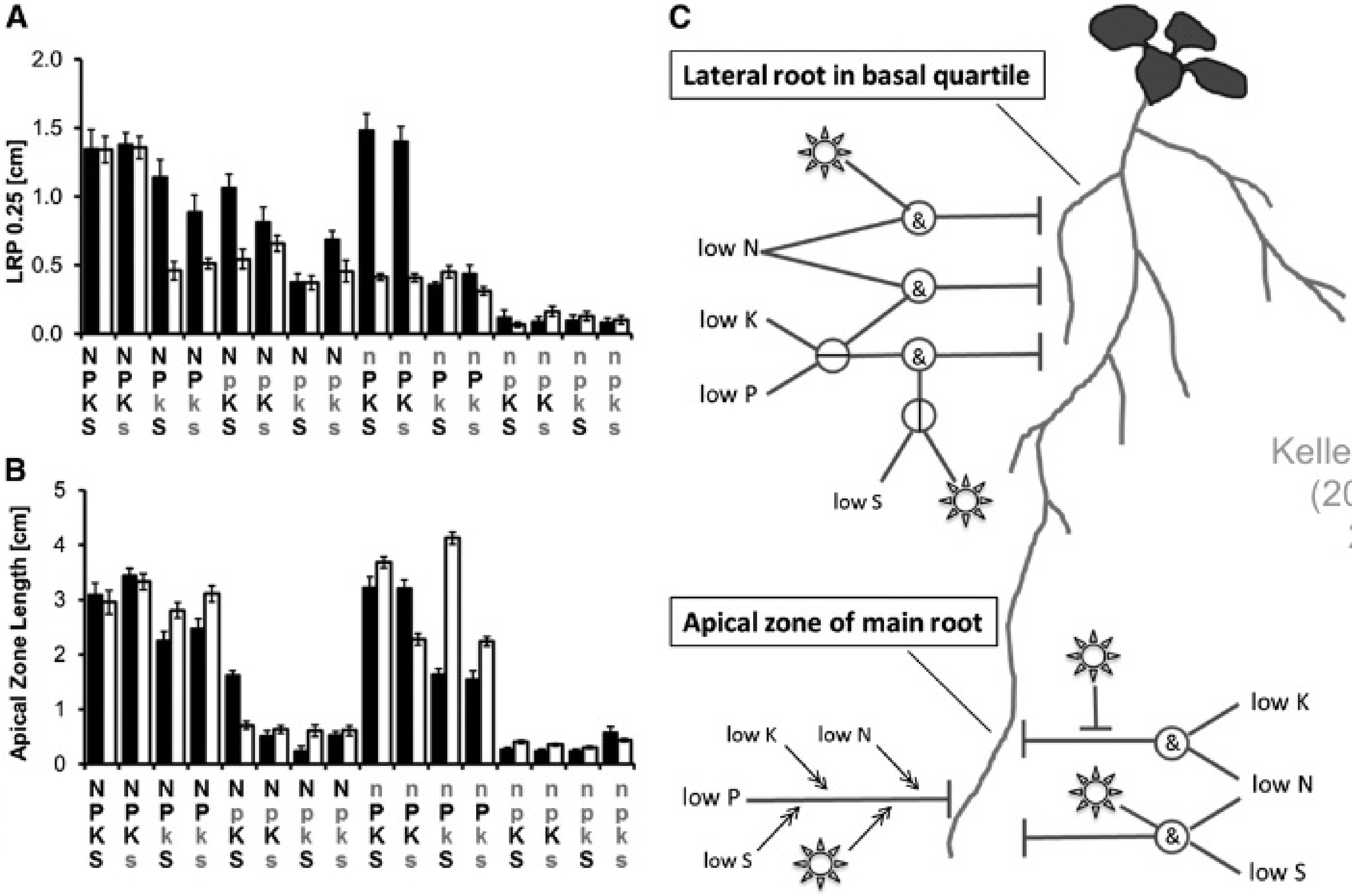
- Interactions between function of the system
  - local supply in N ➔ ramification ➔ local K upake
- Non-additivity ot single (or multiple factors)
  - effect of new dose of a given factor is variable between dose, species, developmental stages, ...
  - effect depend on the environment

EXAMPLE OF EFFECT OF SINGLE NUTRIENT SUPPLY ON ROOT ARCHITECTURE



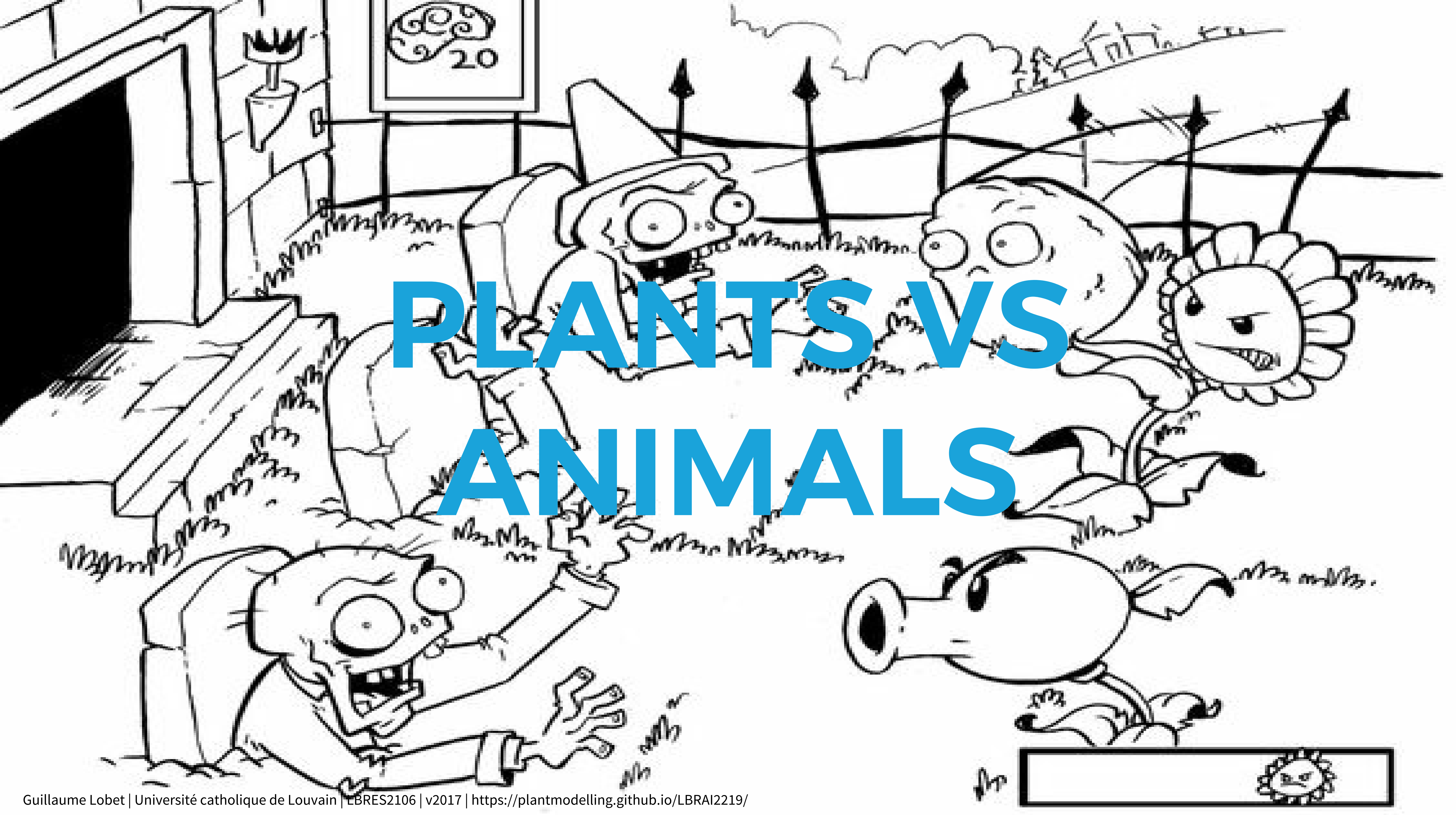
Gruber, B.D. *et al*. (2013) Plasticity of the Arabidopsis root system under nutrient deficiencies. *Plant Physiol*. 163, 161–179

EXAMPLE OF MULTIPLE NUTRIENT SUPPLY ON ROOT ARCHITECTURE



Kellermeier, F. et al. (2014) Plant Cell 26, 1480–1496

PLANTS VS ANIMALS



	Plants	Animals
Food source	Autotroph	Heterotroph
Access to food	Have to grow more to reach food source	Move to food source
Growth	Potentially unlimited	Limited
Environment	Highly heterogeneous	Mostly homogeneous
Death	Can partially die	Die

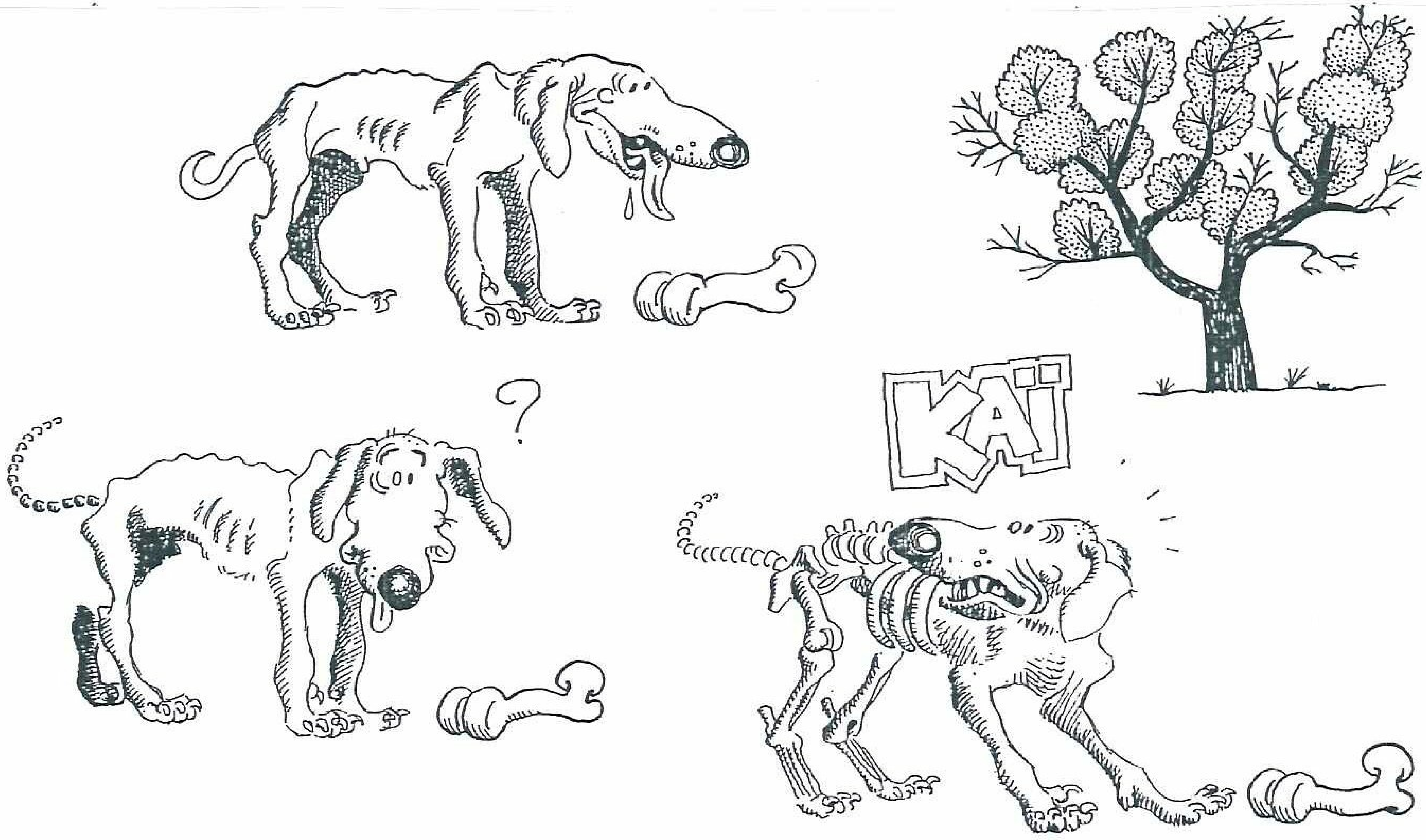


Fig. 43. *Deux manières de mourir.* La possibilité qu'ont les plantes coloniaires d'être à la fois mortes et vivantes est illustrée ici par un chêne-liège, dessiné un an après un incendie (Roger Prodon, communication personnelle). Transposé à l'animal, ce comportement est évidemment grotesque.

