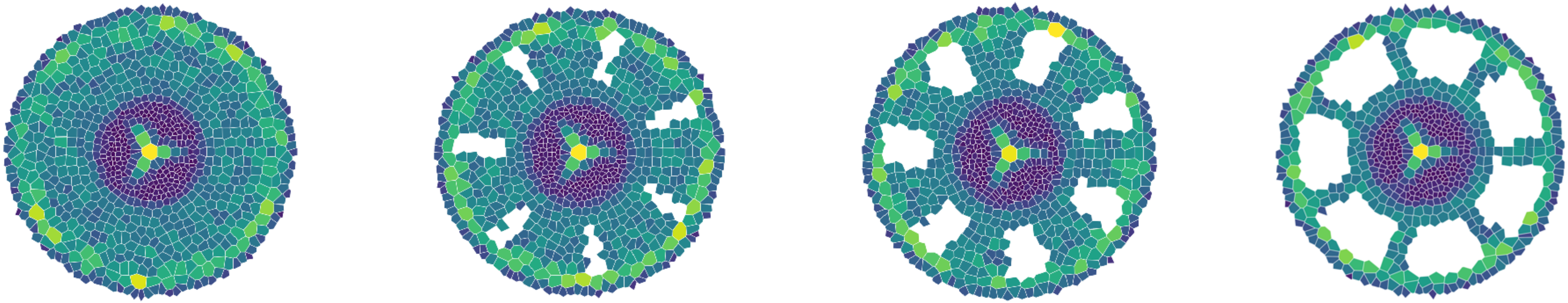


HOW CAN WE USE

COMPUTATIONAL TOOLS TO EXTEND OUR UNDERSTANDING OF **WATER RELATIONS** IN PLANTS ?

Guillaume Lobet, Adrien Heymans, Valentin Couvreur, Xavier Draye, Mathieu Javaux, Daniel Leitner, Félicien Meunier, Sixtine Passot, Andrea Schnepf, Jan Vanderborght

guillaumelobet

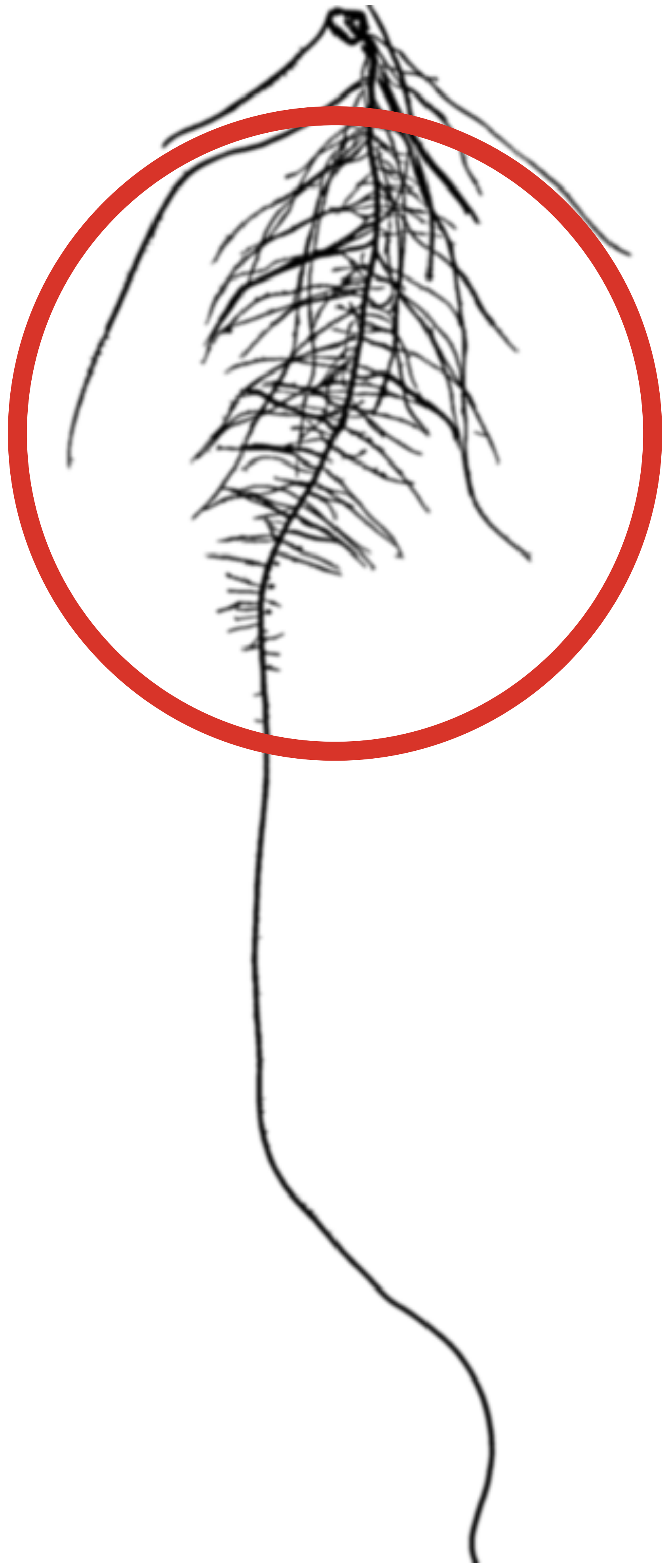
bit.ly/lobet-useps10

bit.ly/lobet-useps10-papers

UCLouvain

JÜLICH Forschungszentrum


WWW.WOOCLAP.COM/USEPS10



ROOT SYSTEMS
ARE **COMPLEX**
& GET **MESSY**
REALLY **QUICKLY**!