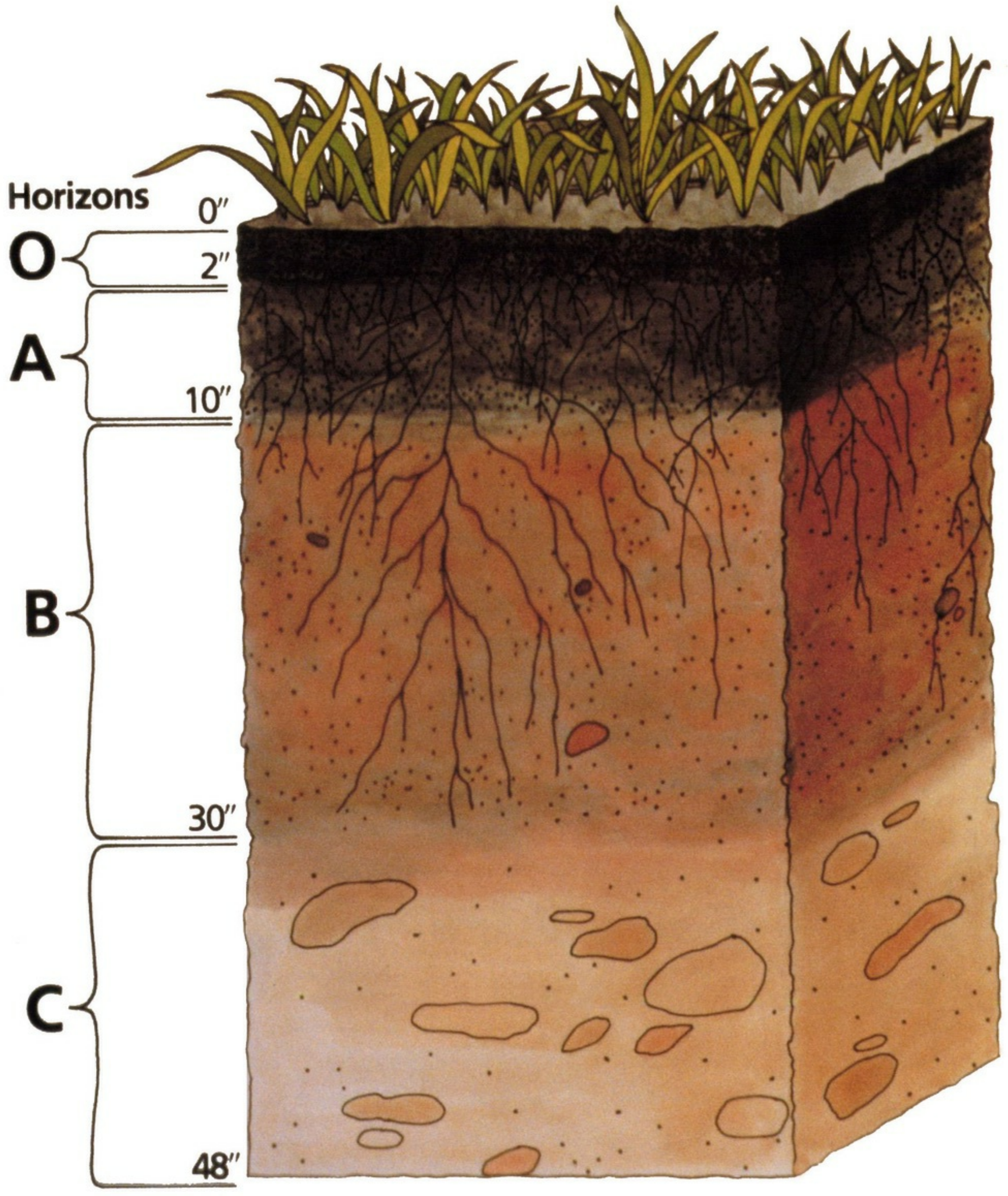
Francis Hallé, Eloge de la plante

SPACE HETEROGENEITY: SOIL VS ATMOSPHERE

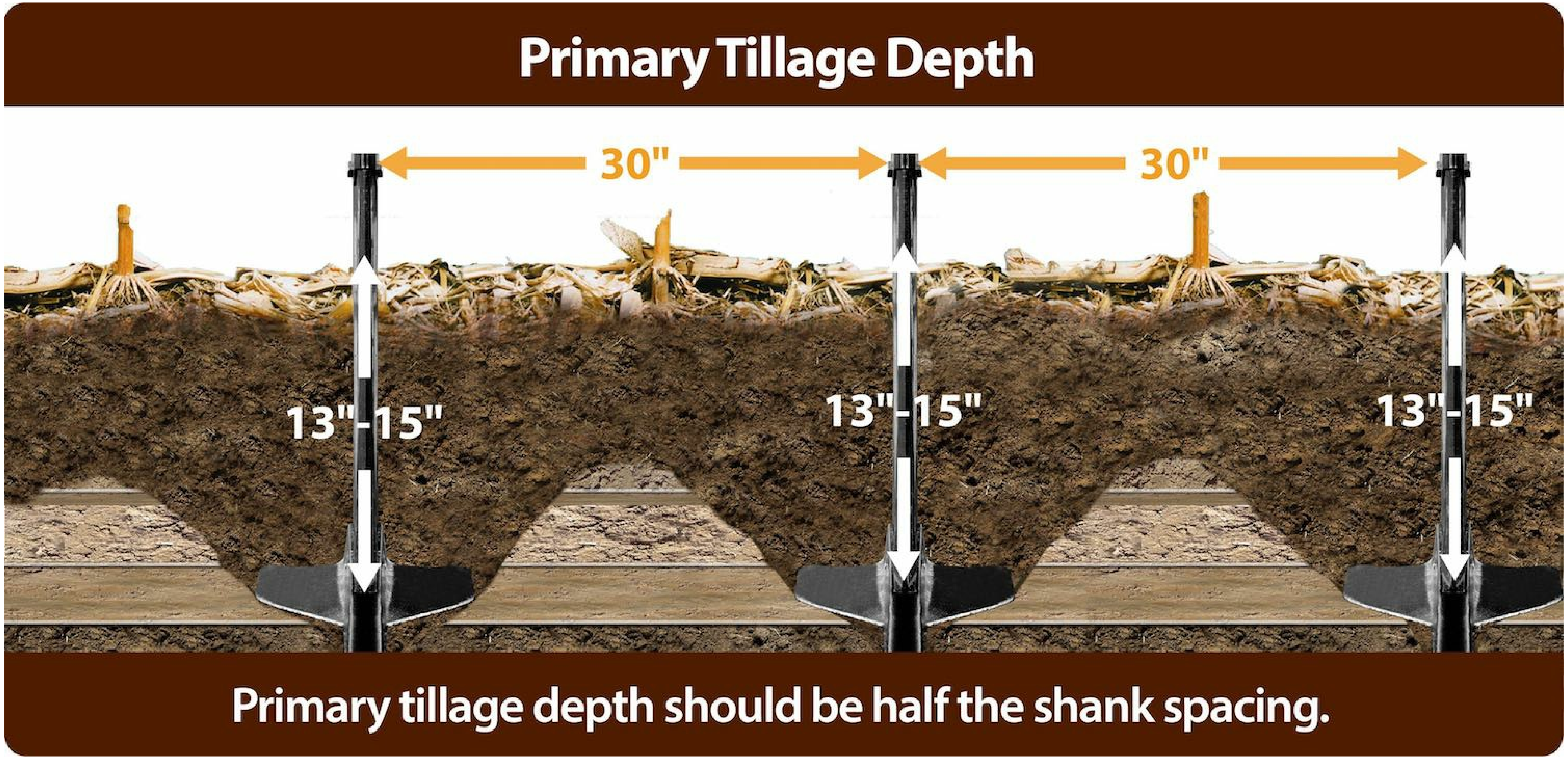
SOME BASICS ABOUT THE SOIL


100 µm

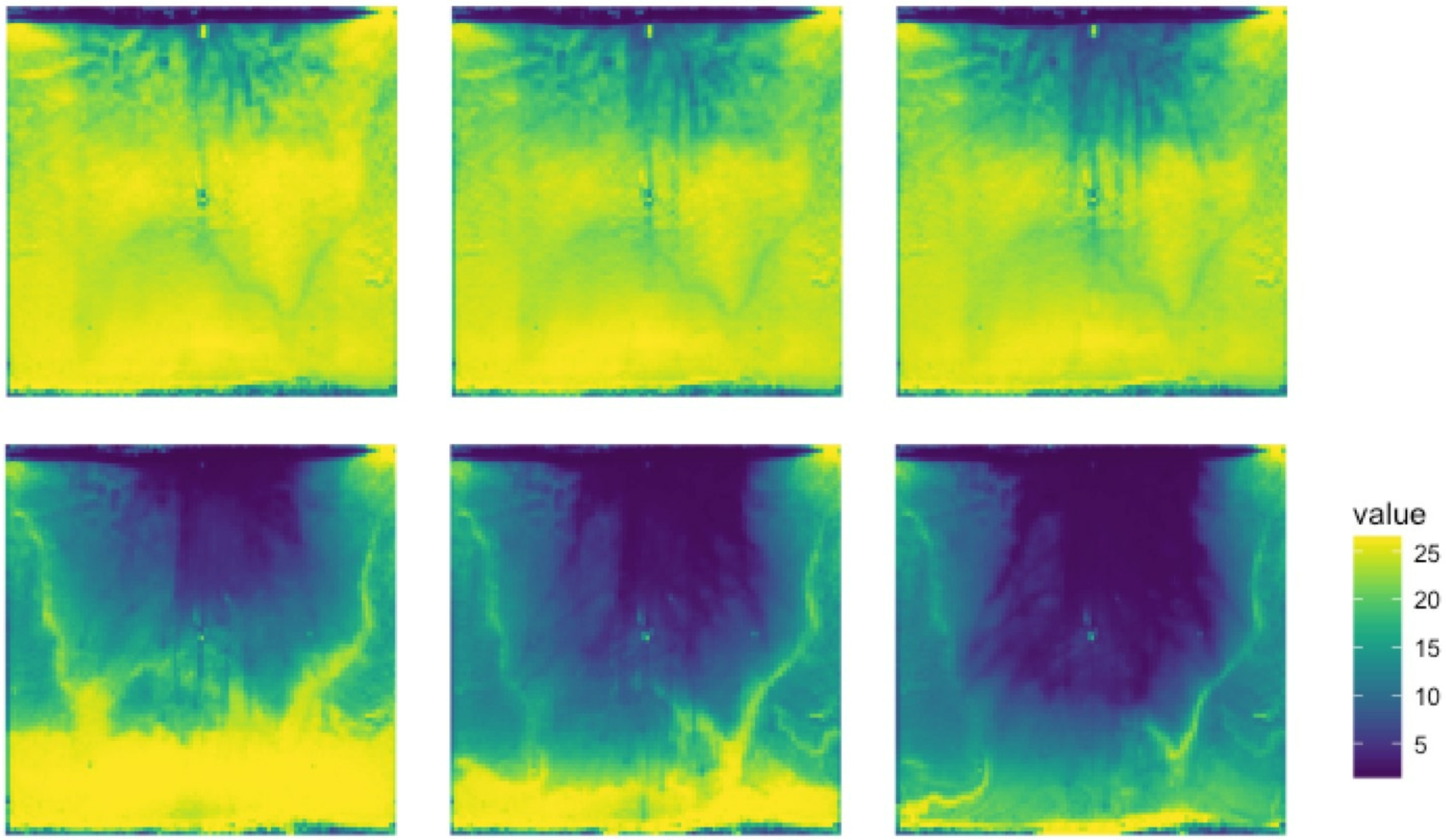
VERTICAL HETEROGENEITY IN THE SOIL



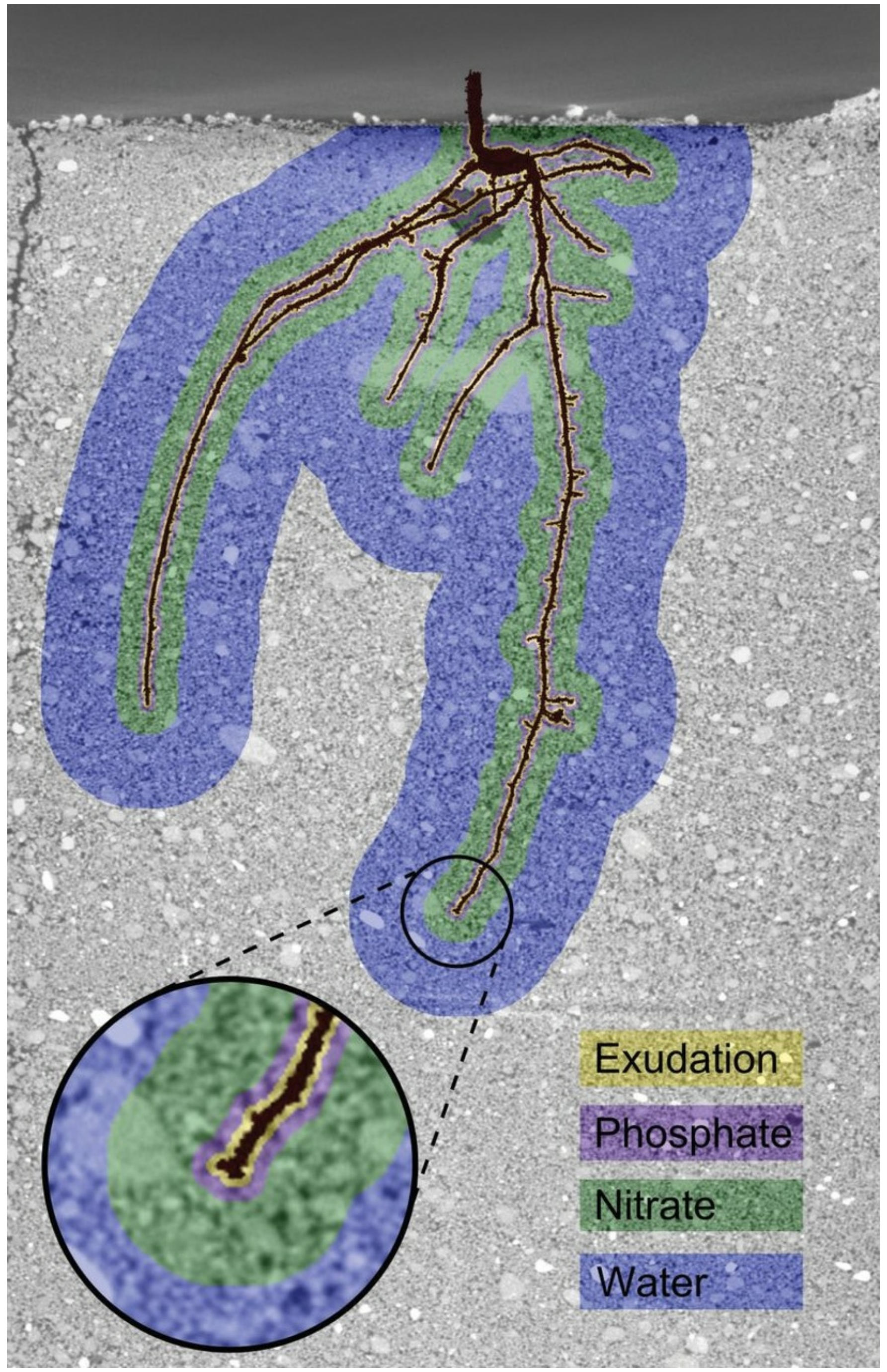
HORIZONTAL HETEROGENEITY IN THE SOIL



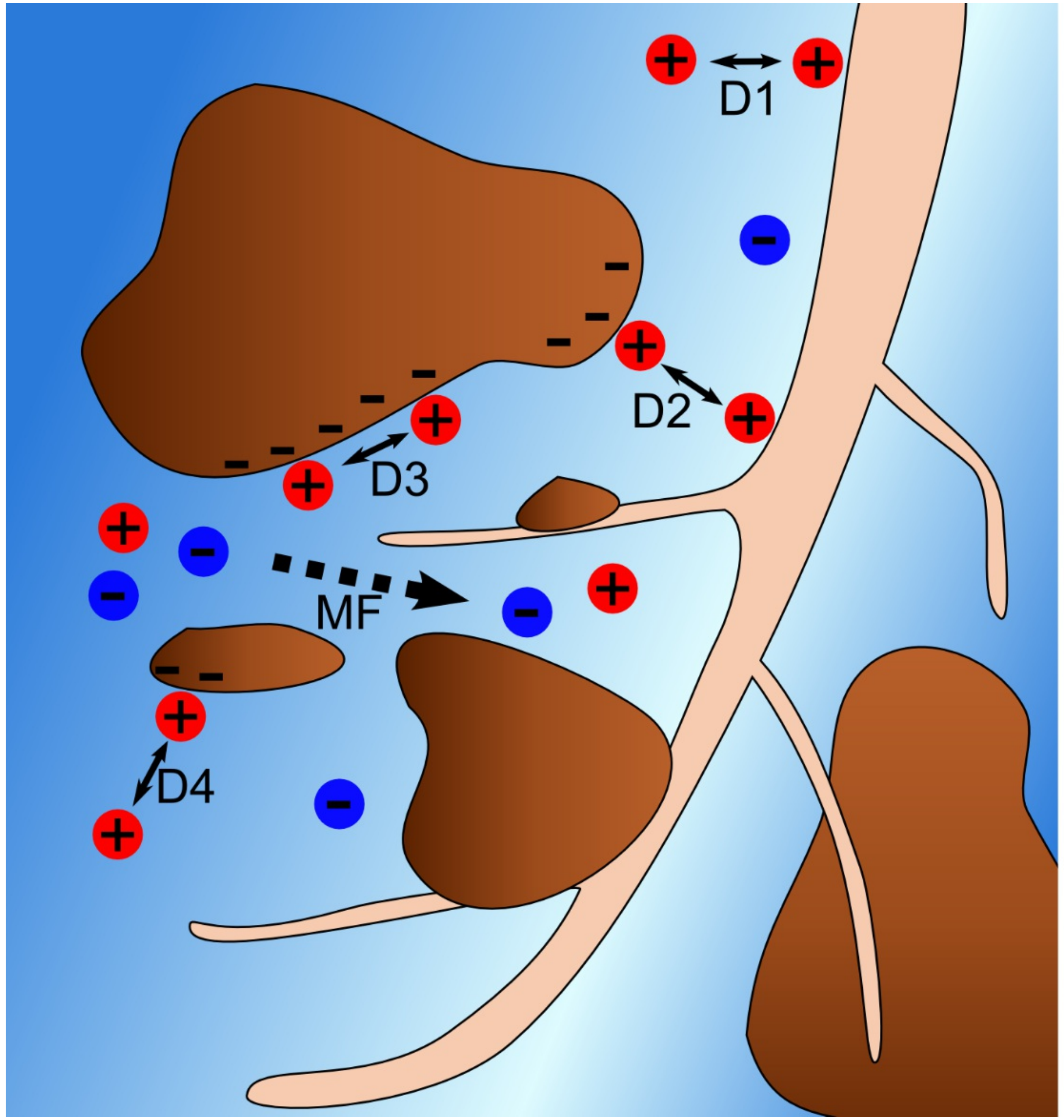
TIME HETEROGENEITY IN THE SOIL



ROOT ENVIRONMENT = RHIZOSPHERE



ION MOVEMENT IN THE SOILS



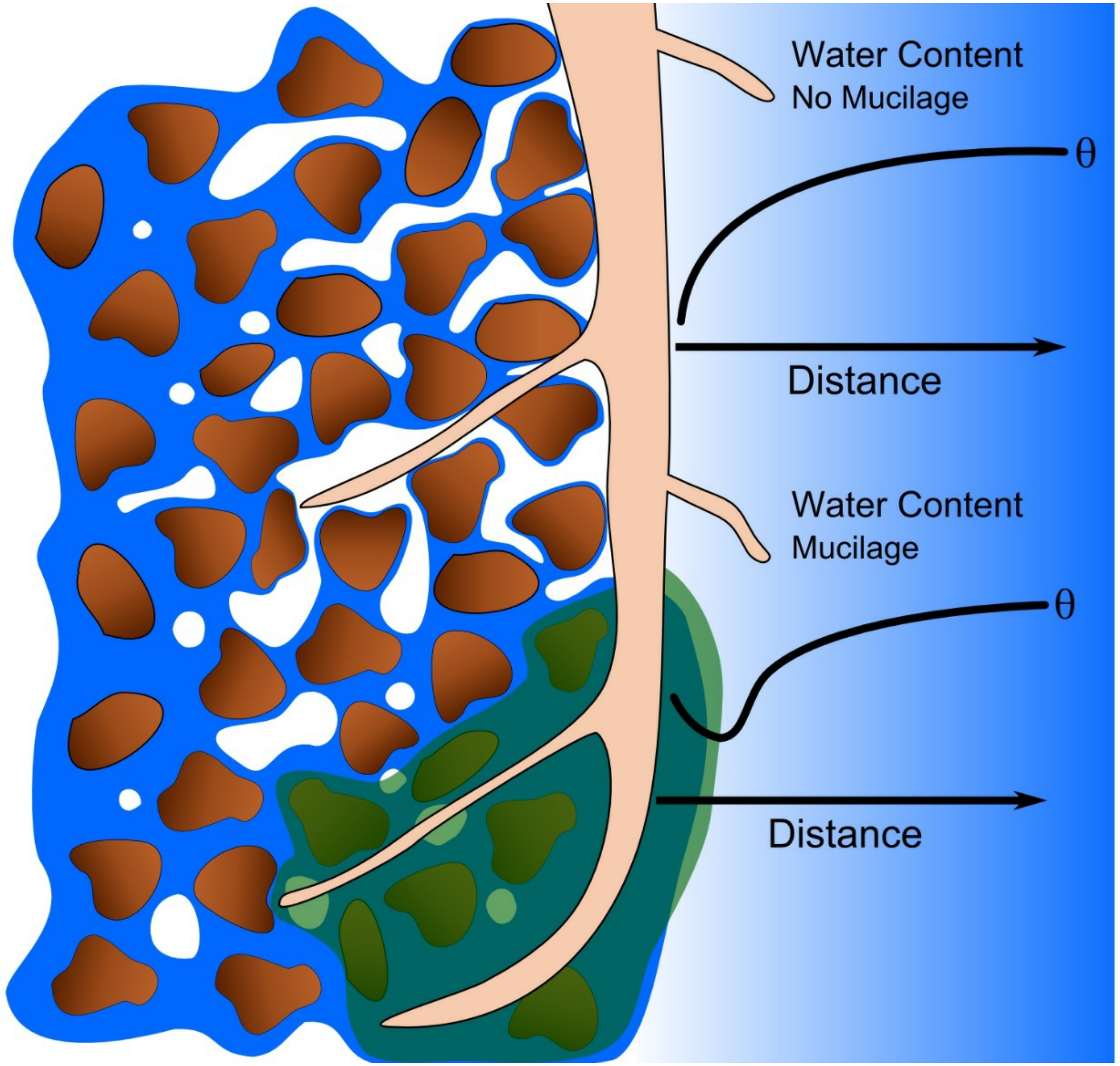
Ions can diffuse from:

solution to root (D1),
particle surface to root (D2),
exchange sites on particle (D3),
or from particle to solution (D4).

Ions can also travel with water to the root surface through the process of mass flow (MF).

York et al. (2016)

WATER MOVEMENT IN THE SOILS

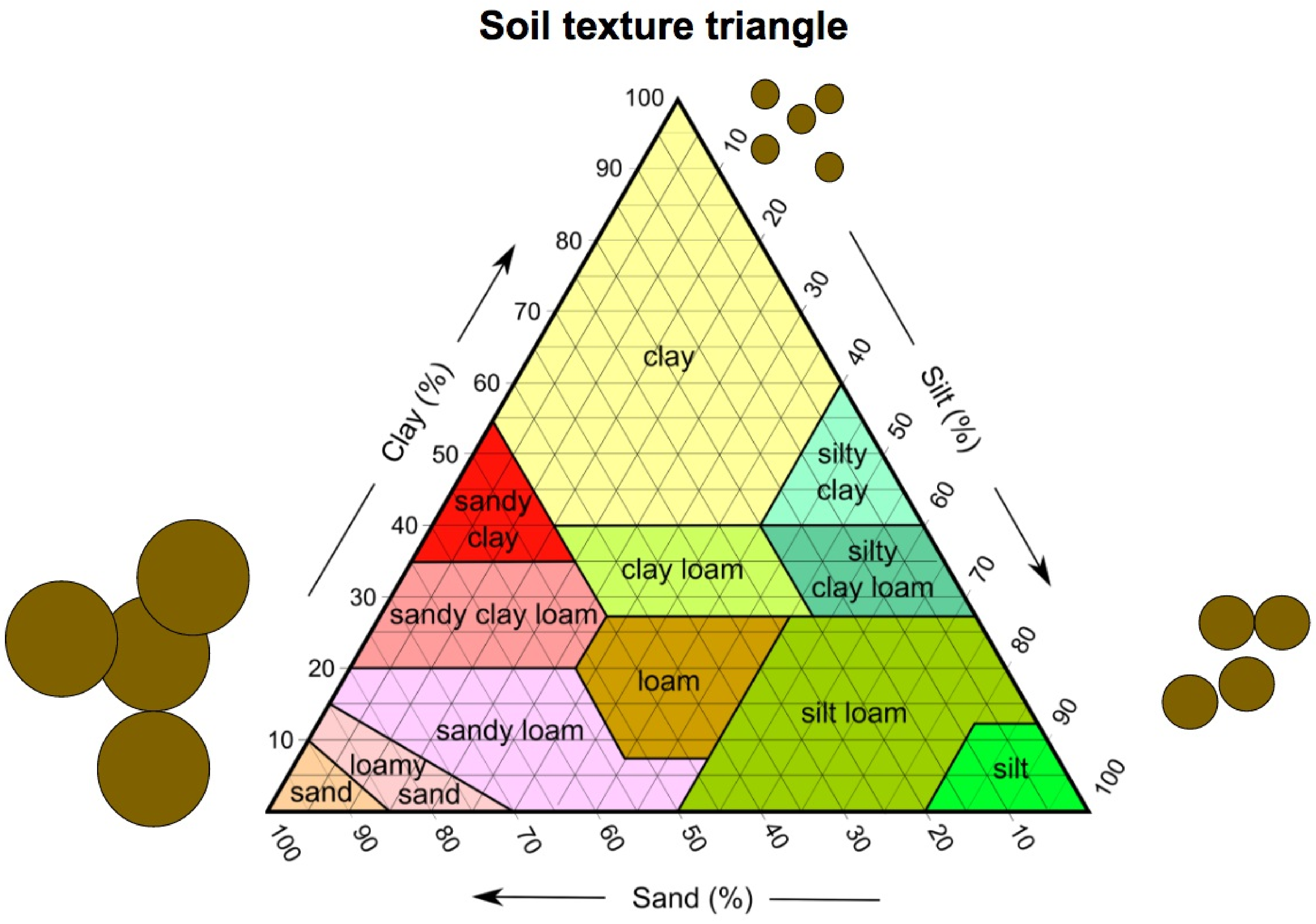


Waters is taken out from pore spaces between particles first, and as more water is extracted the remaining water is more and more difficult to extract. The remaining water clings in thin films to soil particles and is not available for root uptake.

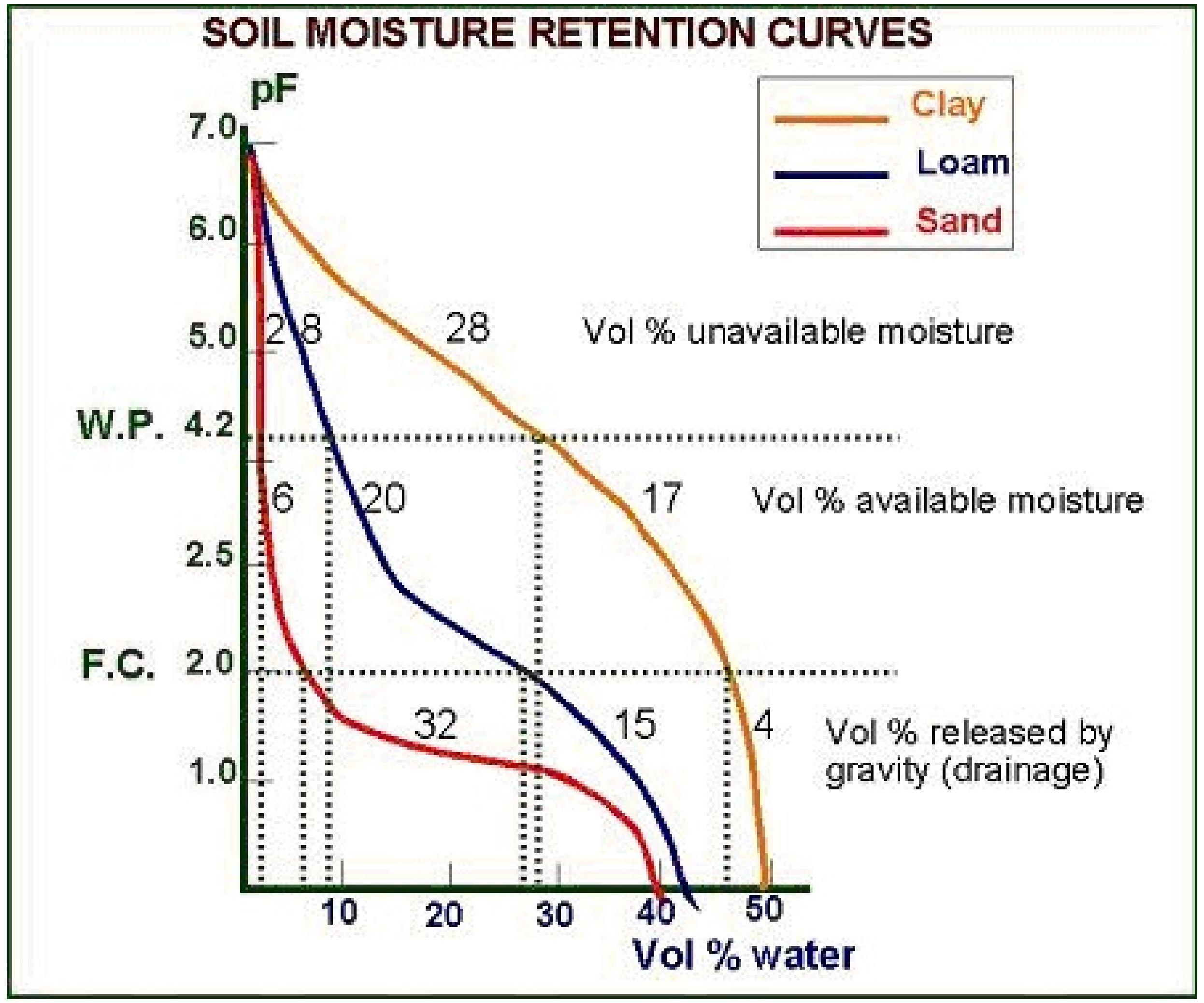
Mucilage exuded by roots may help keep the roots hydrated with better access to water.