LATERAL ROOT GROWTH IS OFTEN ASSUMED TO BE **HOMOGENEOUS**

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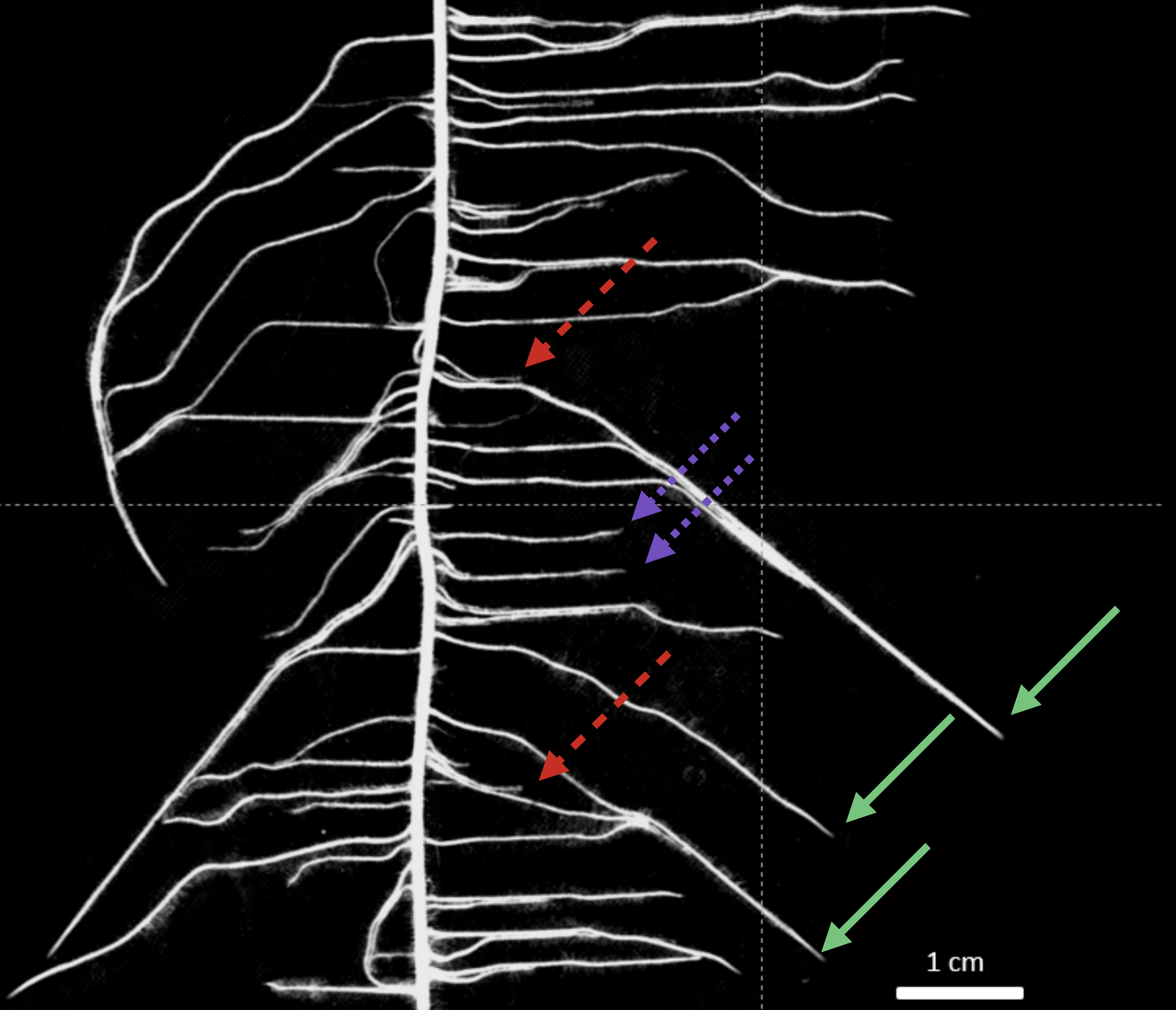
LATERAL ROOT CAN HAVE **DIFFERENT BEHAVIOURS**