York et al. (2016)

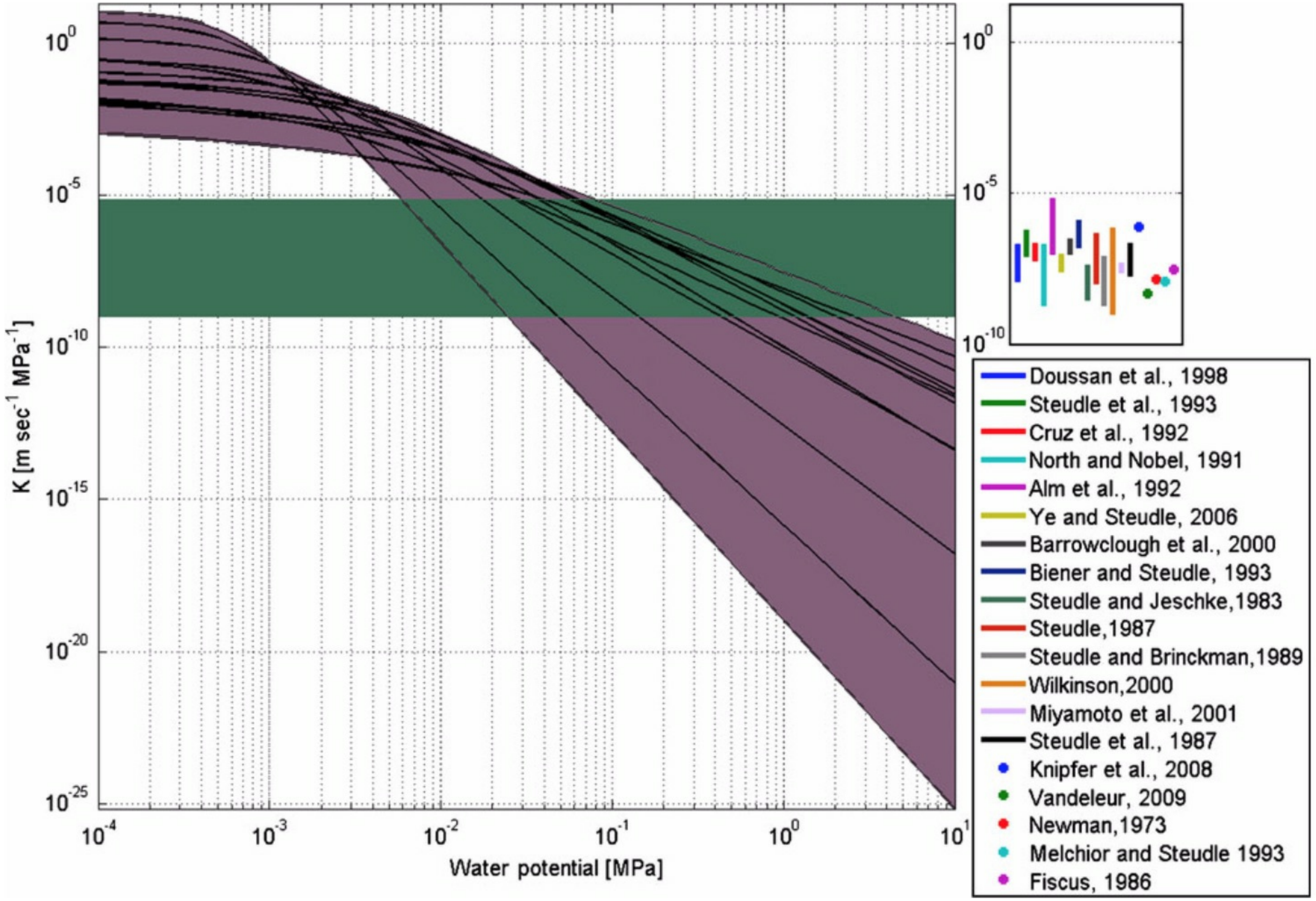
THE SOIL IS COMPLEX MEDIUM



SOIL RETENTION CURVE



SOIL CONDUCTIVITY CURVE



Draye, X. et al. (2010) Model-assisted integration of physiological and environmental constraints affecting the dynamic and spatial patterns of root water uptake from soils. J. Exp. Bot. 61, 2145–2155

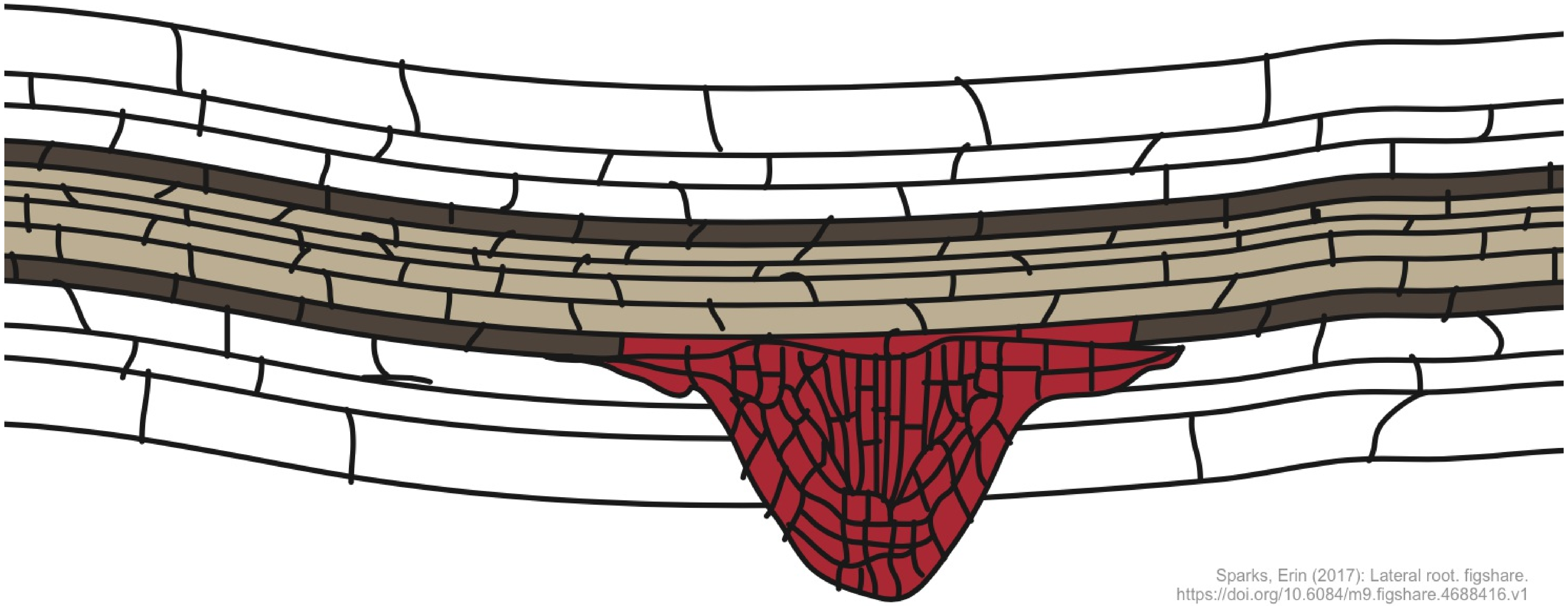
SOIL IS:

- complex media
  - different particule sizes
  - different physico-chemical properties
- highly heterogeneous
  - verticaly
  - horizontaly
  - in time
- non linear behaviour

ROOT SYSTEMS

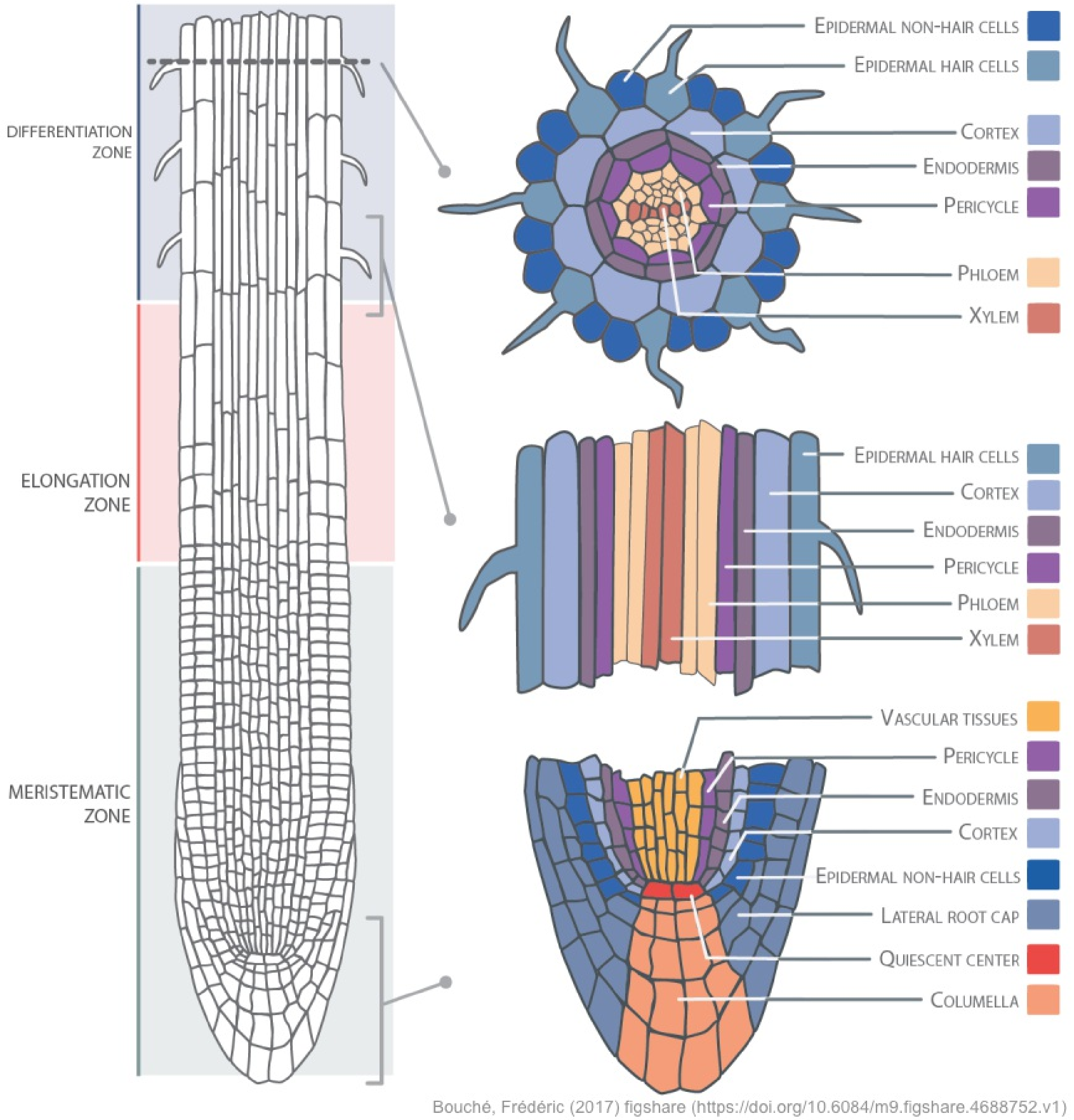
Different types of root systems and how they are built

Press down for details

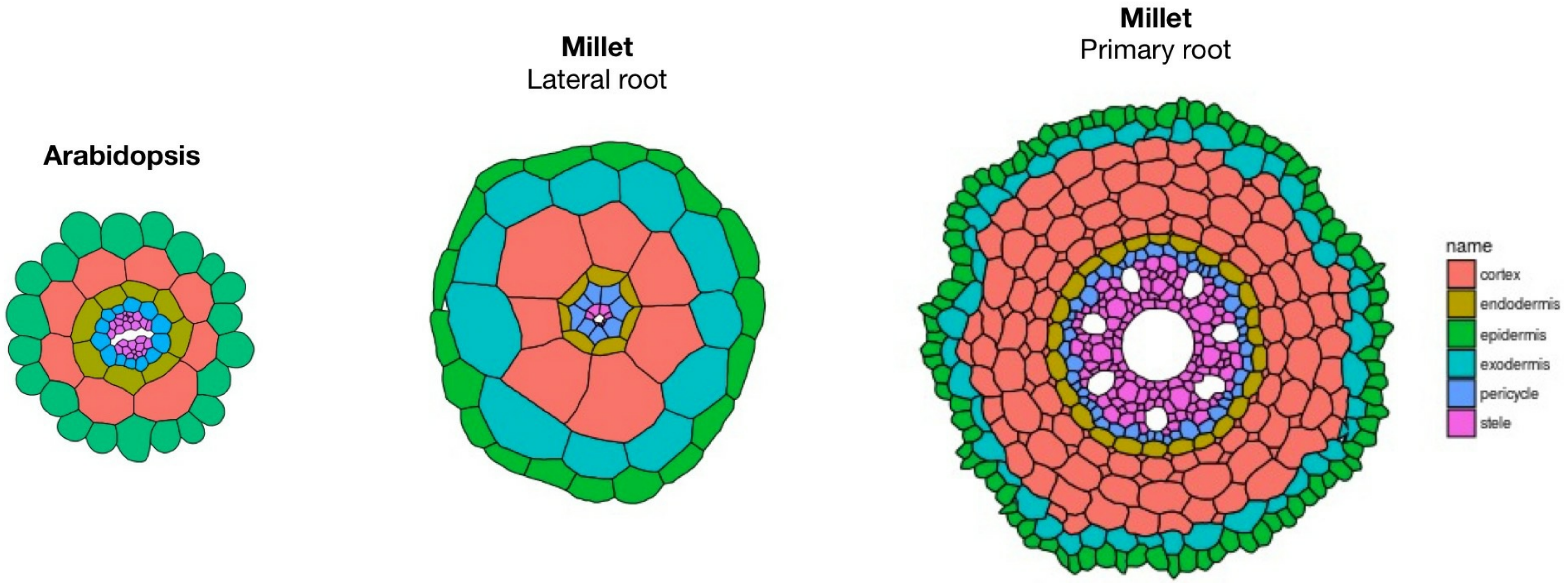


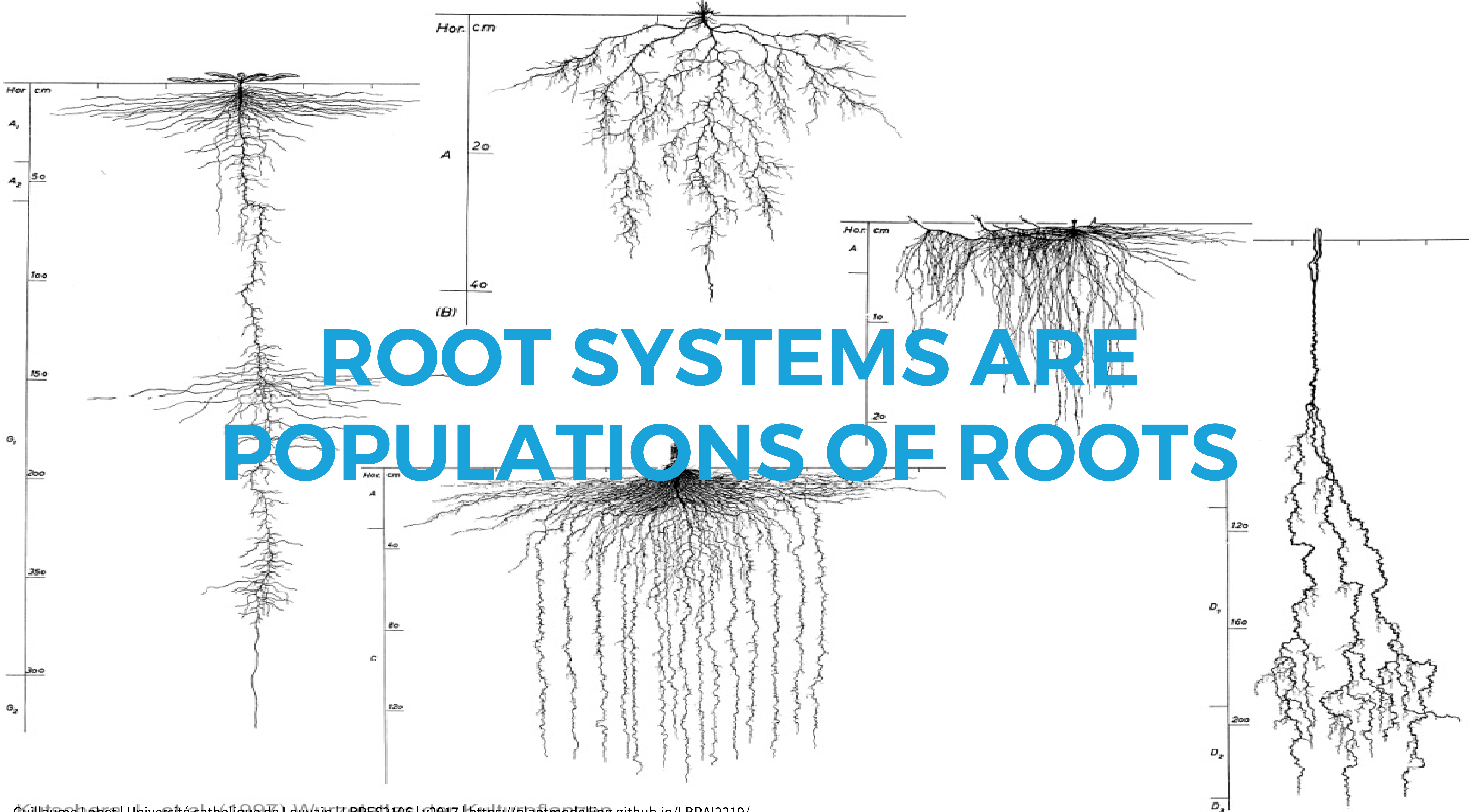
Sparks, Erin (2017): Lateral root. figshare.
https://doi.org/10.6084/m9.figshare.4688416.v1

ROOT HAVE SIMPLE RADIAL AND AXIAL ANATOMY



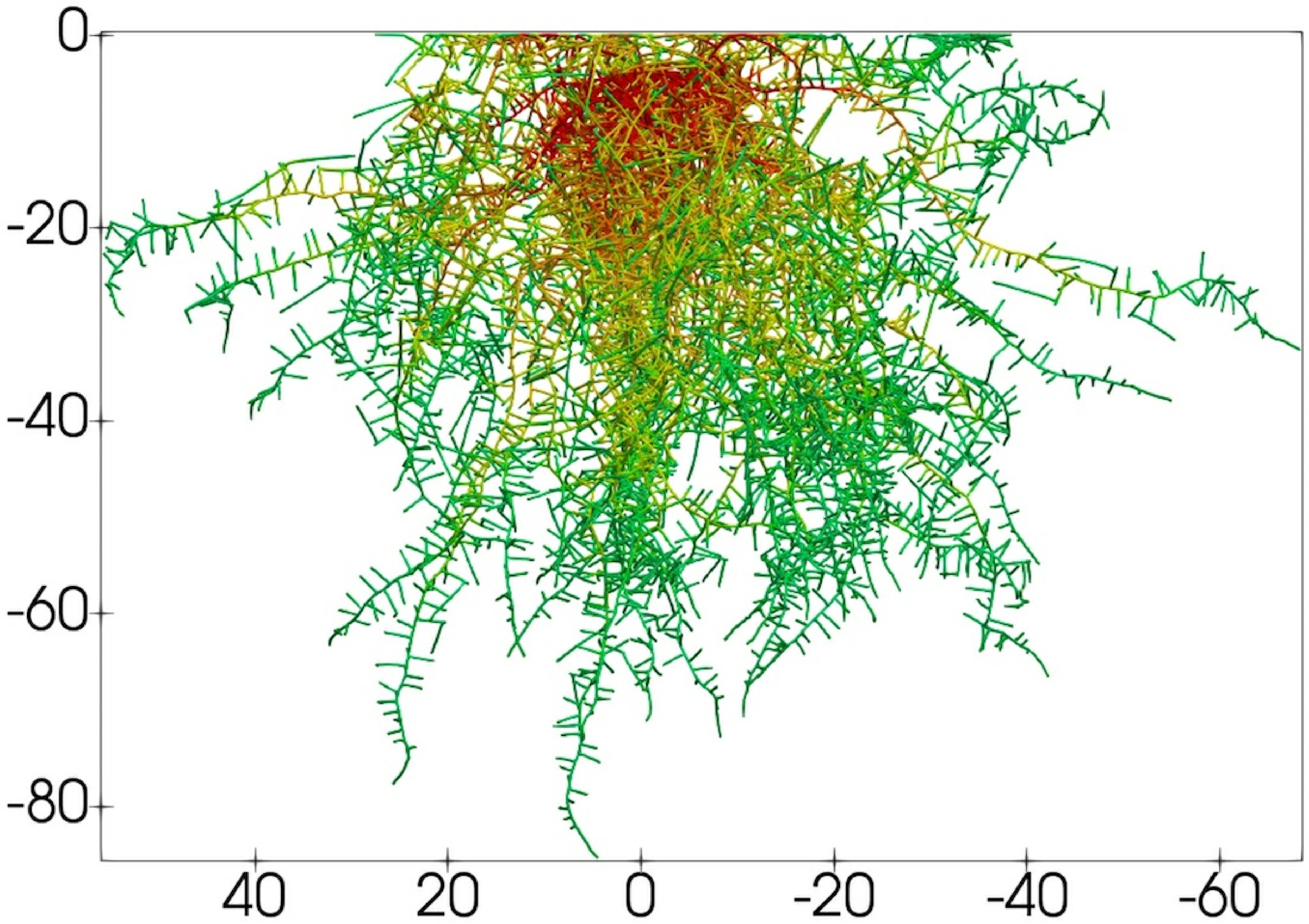
THE ROOT RADIAL ANATOMY IS RELATIVELLY CONSERVED ACCROSS SPECIES





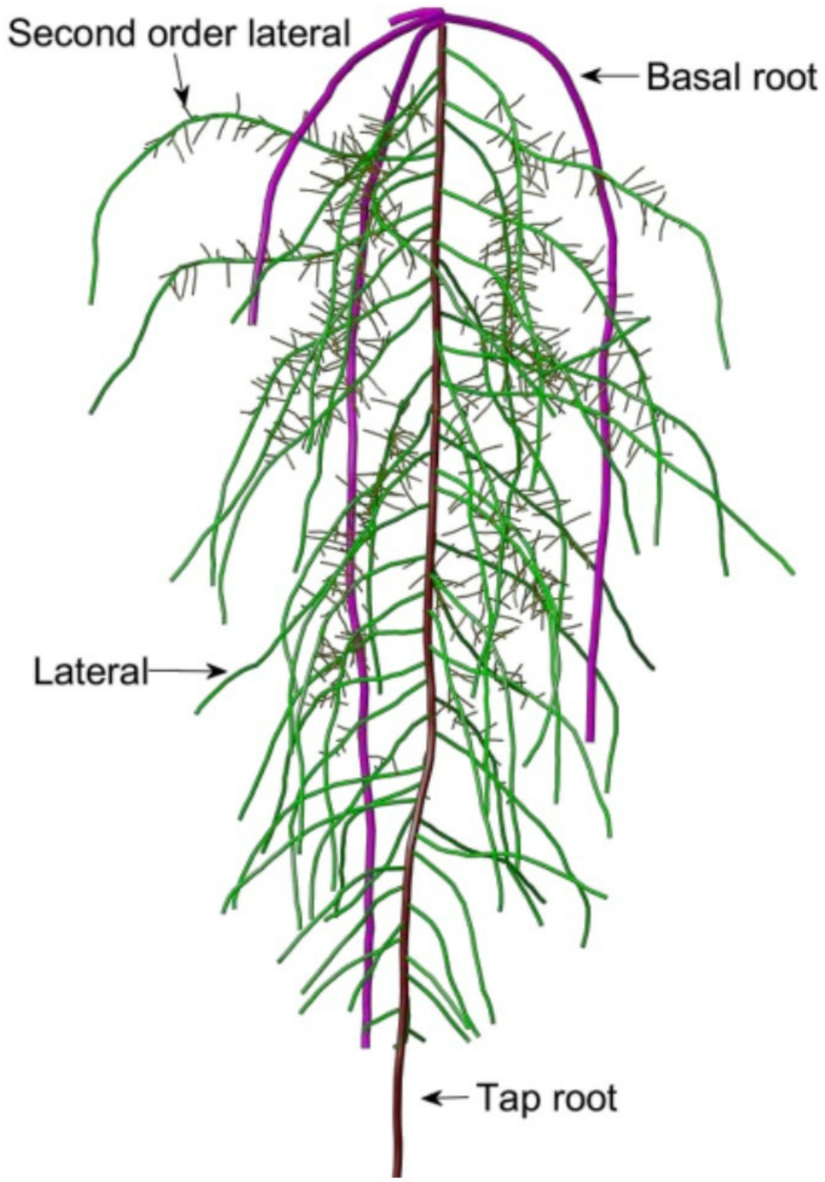
ROOT SYSTEMS ARE POPULATIONS OF ROOTS

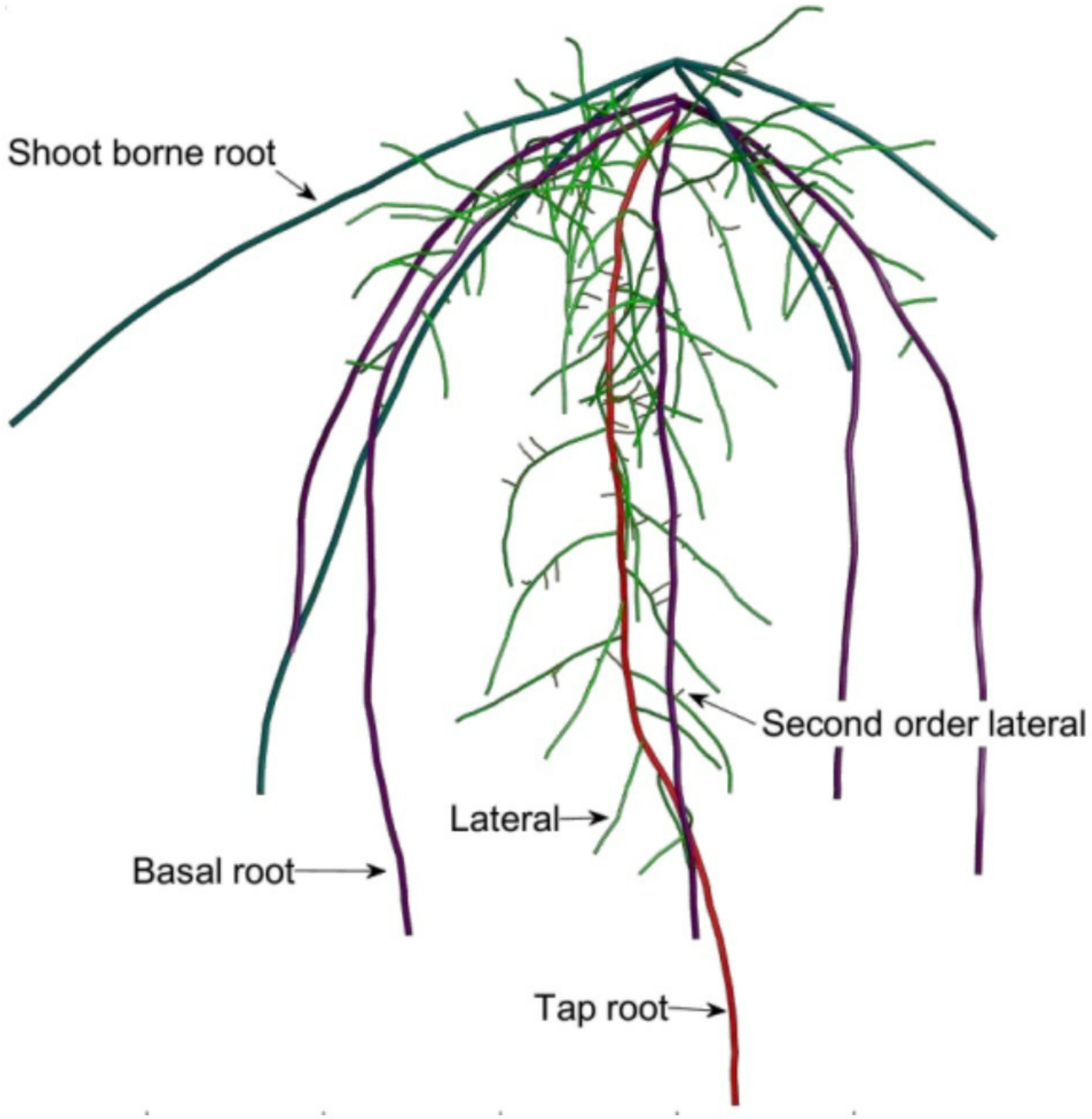
ROOT AGE DISTRIBUTION IN CRYPSIS ACULEATA