Sixtine
Passot

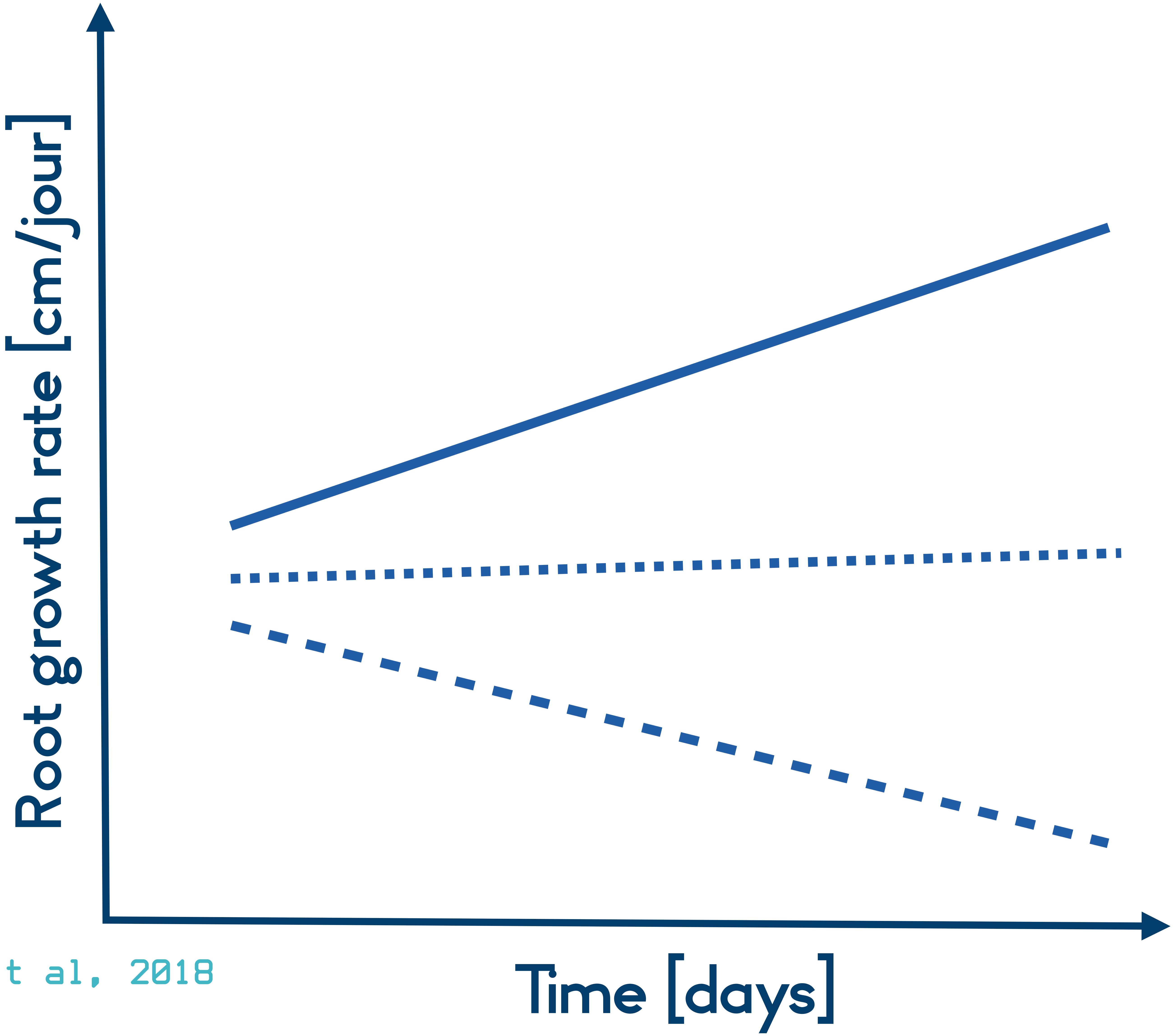
Passot, Moreno et al, 2018
Plant Physiology

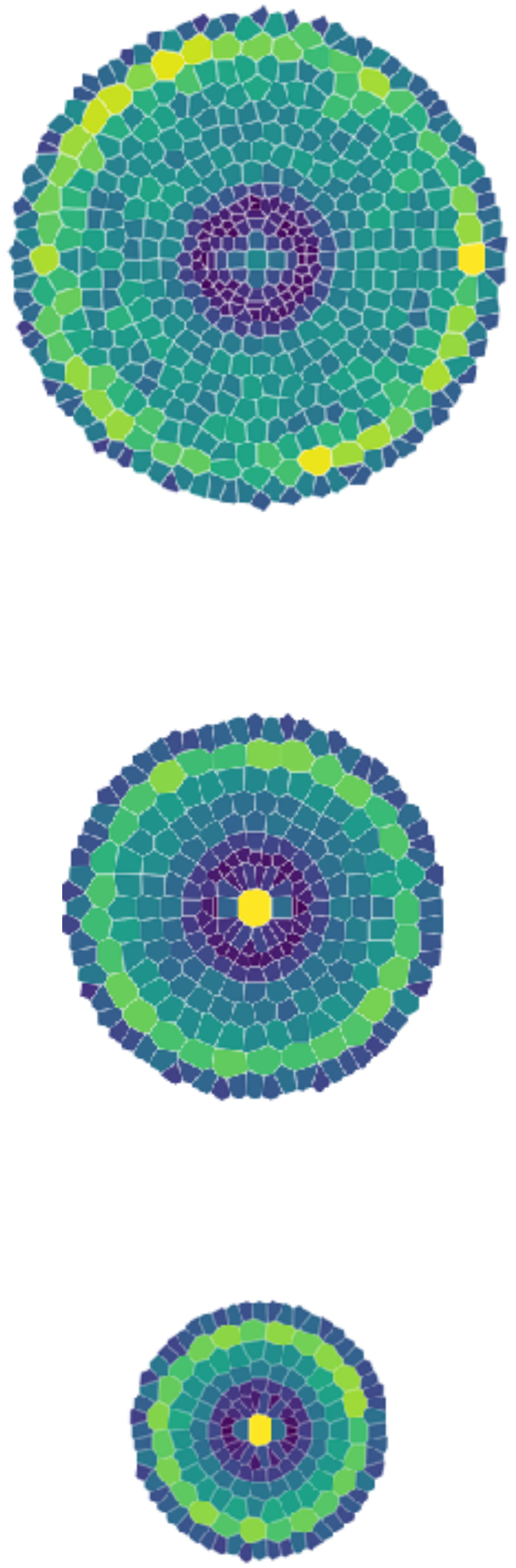
Müller et al, 2019
TIPS



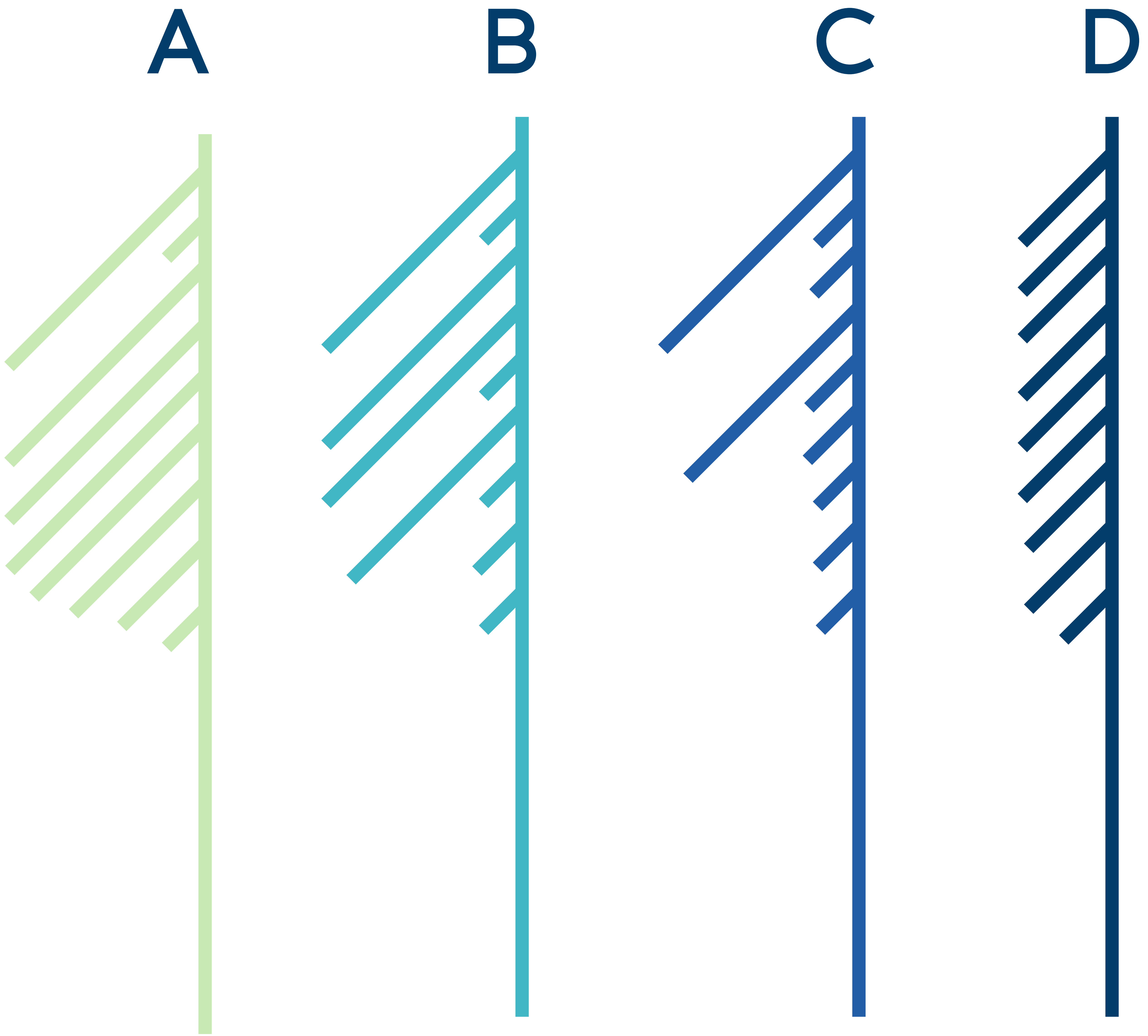
LATERAL ROOT CAN HAVE **DIFFERENT ANATOMIES**