Zörner, et al (2017): Crypsis aculeata - CRootBox parameter file. figshare. https://doi.org/10.6084/m9.figshare.4828945.v1

ROOT NOMENCLATURE

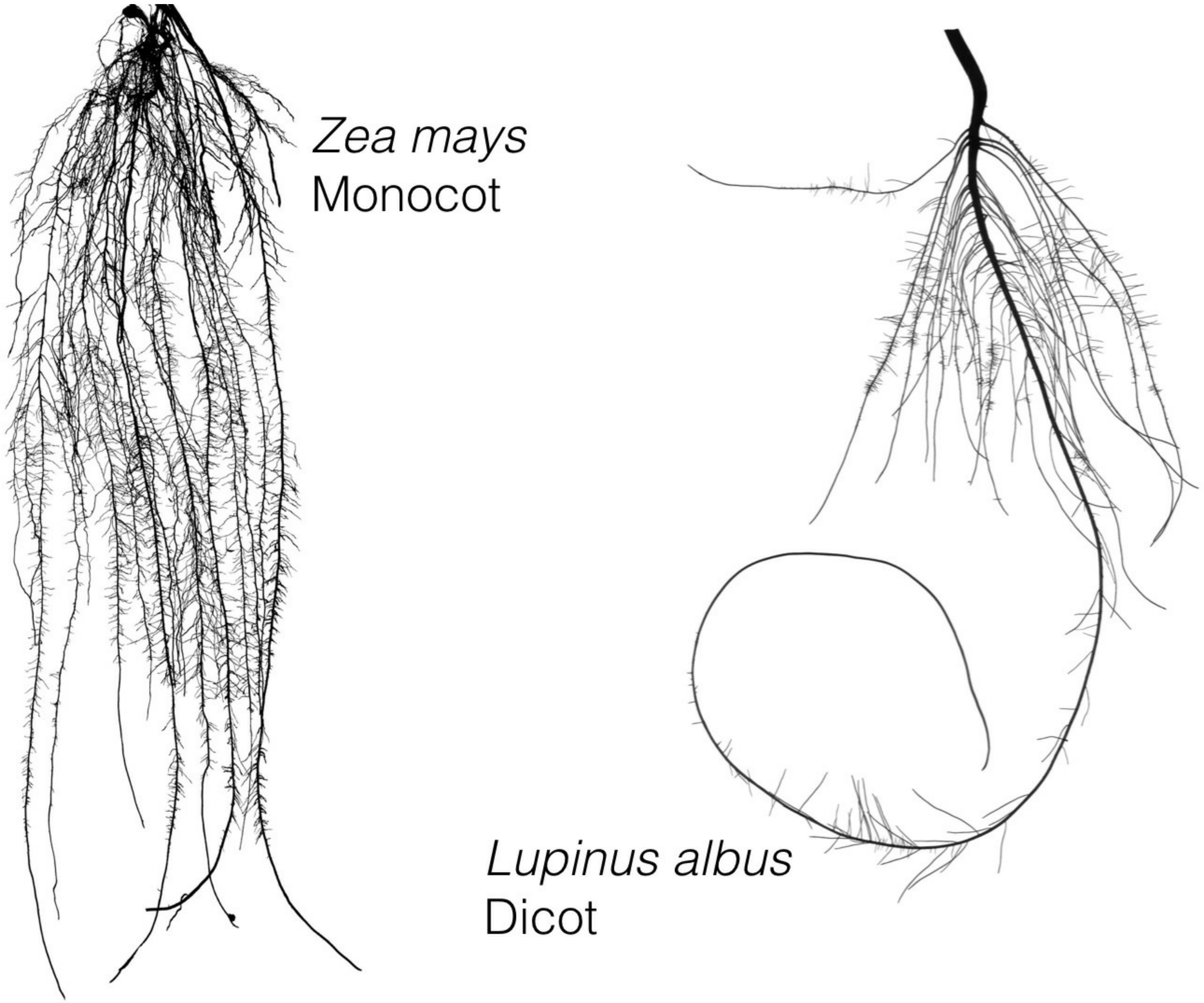




MONOCOTS VS DICOTS

	Monocot	Dicot
Type	fasciculated	herring-bone
Seminals	yes	no
Adventitous roots	yes	(yes)
Secondary growth	no	yes

MONOCOTS VS DICOTS

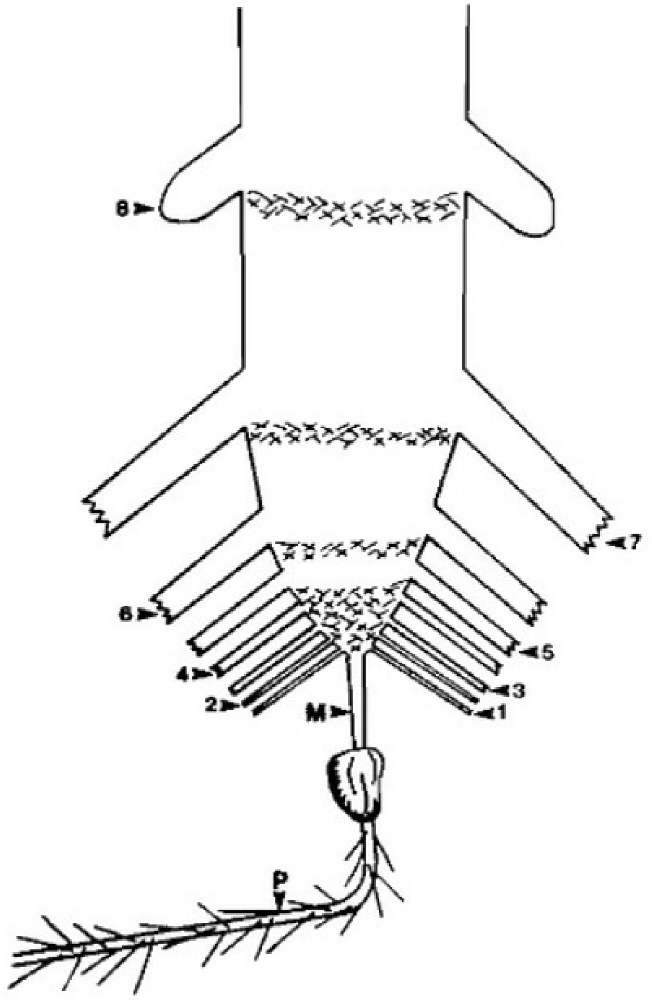


COMPLEX ROOT ARCHITECTURE ARISE FROM A LIMITED NUMBER OF SIMPLE PROCESSES

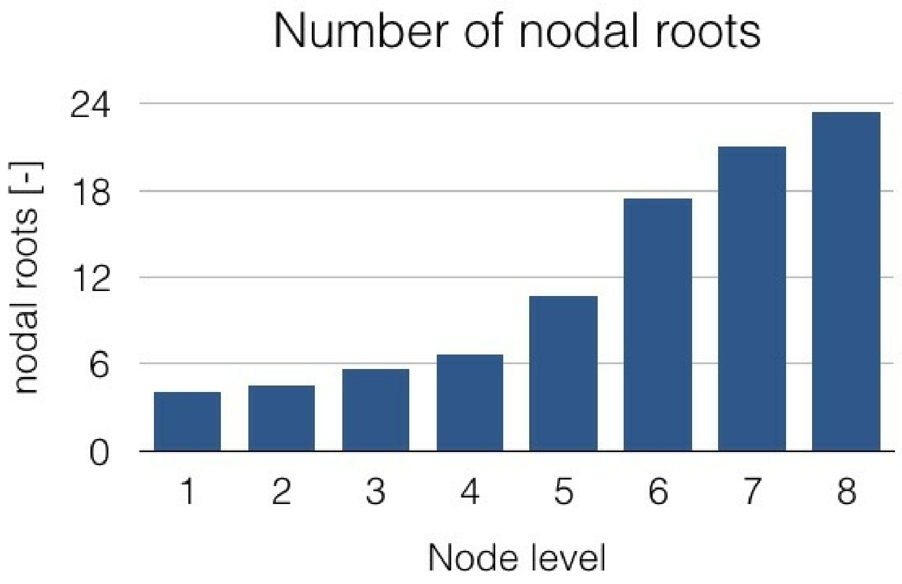
1. Root production
2. Root axial growth
3. Root tropisms
4. Root branching

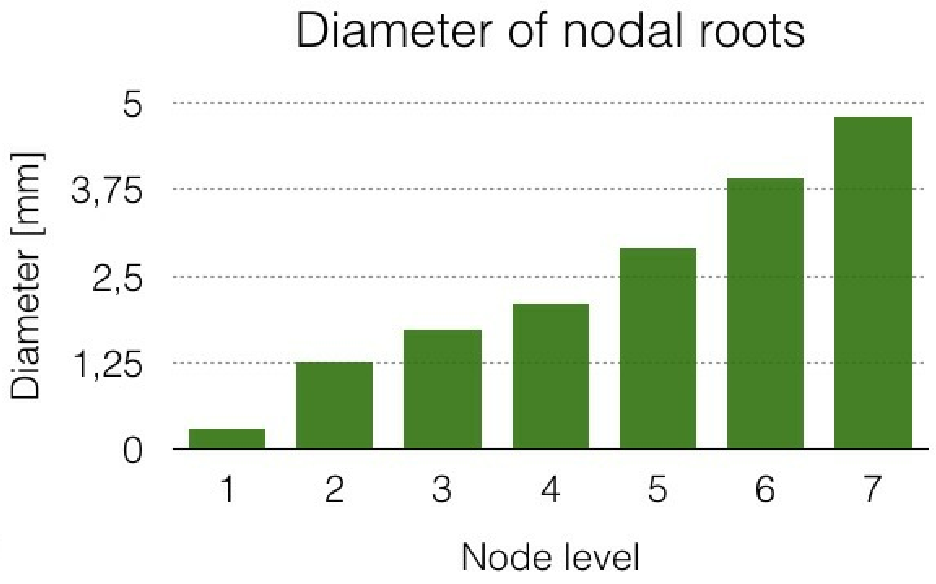
ROOT PRODUCTION

IN MONOCOTS, ROOT PRODUCTION (ORDER 0) DEPEND ON THE NODE /TILLER FORMATION



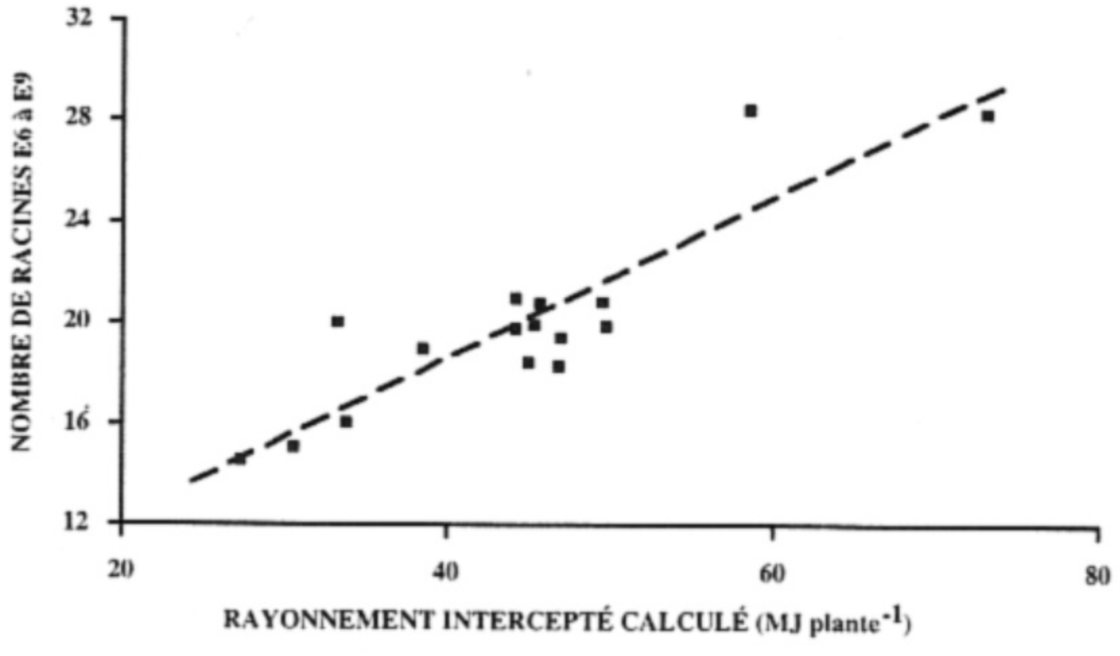
Hoppe, D.C. *et al*. (1986) The nodal roots of Zea: their development in relation to structural features of the stem. *Can. J. Bot*. 64, 2524–2537

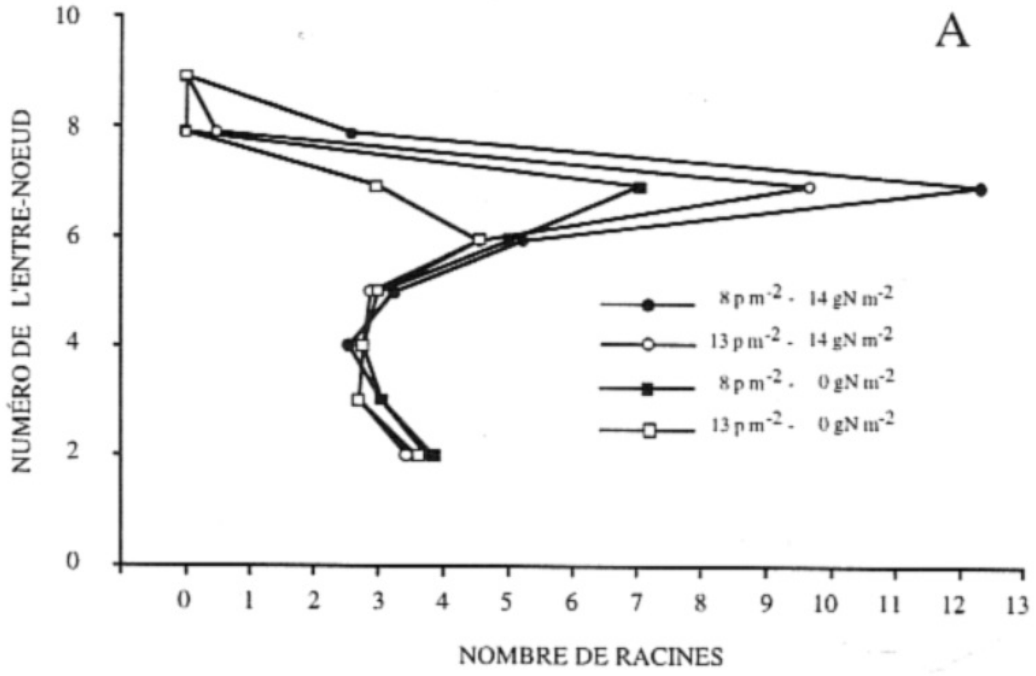




ROOT PRODUCTION = F(ENVIRONMENT)

Light interception, temeprature, soil strenght, nutrients, ...



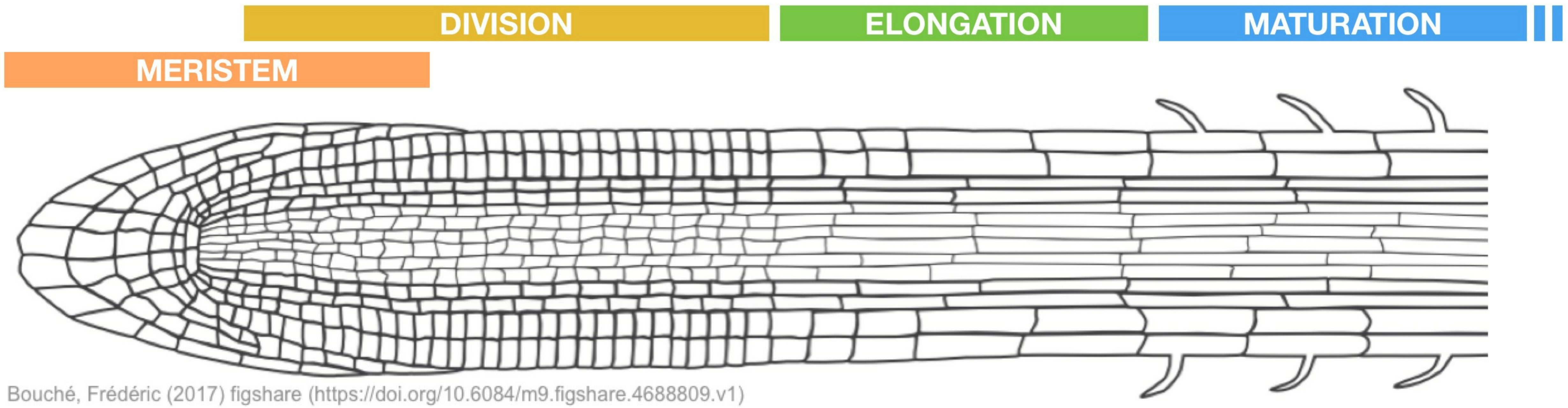


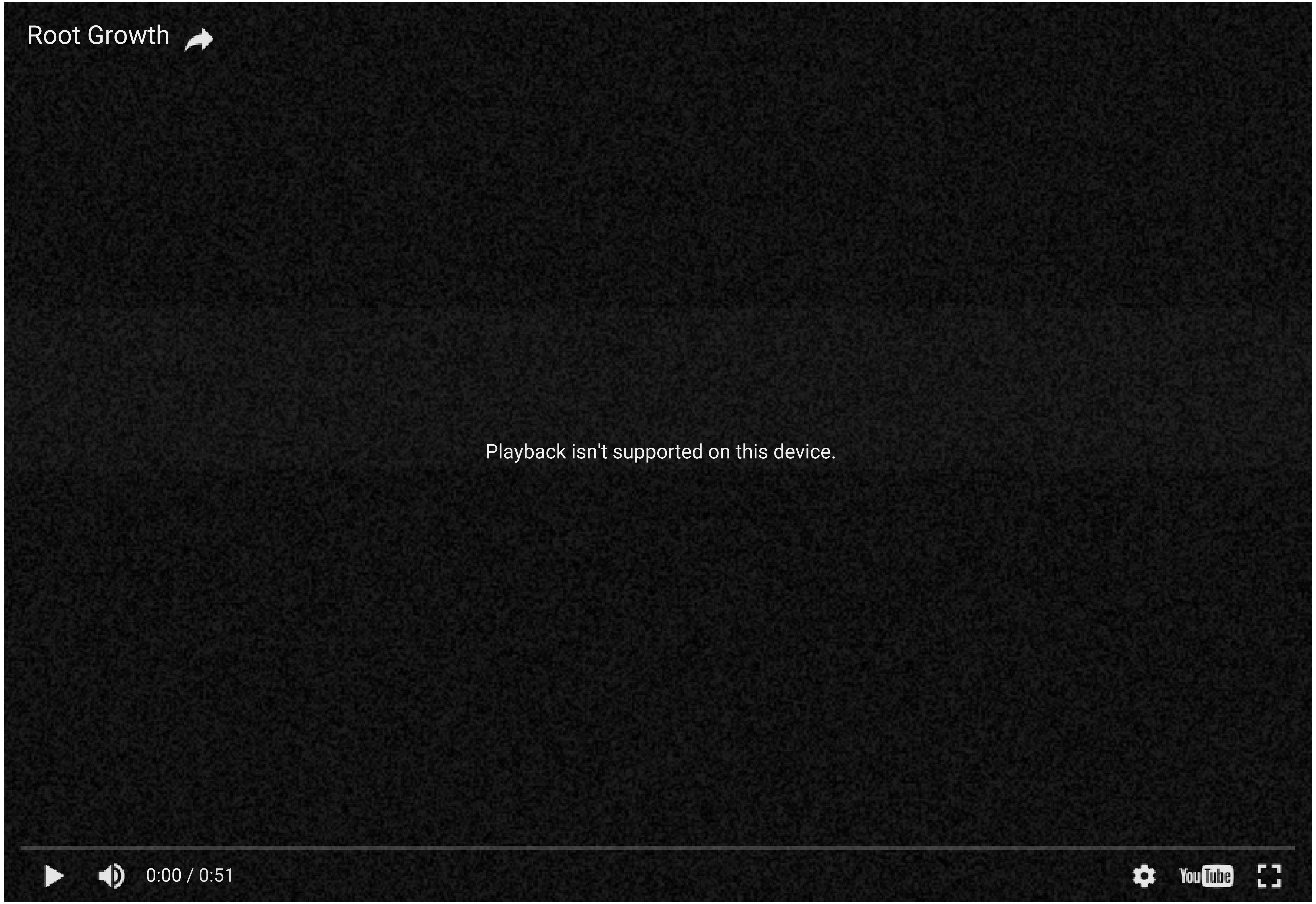
GROWTH

AXIAL GROWTH

Simple process at the single root scale:

1. Cells production
2. Cells division
3. Cells elongation




Root Growth
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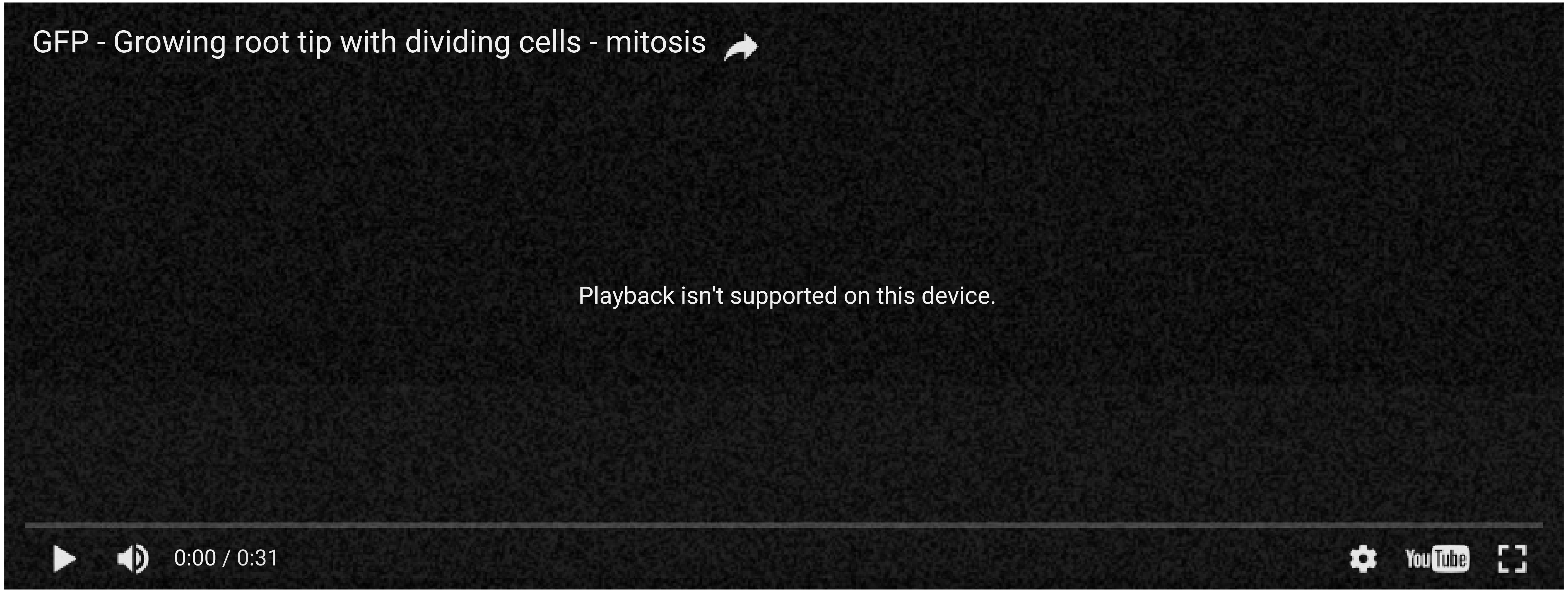
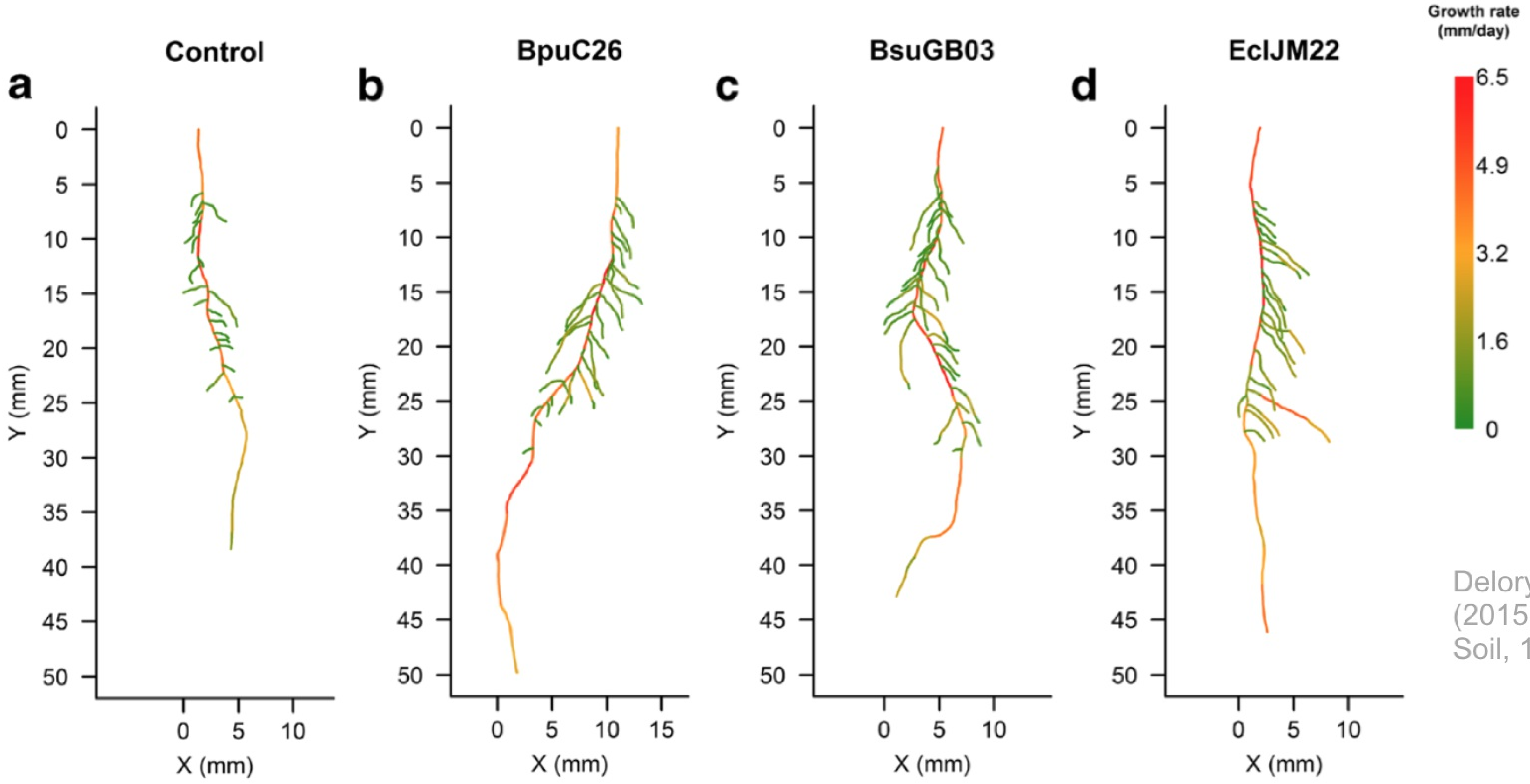
THE MERISTEM IS REGION OF IMPORTANT METABOLIC ACTIVITY

- Water uptake
- Carbon consumption
- Exudation
- ...

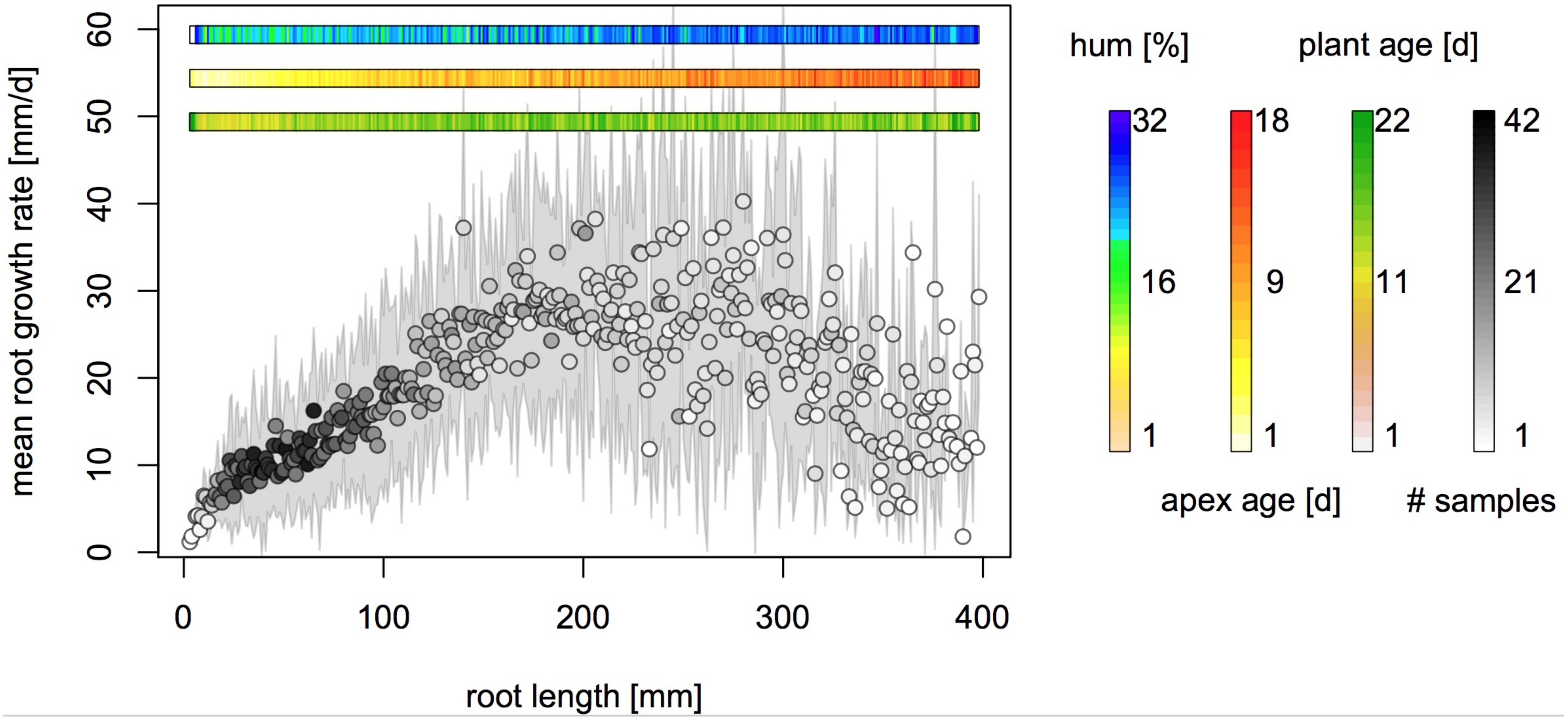


GROWTH RATE IS NOT ALWAYS CONSTANT



Delory, B. M. et al. (2015). Plant and Soil, 1–15.

GROWTH RATE IS NOT ALWAYS CONSTANT



GROWTH AS A FUNCTION OF DIAMETER ?

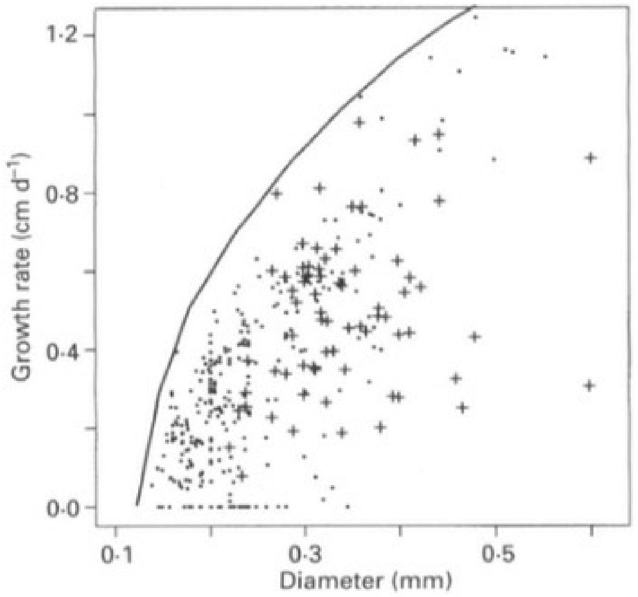


Figure 4. Relationship between apical diameter and growth rate. The hand-drawn line (upper limit of the scatter plot) illustrates a potential growth rate allowed by a given diameter (see the text). Young roots are highlighted (+). These points present the growth during the first 2 d after emergence.

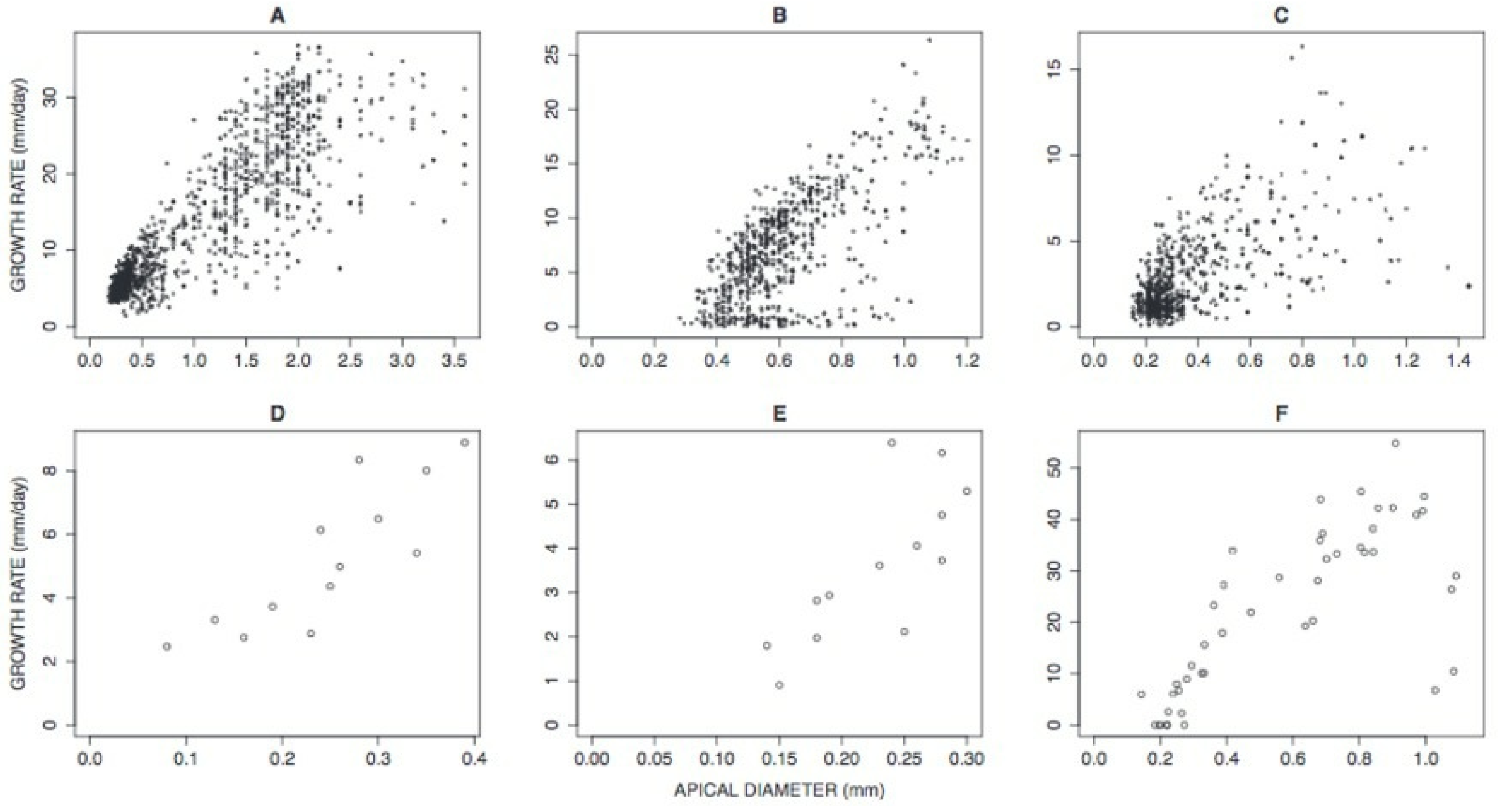


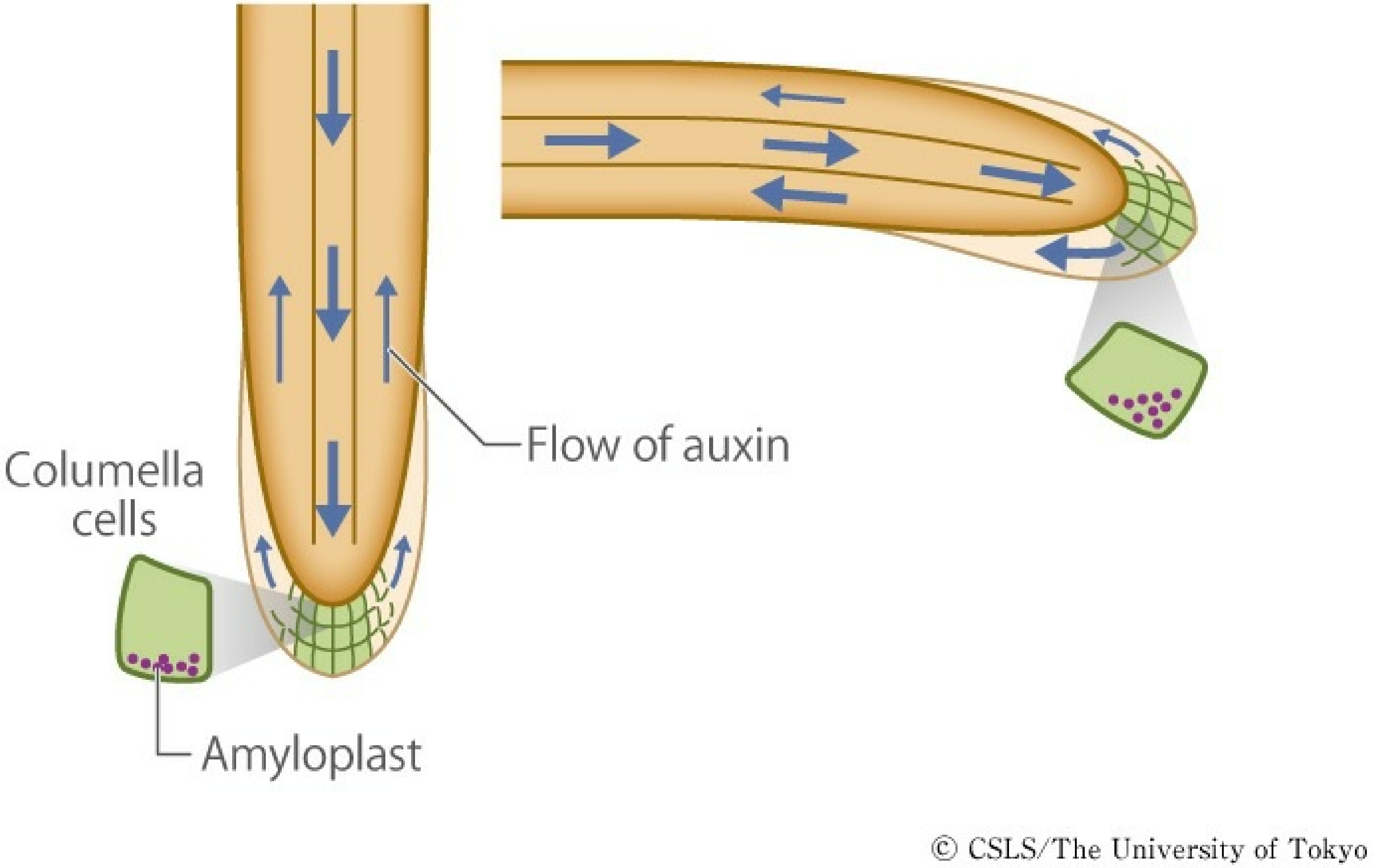
Fig. 1. Relationships between apical diameter and growth rate for the 6 different species. (A) *Musa*, (B) *Pisum sativum*, (C) *Prunus persica*, (D) *Teucrium botrys*, (E) *Thlaspi perfoliata*, (F) *Zea mays*.

Pages, L. (1995). Growth patterns of the lateral roots of young oak (Quercus robur) tree seedlings Relationship with apical diameter. New Phytol. **130**: 503–509.

Pagès, L., Bécel, C., Boukcim, H., Moreau, D., Nguyen, C., and Voisin, A.-S. (2013). Calibration and evaluation of ArchiSimple, a simple model of root system architecture. Ecol. Modell. **290**: 76–84.