Sixtine
Passot





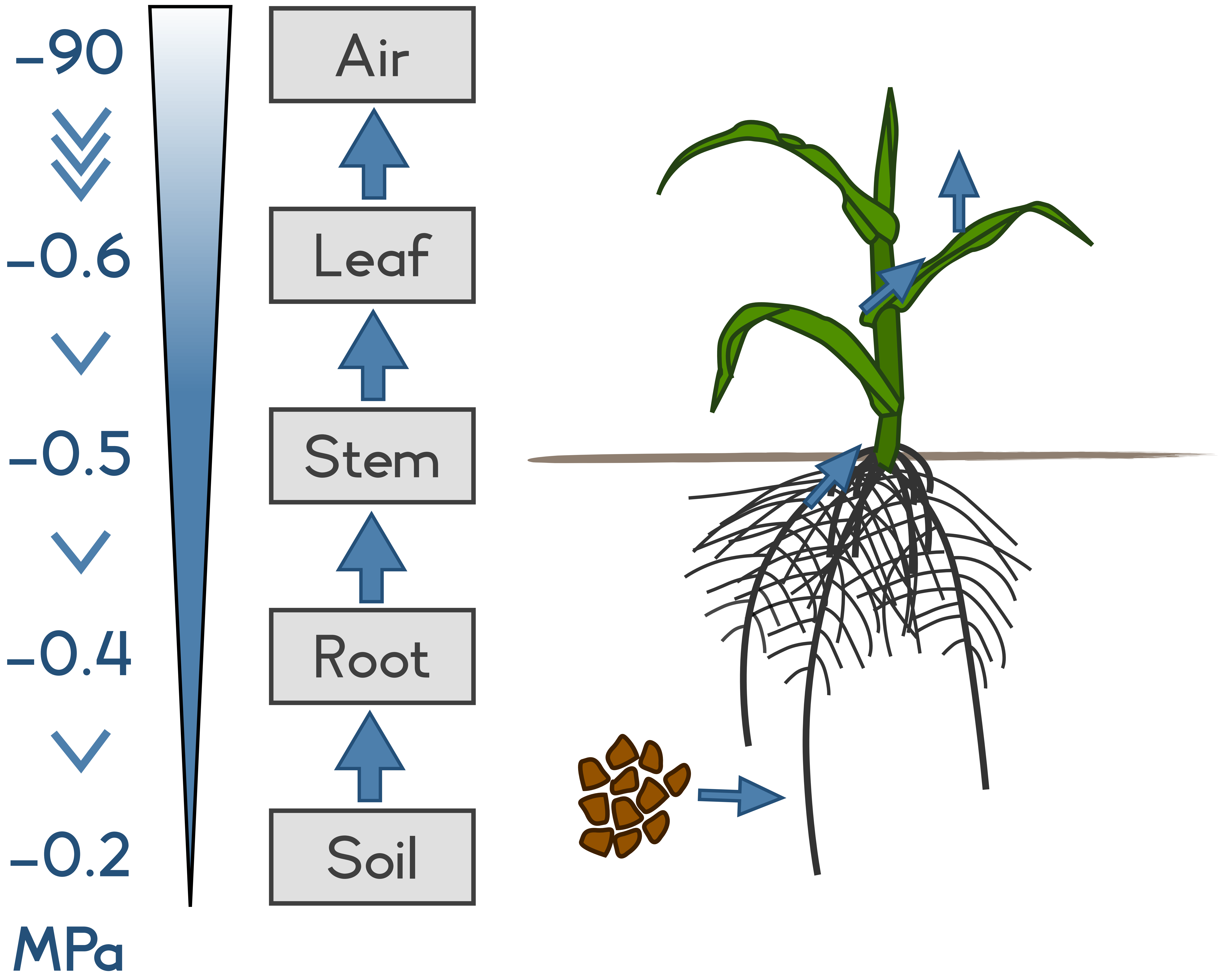
Passot, Moreno et al, 2018
Plant Physiology



WHAT IS THE **FUNCTIONAL IMPLICATION** OF HAVING DIFFERENT LATERAL ROOT TYPES?