TROPISMS

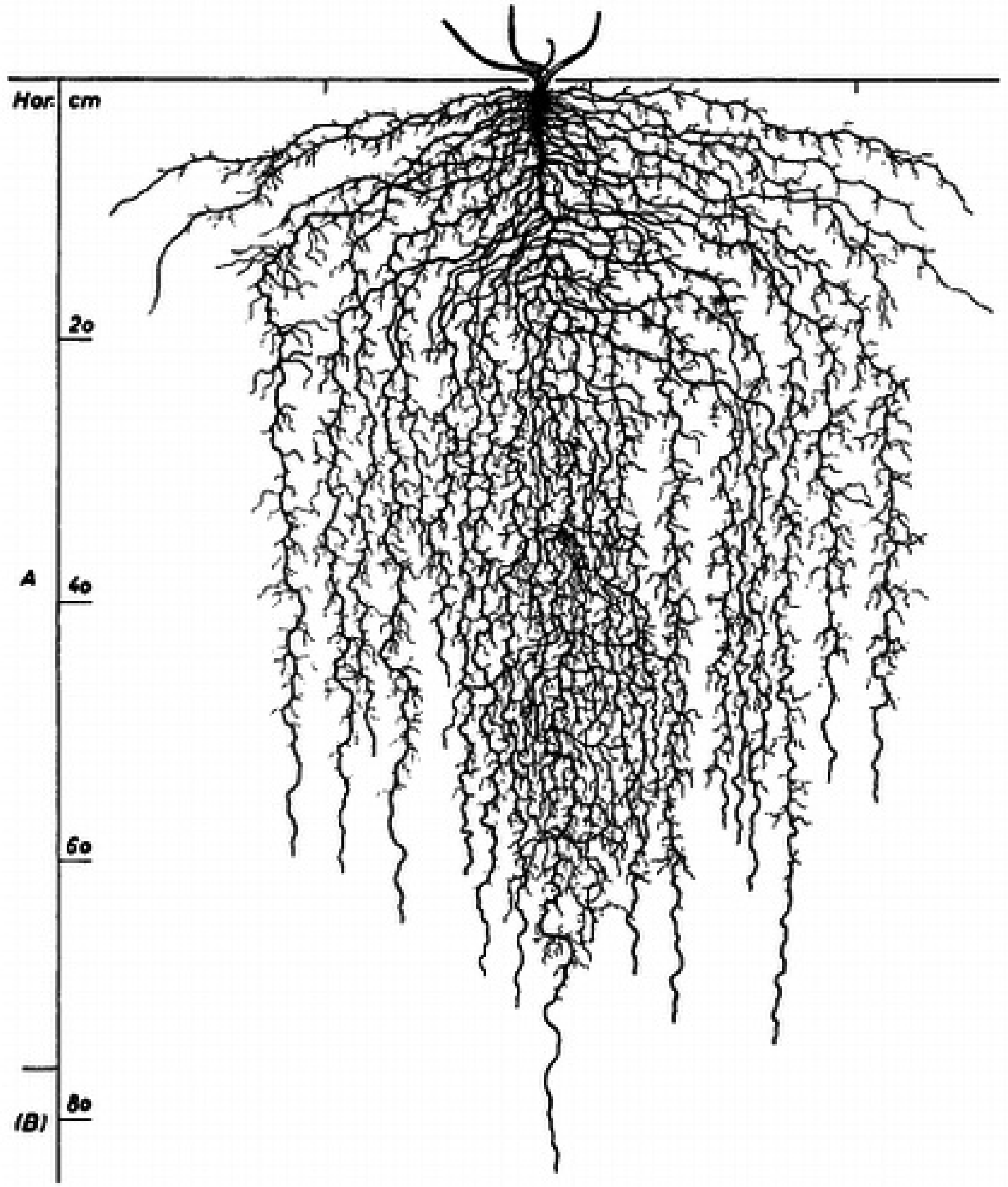
TROPISMS = GROWTH RE-DIRECTION

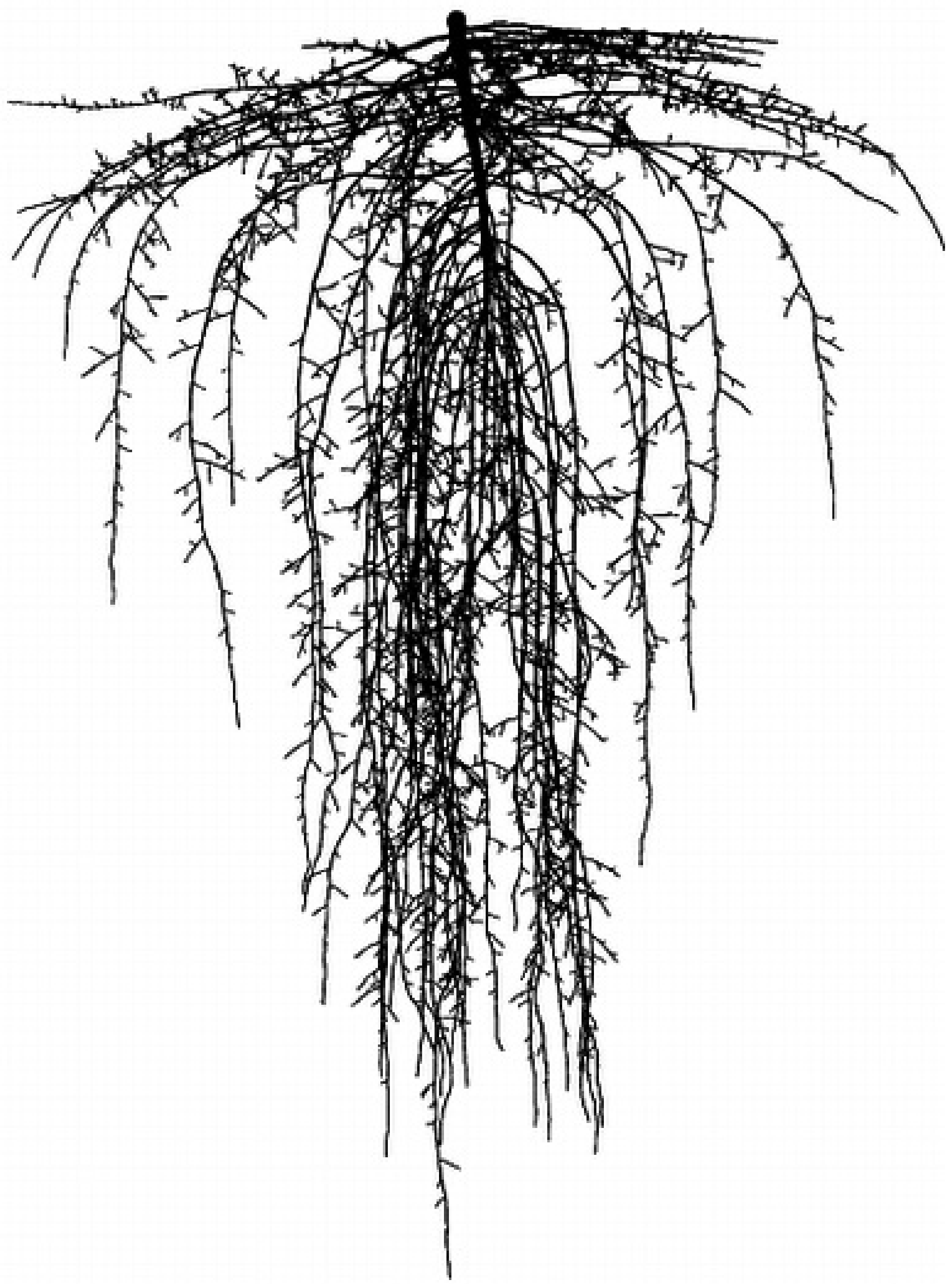


DIFFERENT TYPE OF TROPISMS IN ROOTS

- **Gravitropism**
  - toward the center of the Earth
- **Chemiotropism**
  - toward an increasing concentration in a specific nutrient
- **Hydrotropism**
  - toward increasing water potential values
- Tropisms change with
  - root types
  - root ages
  - environment conditions
  -

GRAVITROPISM = F(ROOT AGE)





GRAVITROPISM = F(SOIL TEMP)

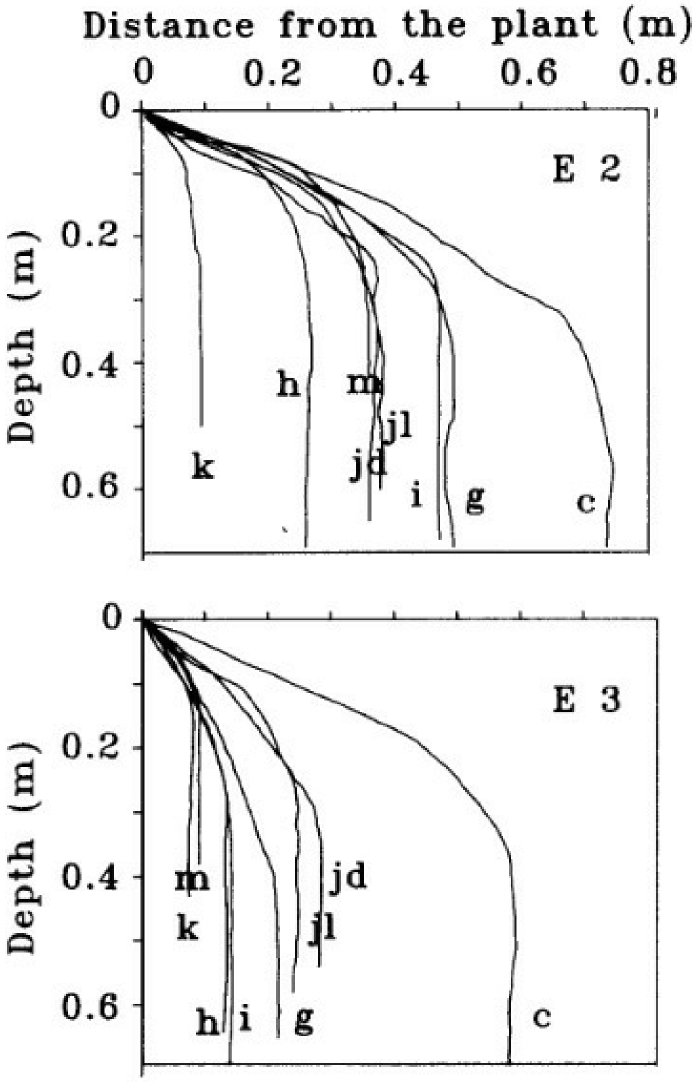


Fig. 3. Mean trajectories of E2 and E3 roots in the 8 treatments. Labels of treatments as in Table 1.

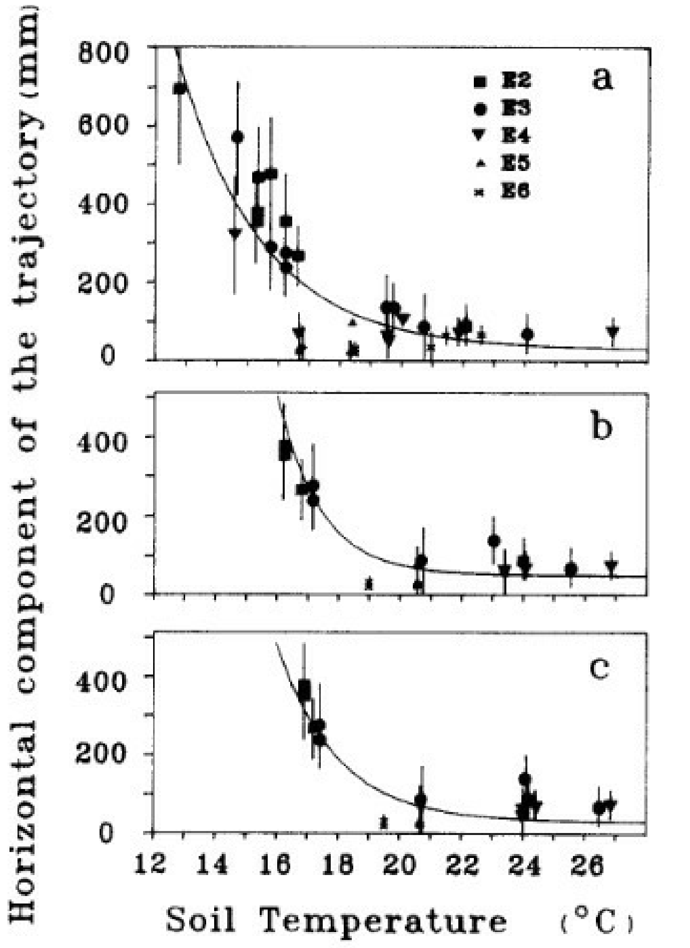


Fig. 4. Relationship between the soil temperature and the horizontal distance travelled by the root apex in the 0–0.40 m layer. (x_{40}), for all the studied internodes in the 8 treatments. **a**: soil temperature at the 100-mm depth at the meteorological station; **b** and **c**: soil temperatures measured at the 100- and the 25-mm depth, respectively. The latter were measured in Grignon in 1989 only.
Equations of the fitted curves: a: $x_{40} = \exp(-0.368\,T + 11.29) + 30$; b: $x_{40} = \exp(-0.718\,T + 17.60) + 30$; c: $x_{40} = \exp(-0.518\,T + 14.40) + 30$.

Tardieu, F. et al. (1991)
Plant Soil 131, 207–214

ROOT BRANCHING

BRANCHING

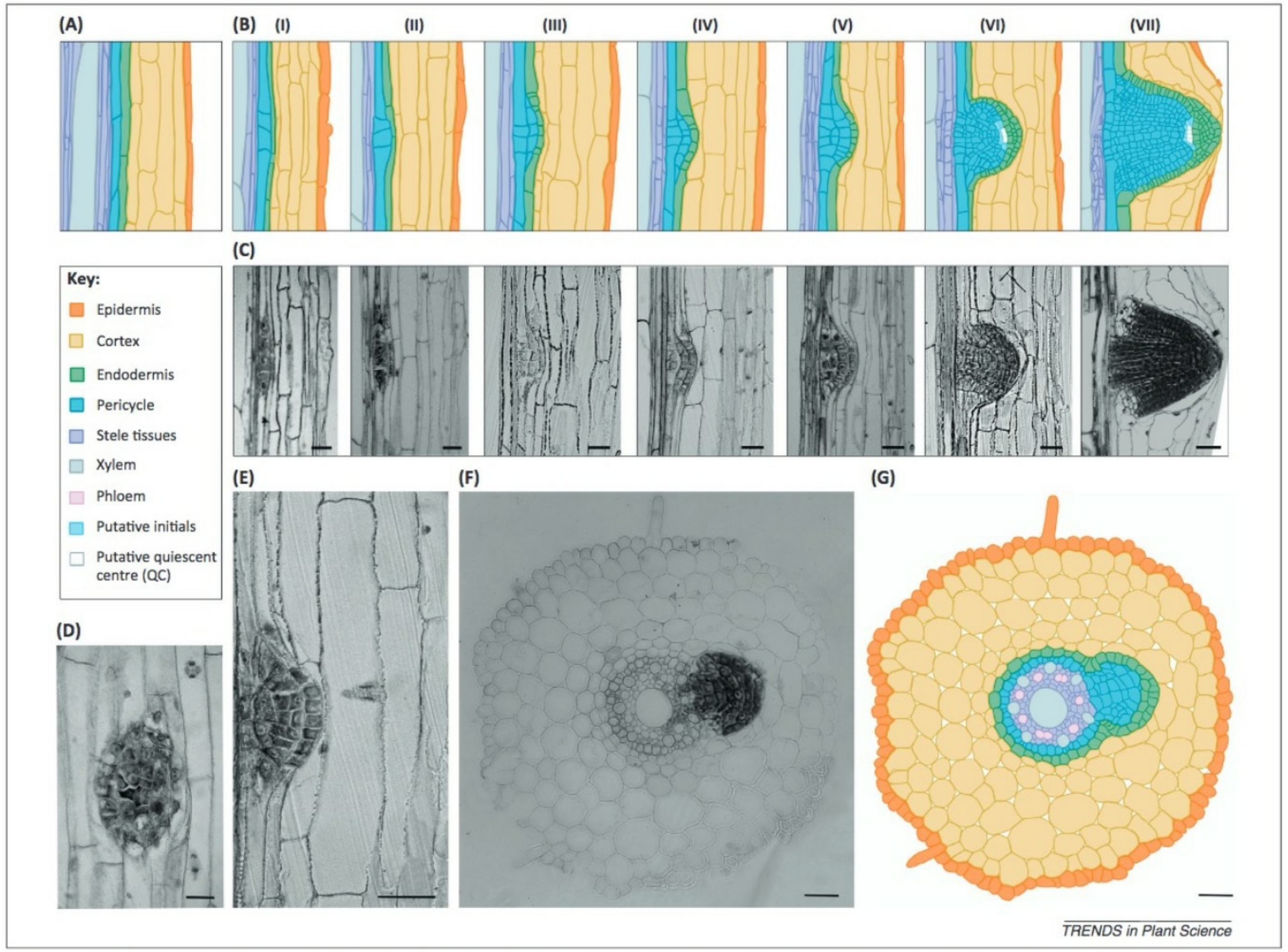
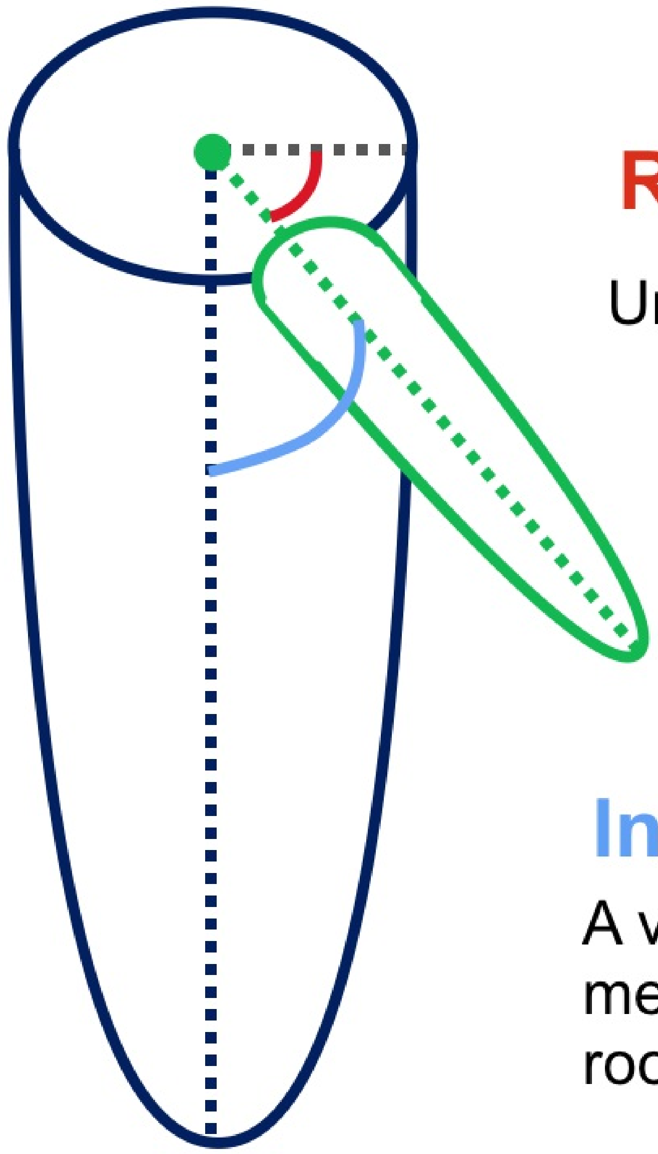


Figure 1. Lateral root development in barley. **(A)** Illustration of a longitudinal section showing the typical tissue organisation of cereal roots. The number of cortex layers that have to be penetrated by the developing meristem is much larger than in *Arabidopsis*. **(B)** Succession of morphological stages during lateral root development and emergence (arbitrary stages). **(C)** Original toluidine blue stained sections used for illustrations in (B). **(D)** Periclinal and **(E)** anticlinal longitudinal sections of the growing lateral roots. The sections show an extensive cortical region around the primordium where divisions are taking place. **(F)** Radial tissue organisation of cereal roots (toluidine blue staining). **(G)** Illustration of the section in (F) to highlight the deformation of the cortex that occurs during lateral root penetration. (Scale bars = 50 μm).

Orman-Ligeza, B. *et al*. (2013) Post-embryonic root organogenesis in cereals: branching out from model plants. *Trends Plant Sci*.

LATERAL ROOTS EMERGE WITH A GIVEN ANGLE

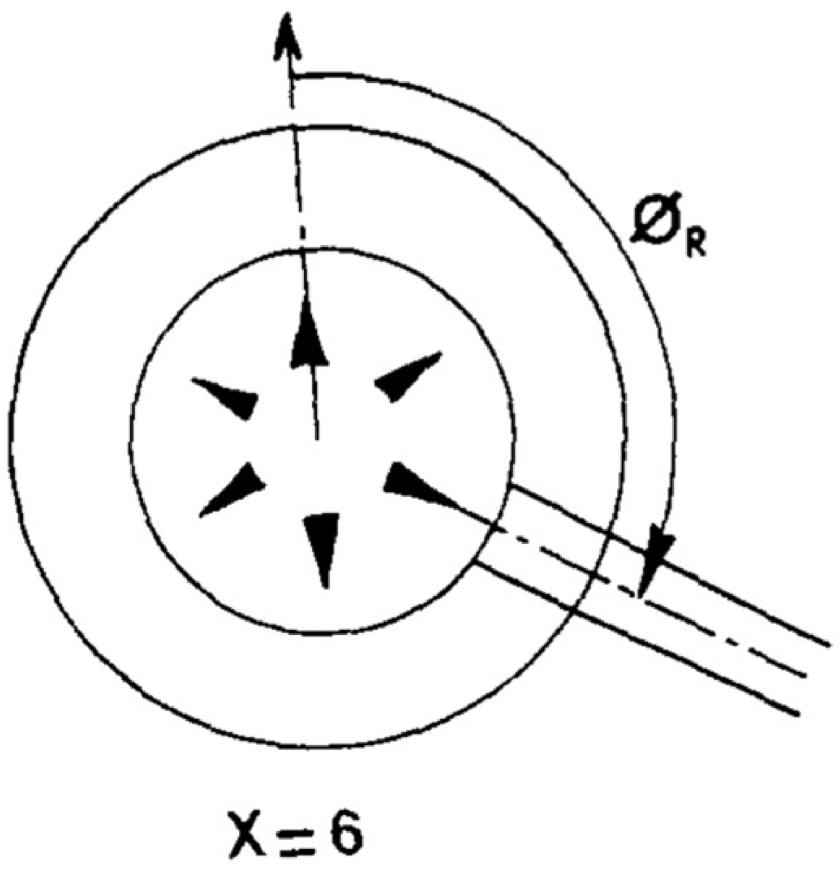


Radial angle

Uncommon metric

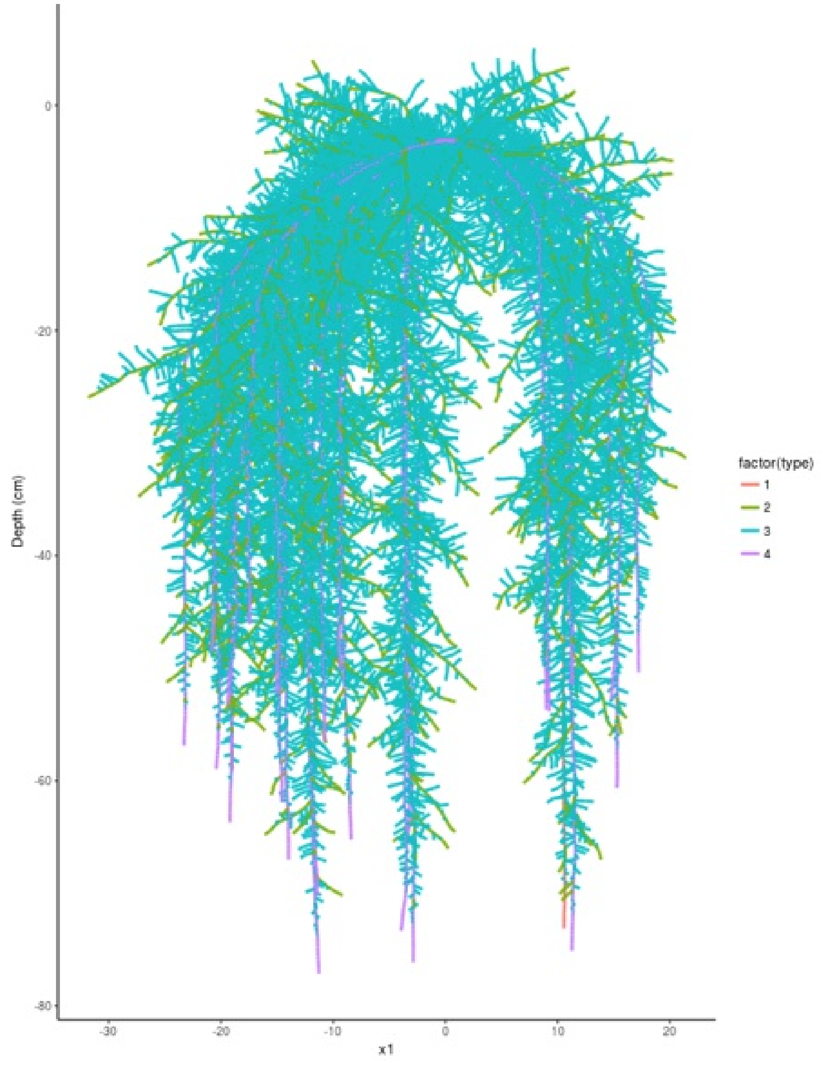
Insertion angle

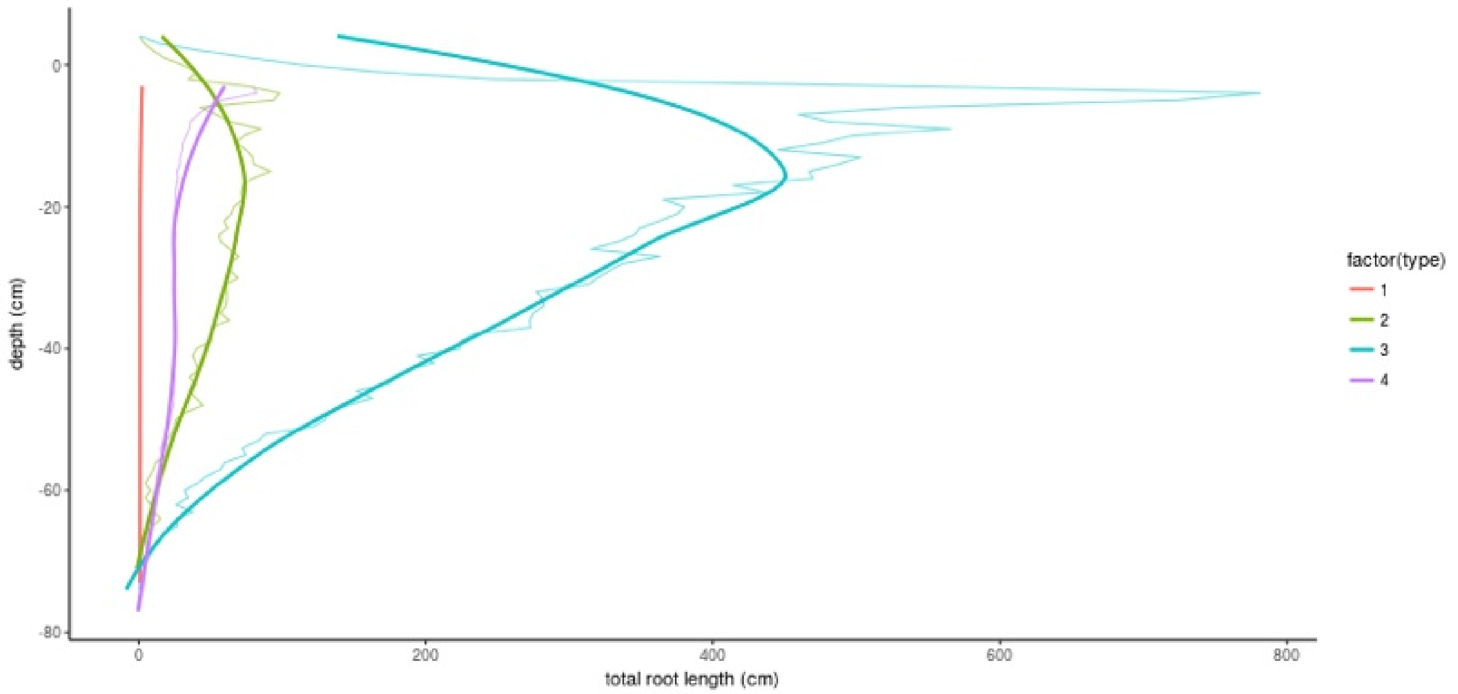
A very common metric retrieved from root images



[Pagès, L. et al. (1989). Plant and Soil, 119(1), 147–154.]

LATERAL ROOTS REPRESENT A LARGE PROPORTION OF THE TOTAL ROOT SYSTEM

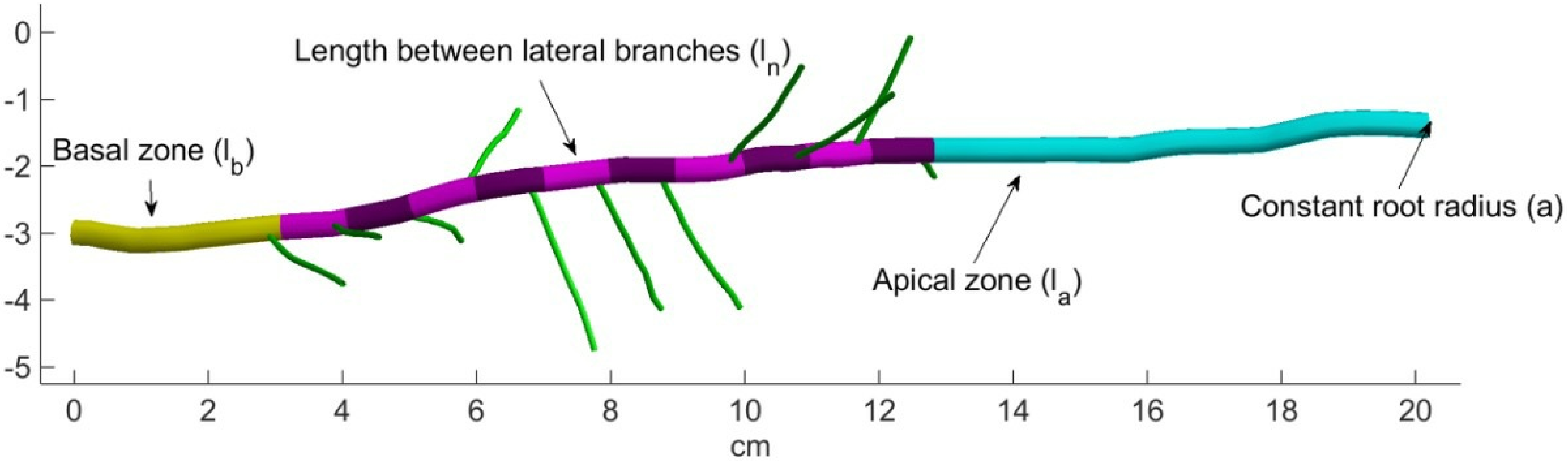


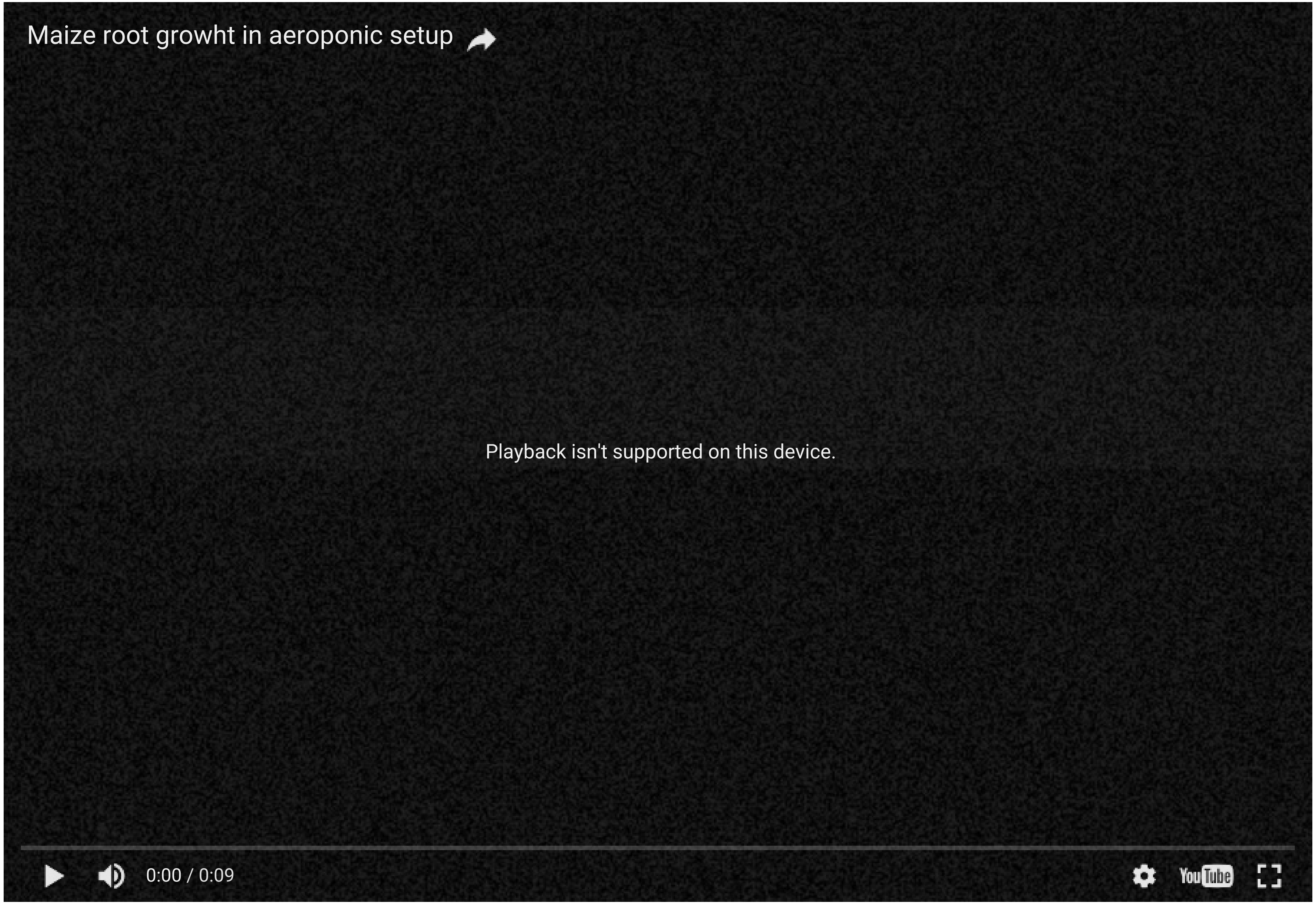


Metric	Value	Unit
Total root length	23318	[cm]
Number of roots segments	30845	[-]
Maximal depth	77	[cm]

THE PARENT ROOT CAN BE DIVIDED IN DIFFERENT REGIONS

- Basal zone
- Branched zone
- Apical zone




Maize root growht in aeroponic setup
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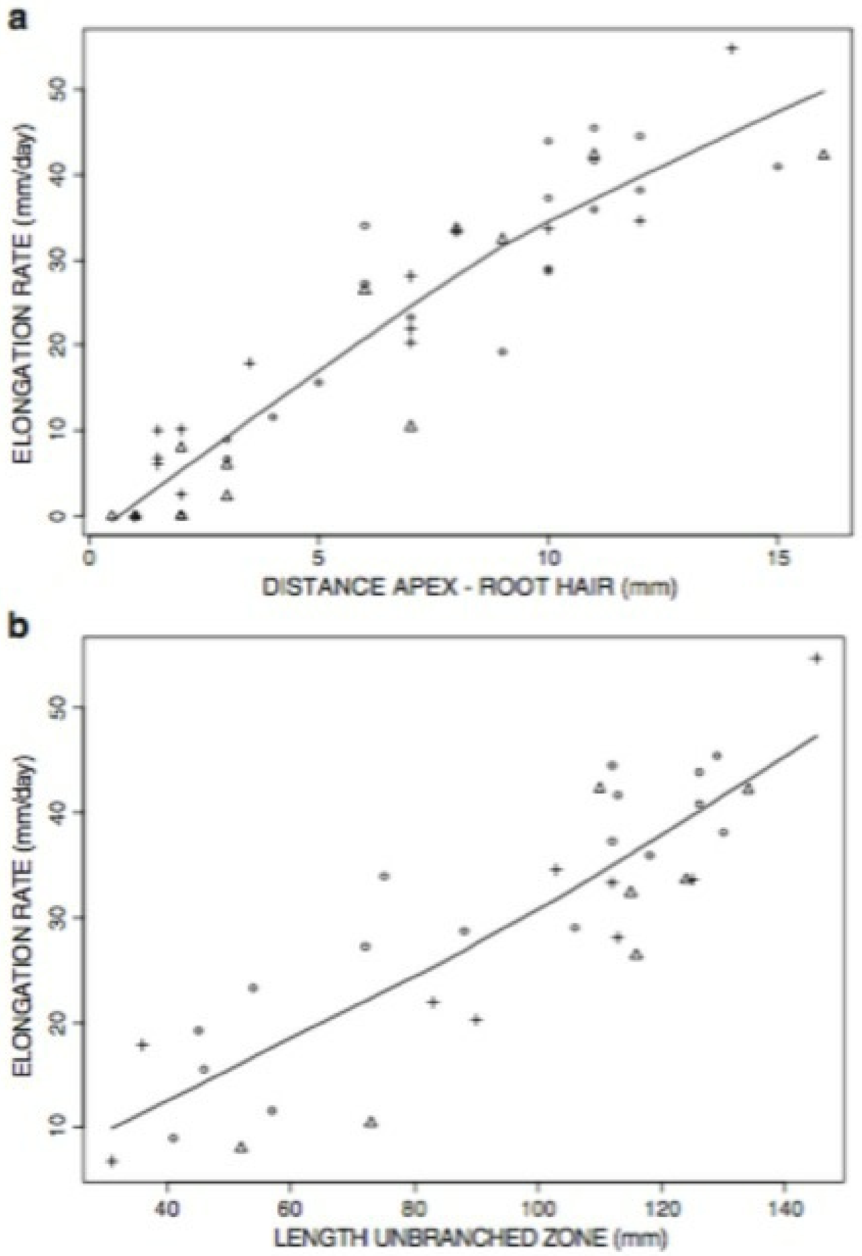
LAUZ = F(GROWTH)

LAUZ = Length of Apical Unbranched Zone

Fig. 2 Relationships between indicators and elongation rate, presented in two examples. **a** Elongation rate versus distance from the apex to the nearest root hair at least 0.2 mm long (L_{hair}); **b** Elongation rate versus length of the unbranched zone (L_{lat}). Each point represents a root measured in a root box. Symbols indicate substrates (circles: nylon mesh; triangles: peat/vermiculite; plus: peat/sand). The curves represent the trends, as evaluated by a local regression smoother (lowess)



Pagès, L., Serra, V., Draye, X., Doussan, C., and Pierret, A. (2010). Estimating root elongation rates from morphological measurements of the root tip. Plant Soil **328**: 35–44.

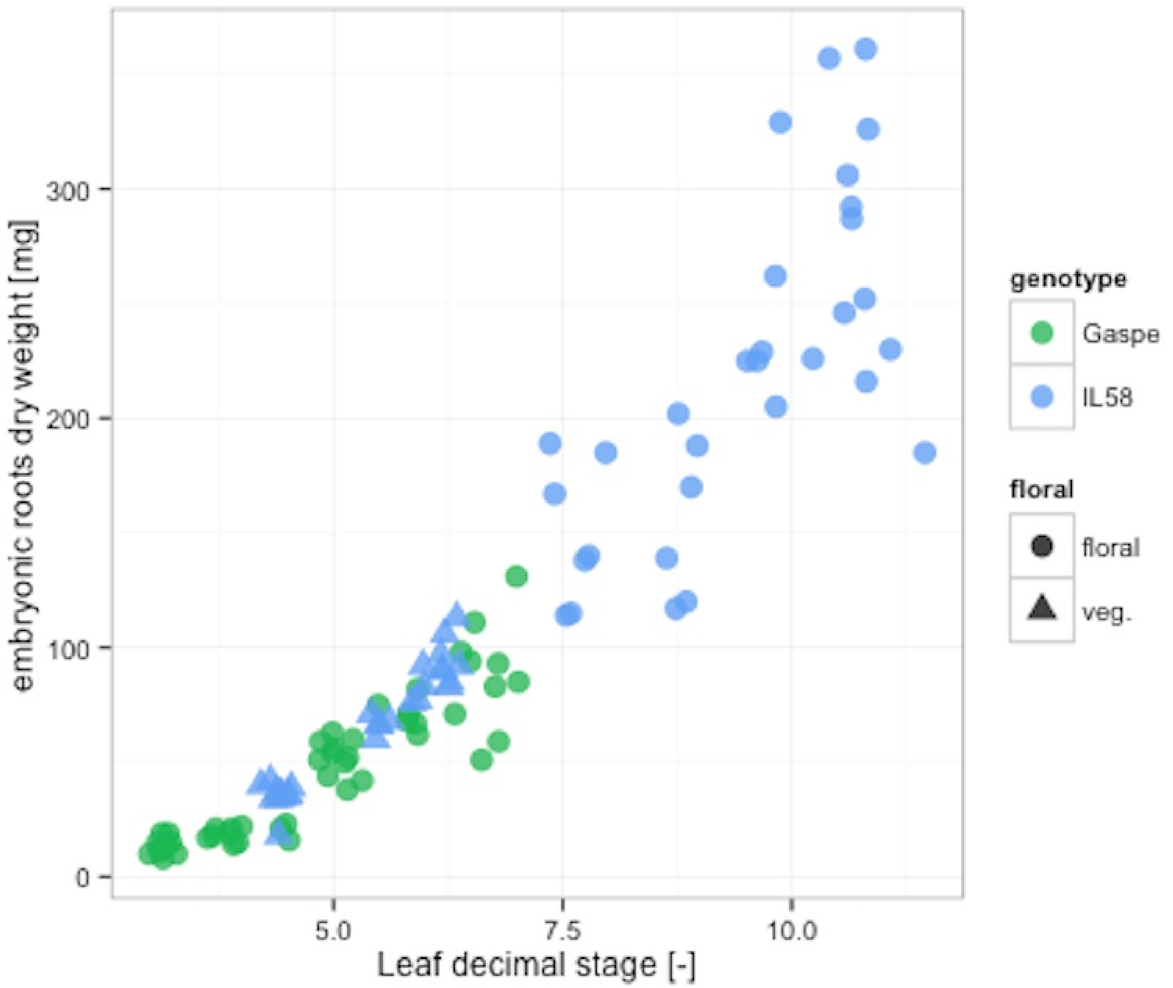
INTEGRATIONS

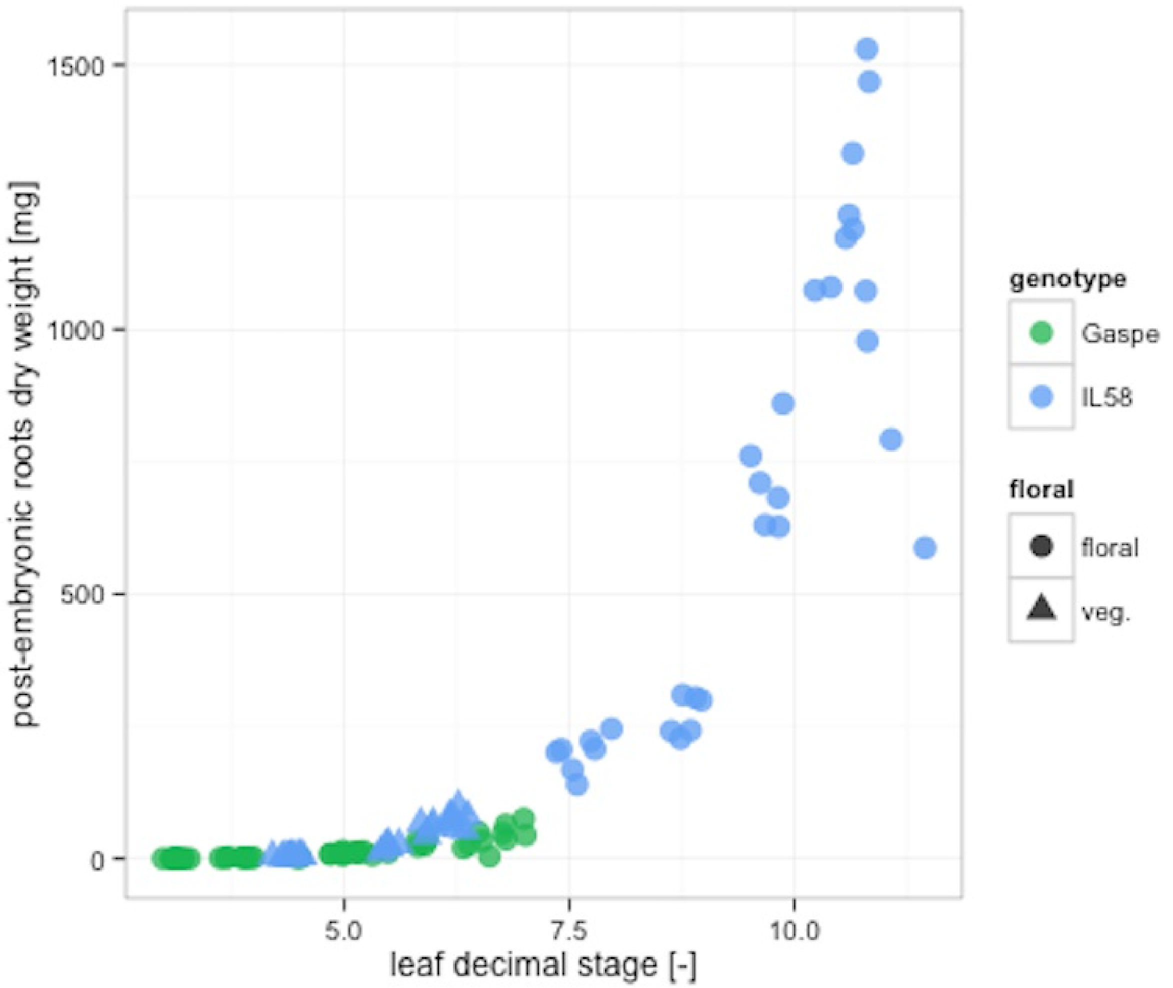
DIFFERENT STRATEGIES

- Dicots
    - [x,y] exploration -> lateral roots
    - [z] exploration -> primary axis
    - secondary growth -> large number of laterals
    - Axes stop growing -> stay alive
- Monocots
    - [x,y,z] exploration -> primary axis (nodals)
    - no secondary growth -> limited number of laterals
    - Axes stop growing -> reduce the branching region
    - post-embryonic root system much more important
    - nodal root production stops at flowering