WWW.WOOCLAP.COM/USEPS10

WATER FLOW IN THE SOIL–**PLANT**–ATMOSPHERE



WATER FLOW IN THE SOIL–**PLANT**–ATMOSPHERE IS A **PASSIVE** PROCESS

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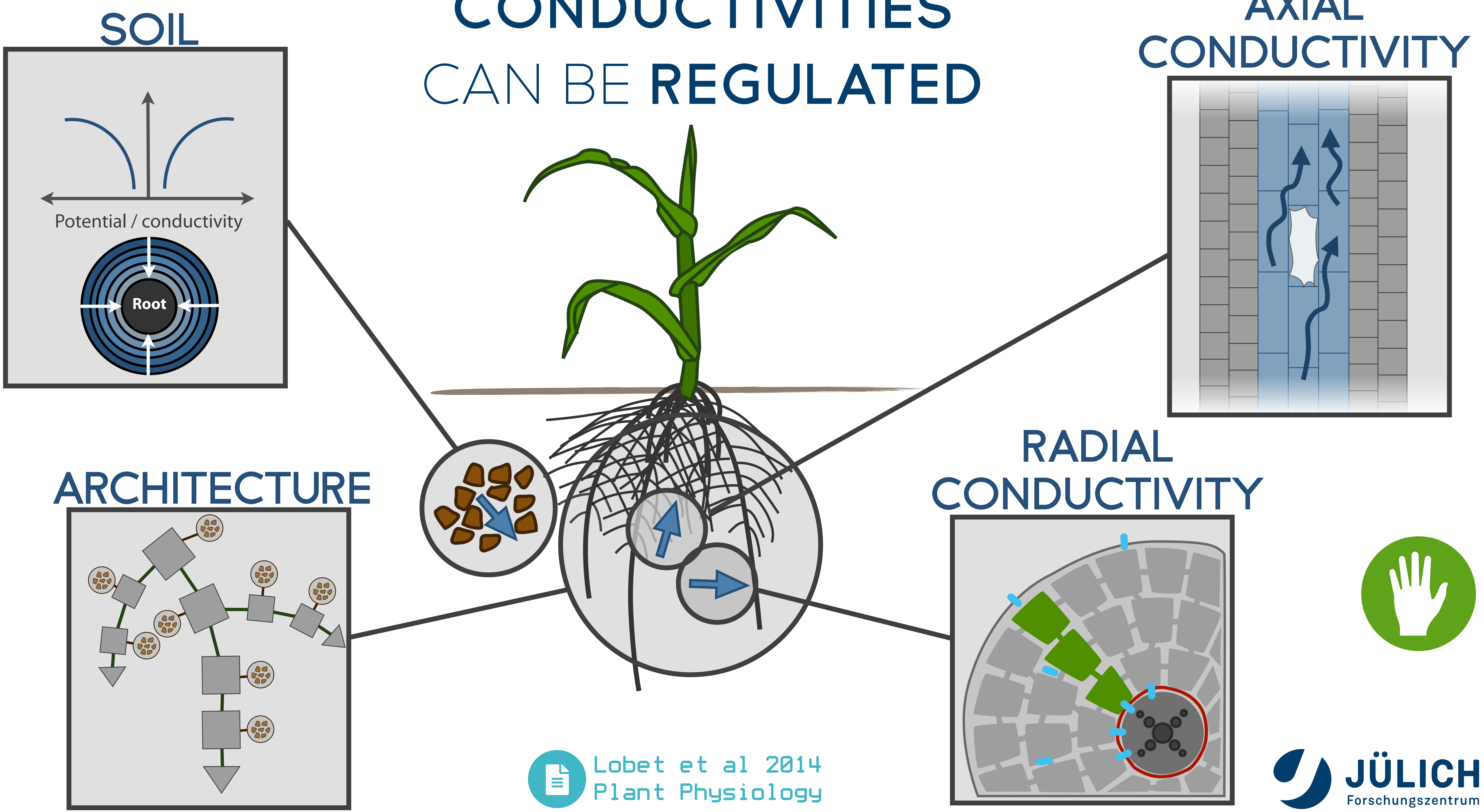
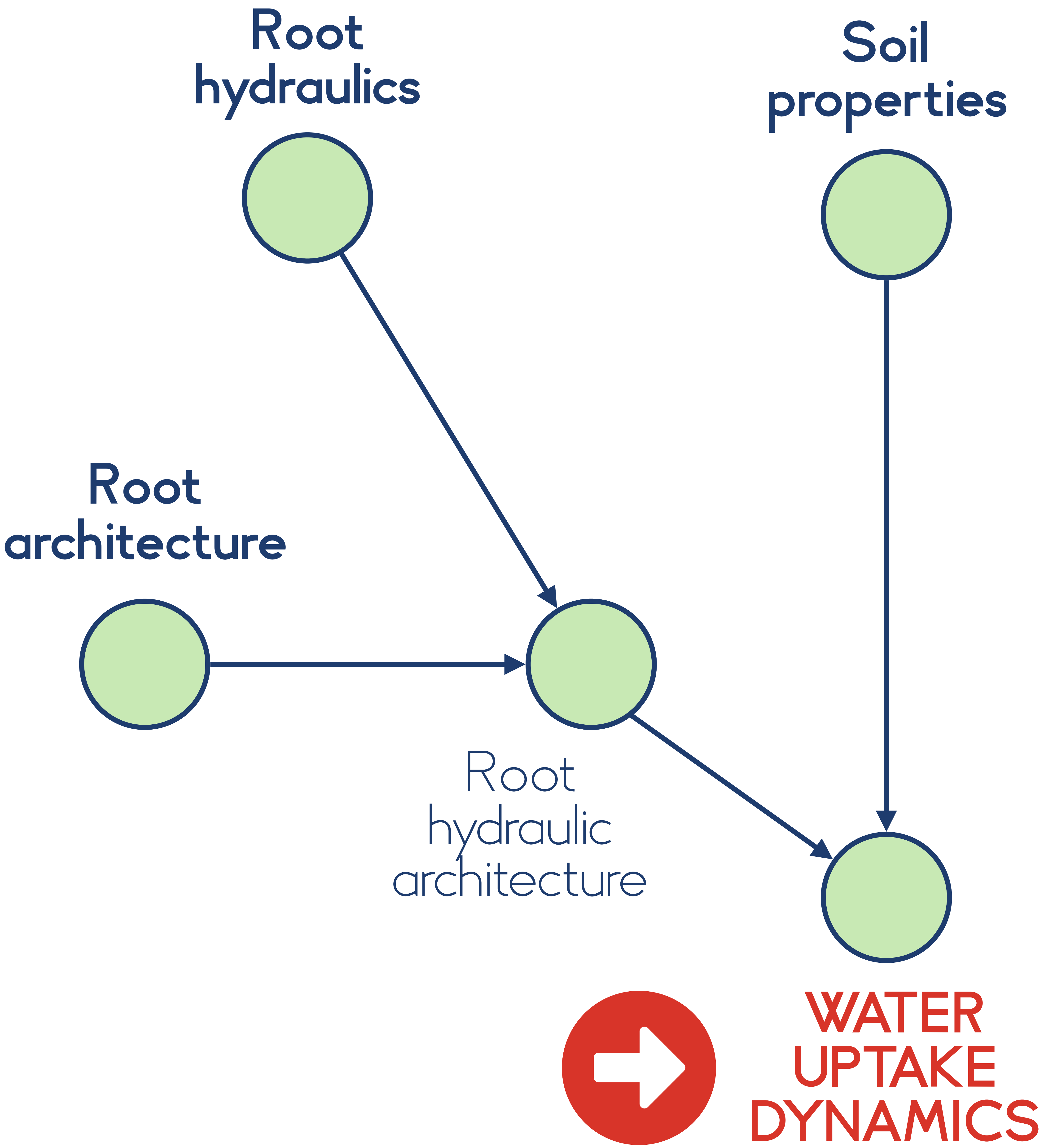
$$\mathrm{FLUX} = \Delta P \cdot K$$