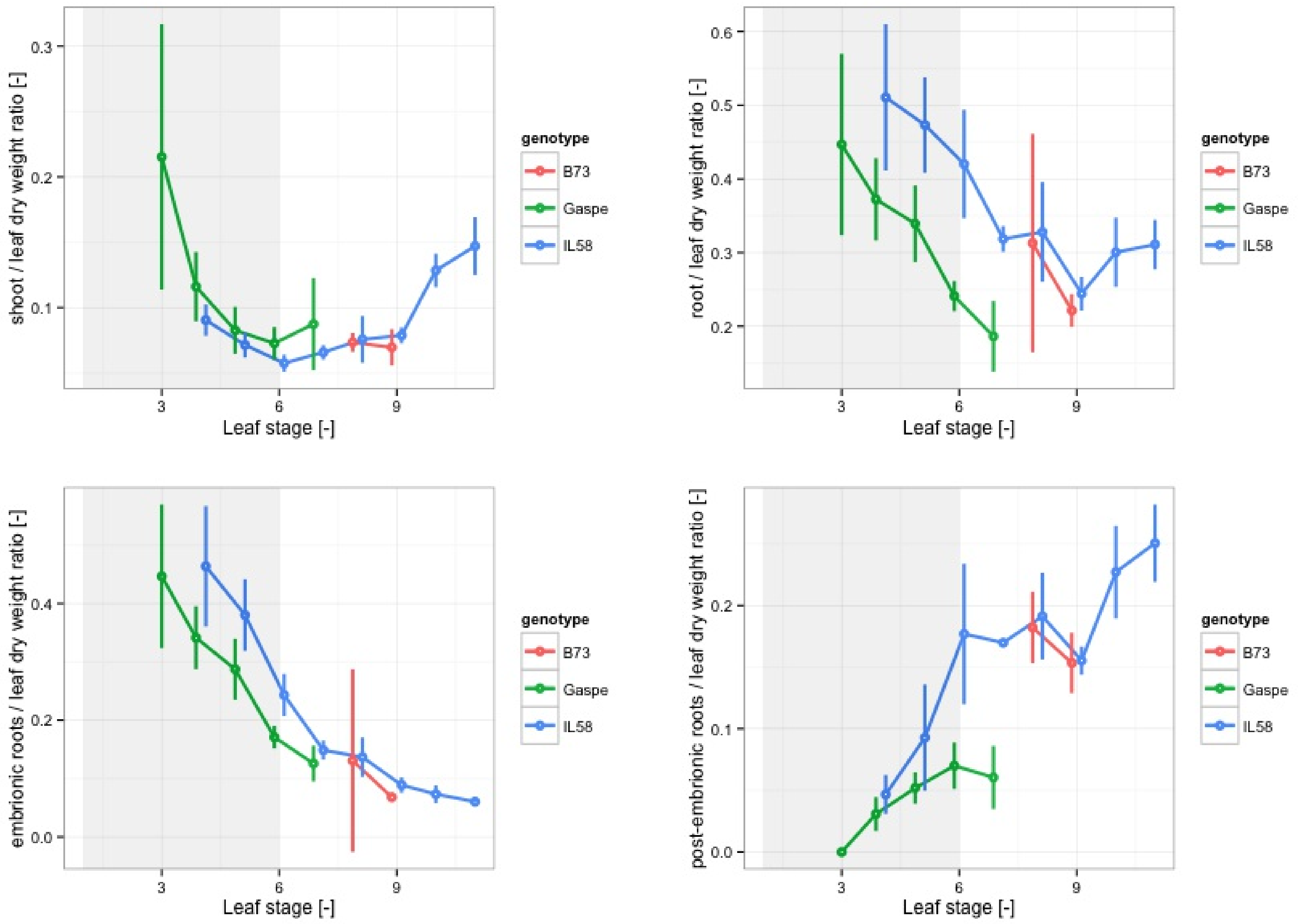
ROOT HAVE A COST

- Different costs:
  - production
  - maintenance
  - exudation

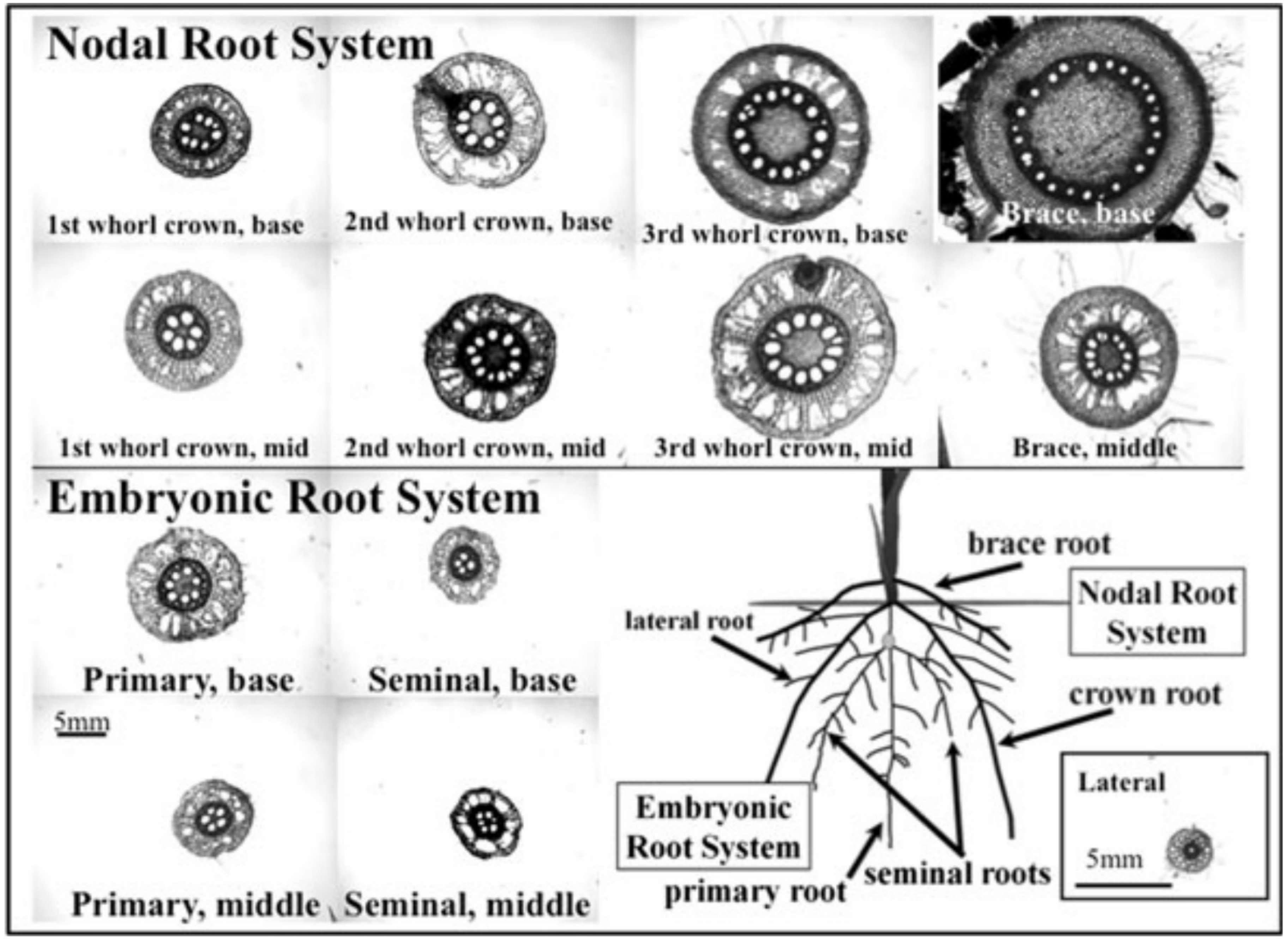




ROOT / SHOOT ALLOCATION

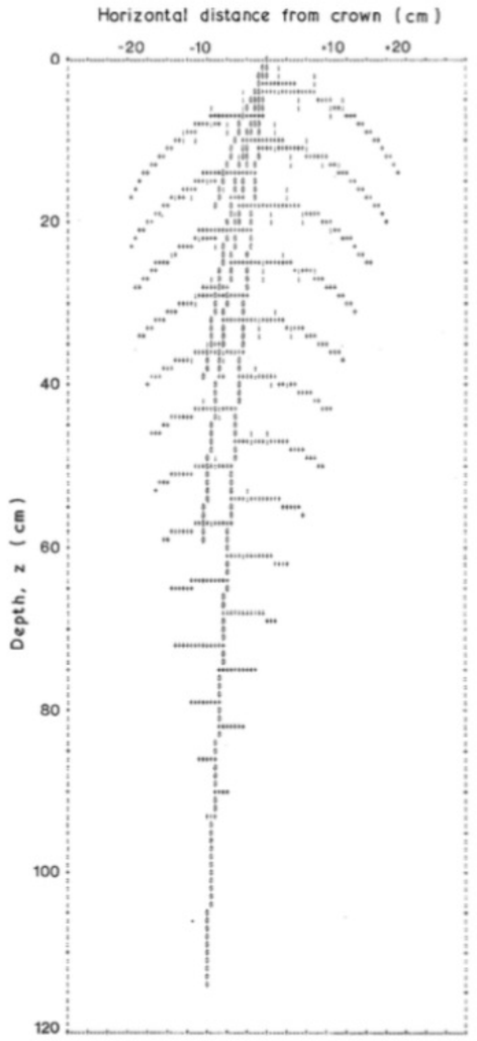


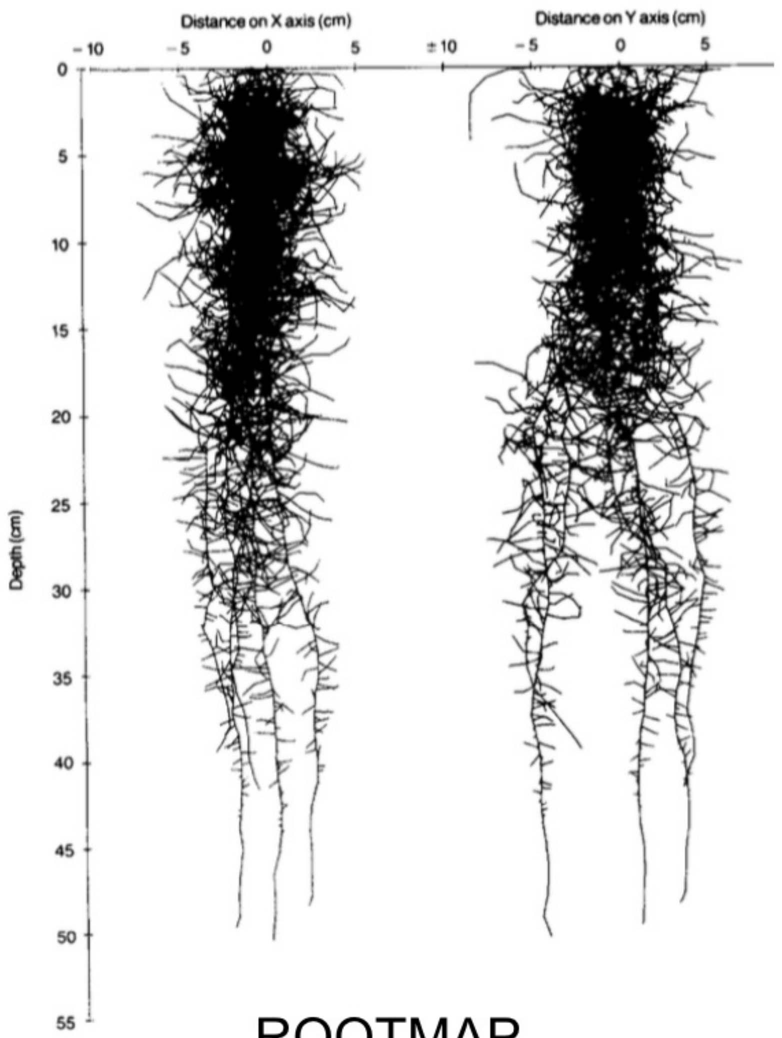
REDUCING MAINTENANCE COST -> AERENCHYMA



Burton, A.L. et al. (2012) Plant Soil

MODELLING ROOT SYSTEM ARCHITECTURES - 1





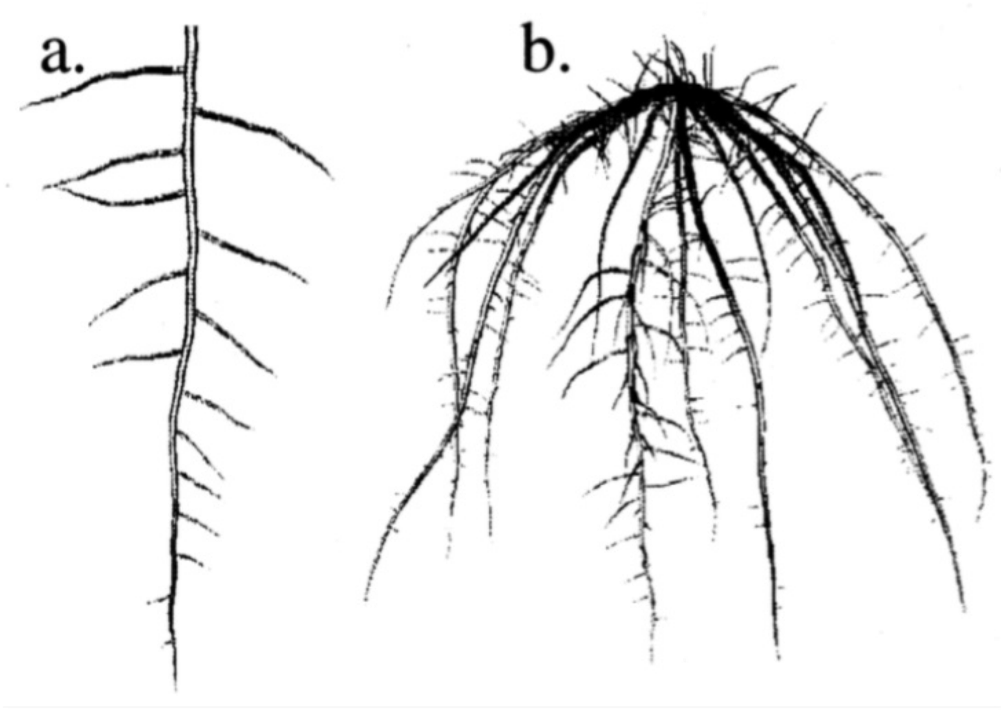
ROOTMAP

Lungley, D. R. (1973). Plant and Soil, 38(1), 145–159.

Diggle, A. J. (1988). Plant and Soil, 105(2), 169–178

Pagès, L., Jordan, M. O., & Picard, D. (1989). Plant and Soil, 119(1), 147–154

MODELLING ROOT SYSTEM ARCHITECTURES - 2

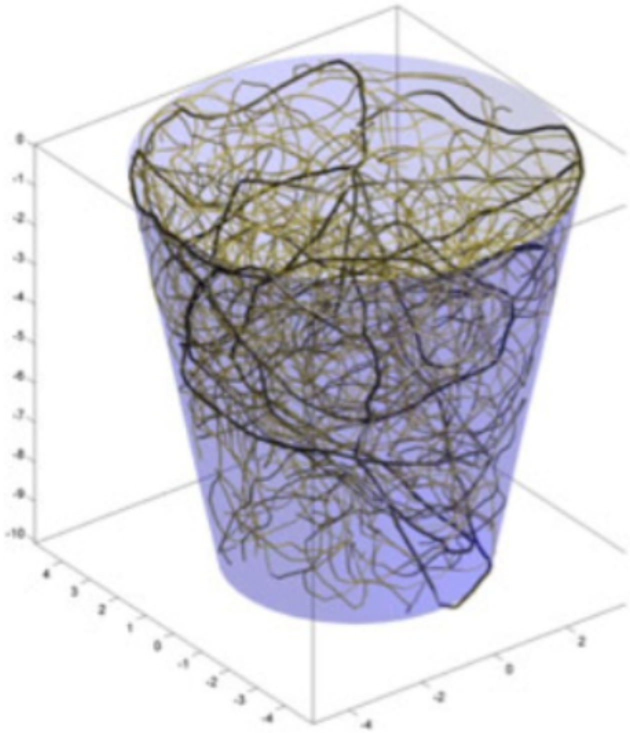


SIMROOT

Lynch, J. P. et al (1997). SimRoot: Plant and Soil, 188(1), 139–151.

ROOTTYP

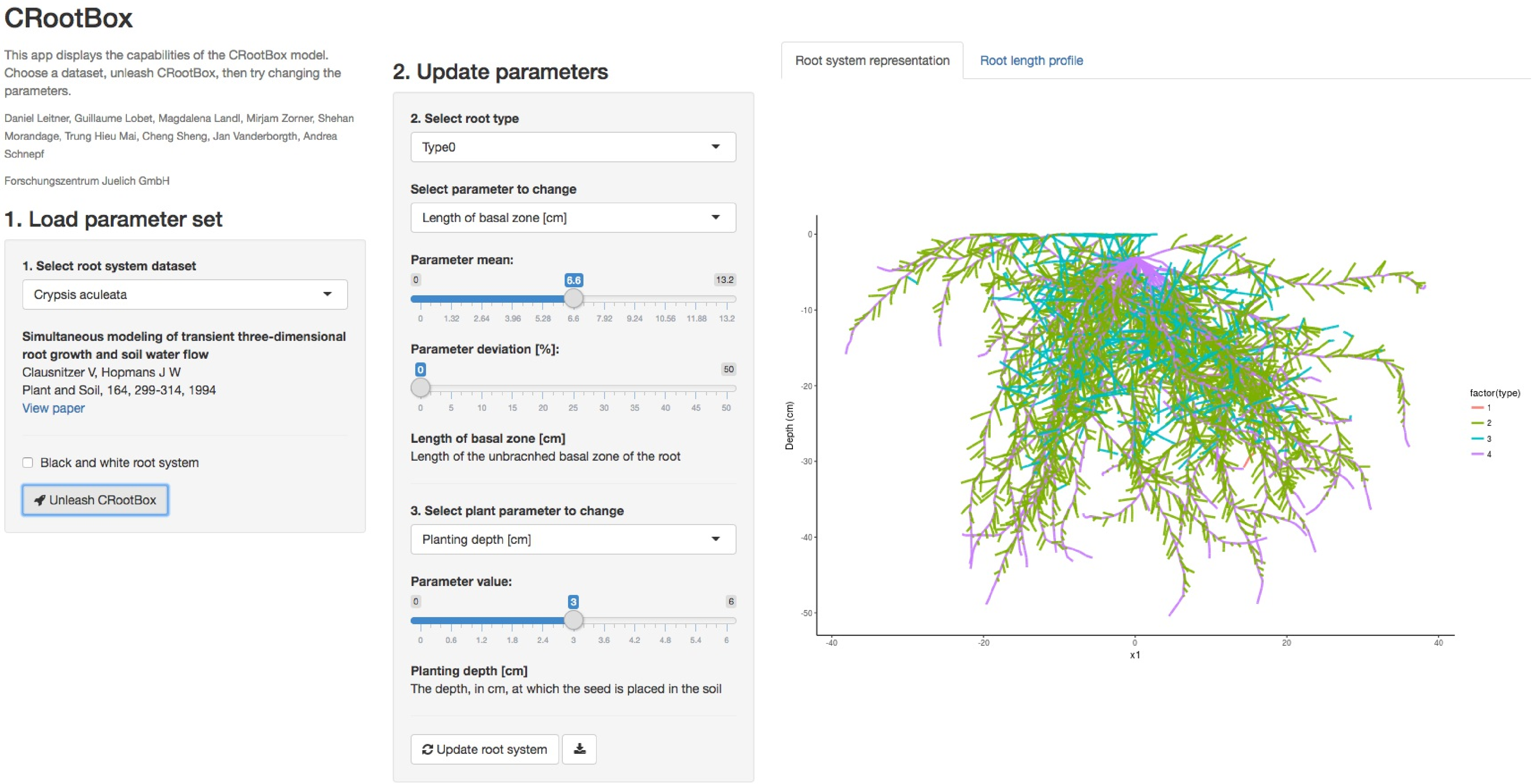
Pagès, L. et al. (2004). Plant and Soil, 258, 103–119.



ROOTBOX

Leitner, D. et al. (2010). Plant and Soil, 332, 117–192.

TRY OUT THE MODEL



https://bit.ly/crootbox

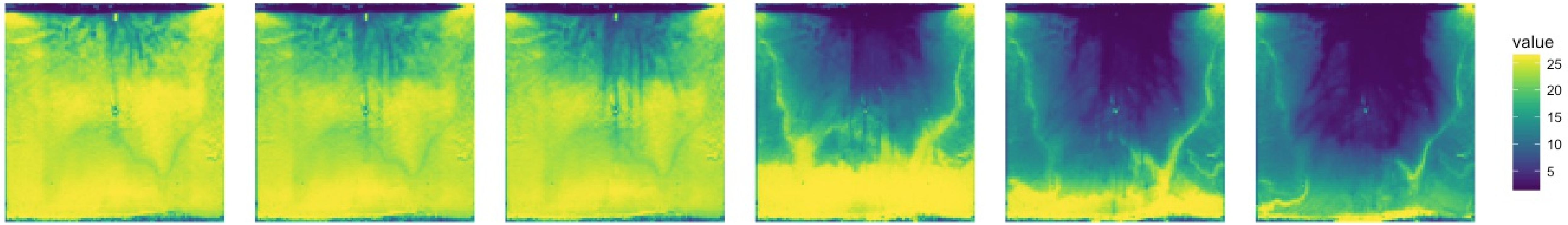
EXERCICES

1. Choose a plant species
2. Maxime exploration and reduce cost
3. Maxime uptake of a top-layer, immobile ressource
4. Maxime uptake of a mobile ressource

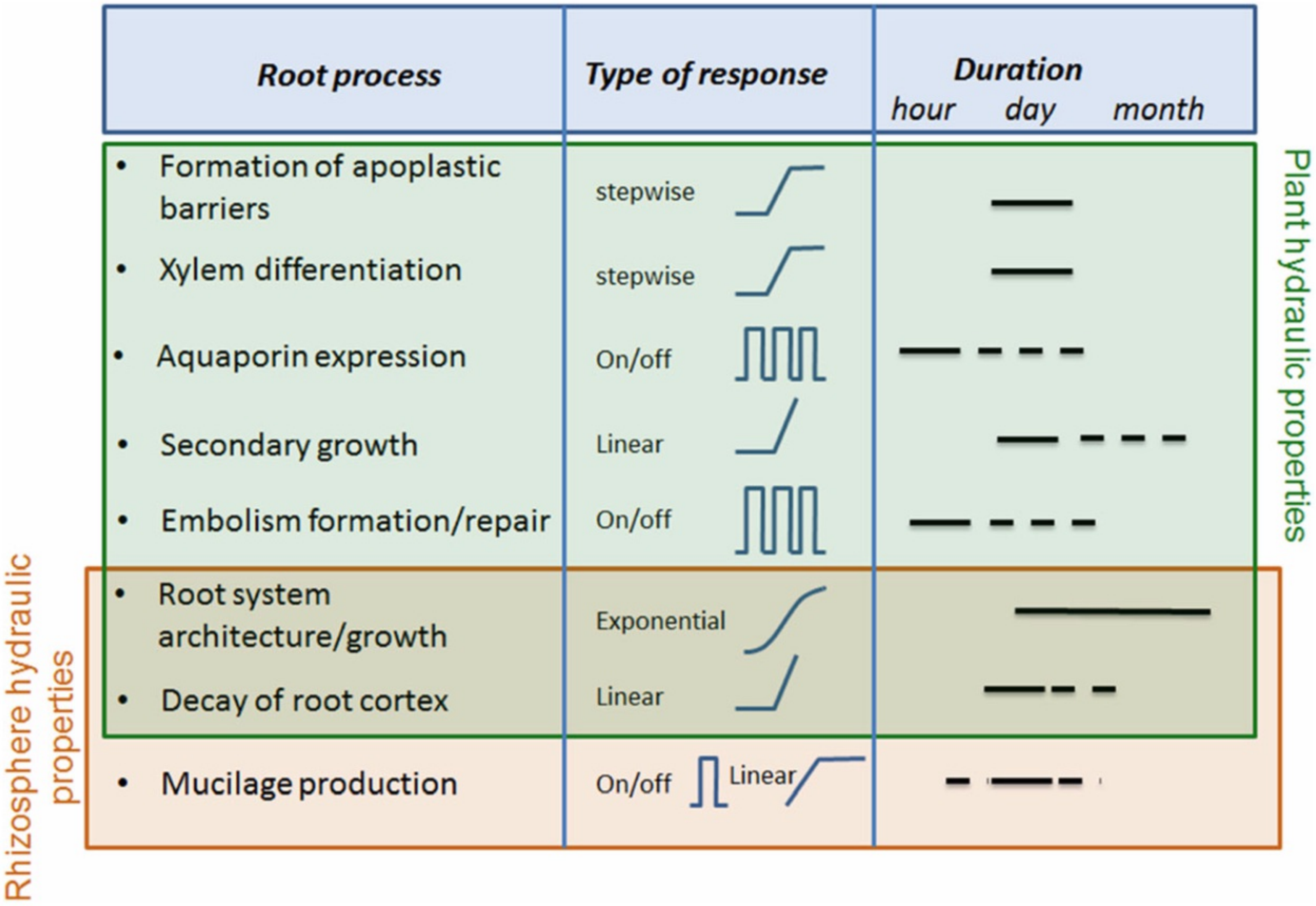
HOW DO ROOT ARCHITECTURE SHAPE WATER UPTAKE?

About root hydraulic architecture, root density profile and drought

Press down for details



ROOT PROCESS AND WATER UPTAKE



Vetterlein, D. and Doussan, C. (2016) Plant Soil

WATER FLOW TROUGHT THE ROOT CYLINDER

THREE PATHWAYS

- Apoplastic pathway
  - mass movement
  - water potential differences
  - high transpiration (day)
- Symplatic pathway
  - diffusion
  - osmotic differences
  - low transpiration (night)
- Transcellular pathway

HOW DO WATER UPTAKE AFFECT ROOT ARCHITECTURE?

HYDRO-PATTERNING