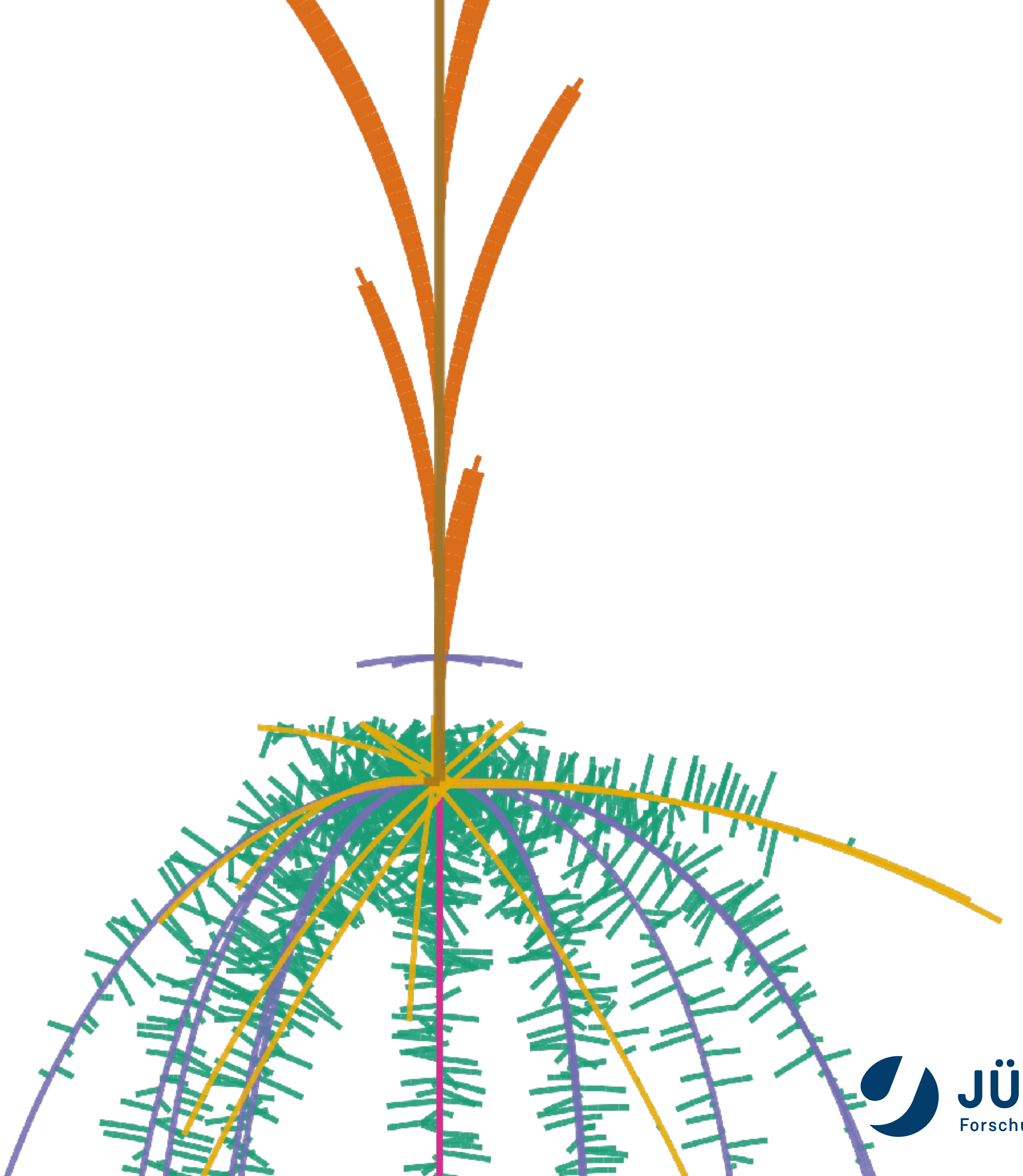
CONDUCTIVITIES CAN BE **REGULATED**



VARIABLES NEEDED TO UNDERSTAND WATER FLOW IN THE SOIL–PLANT SYSTEM



PLANTS
MODELS
CAN HELP
INTEGRATE
INFORMATION
ACROSS THE
WHOLE SYSTEM



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1

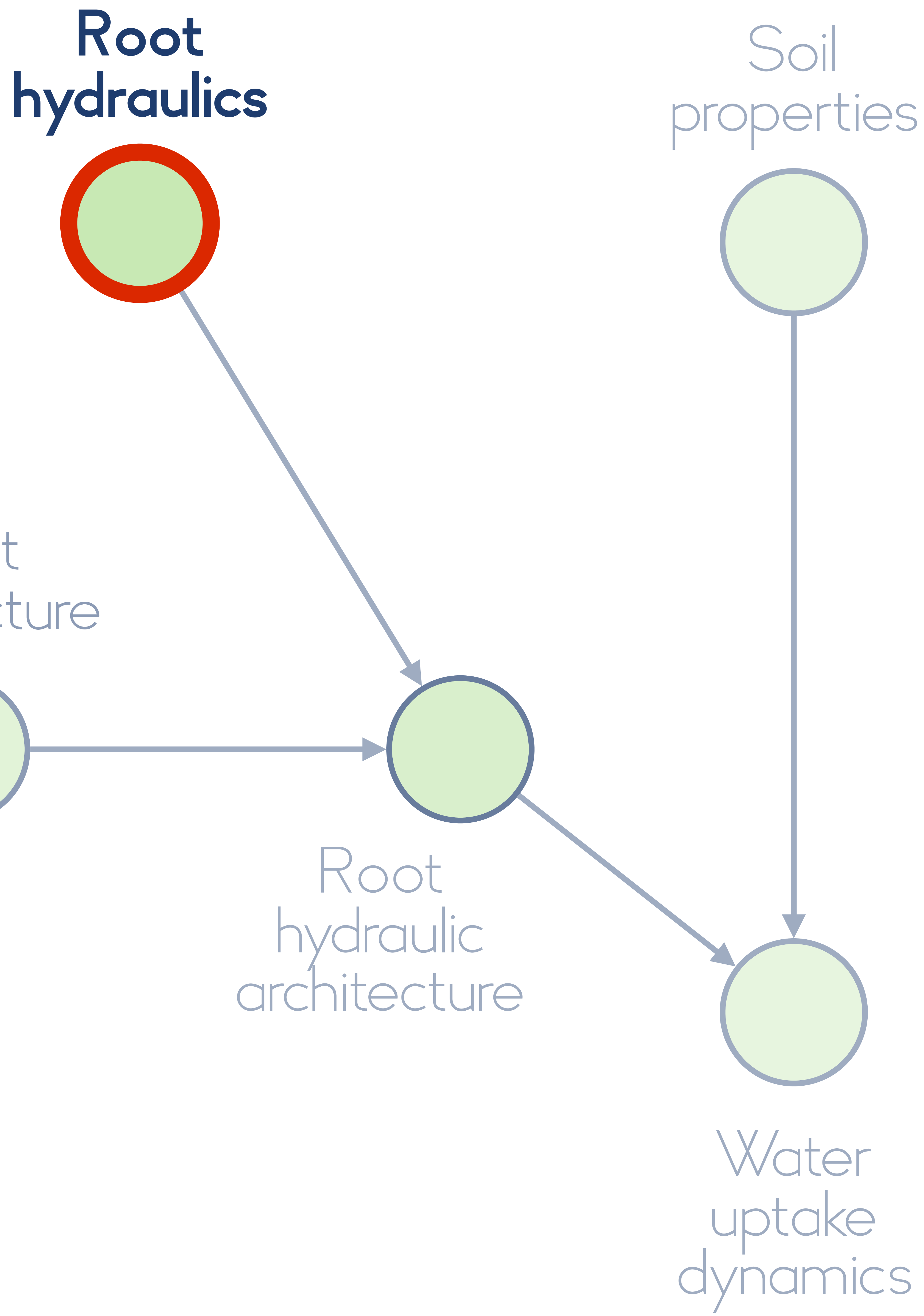
ROOT HYDRAULICS

Xavier **Draye**

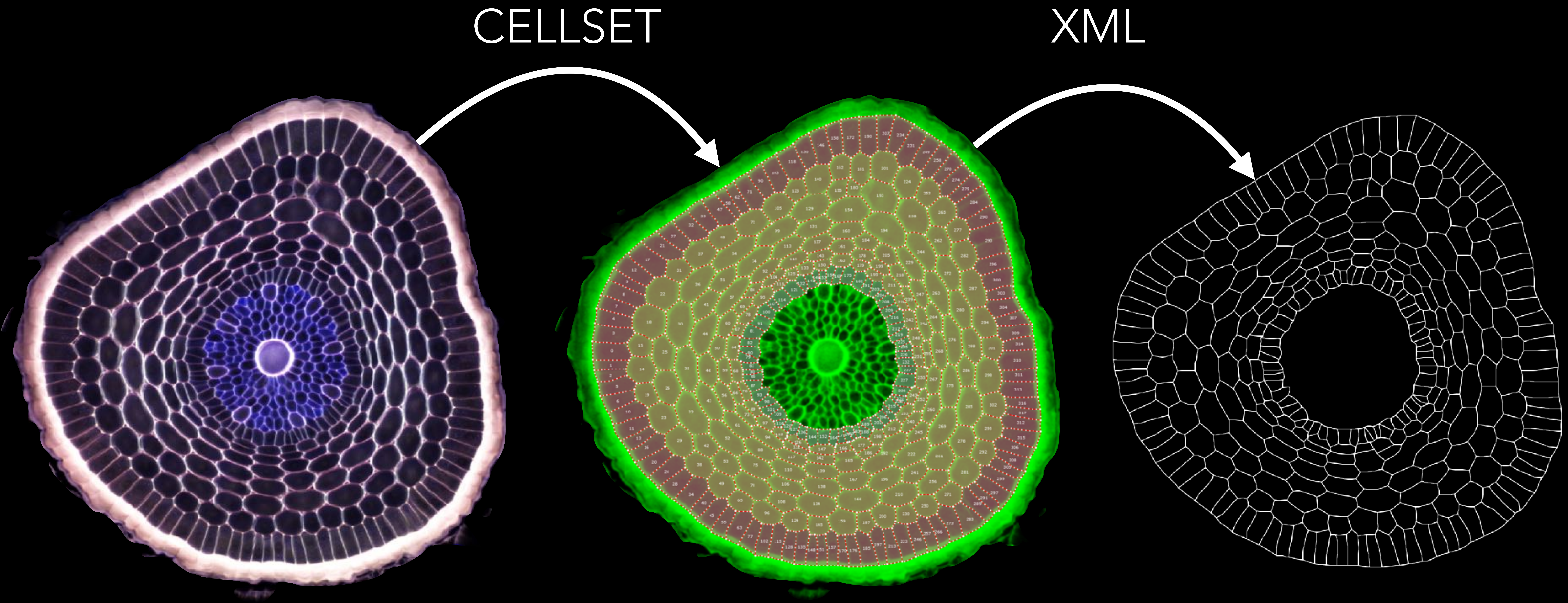
Valentin **Couvreur**

Guillaume **Lobet**

Adrien **Heymans**

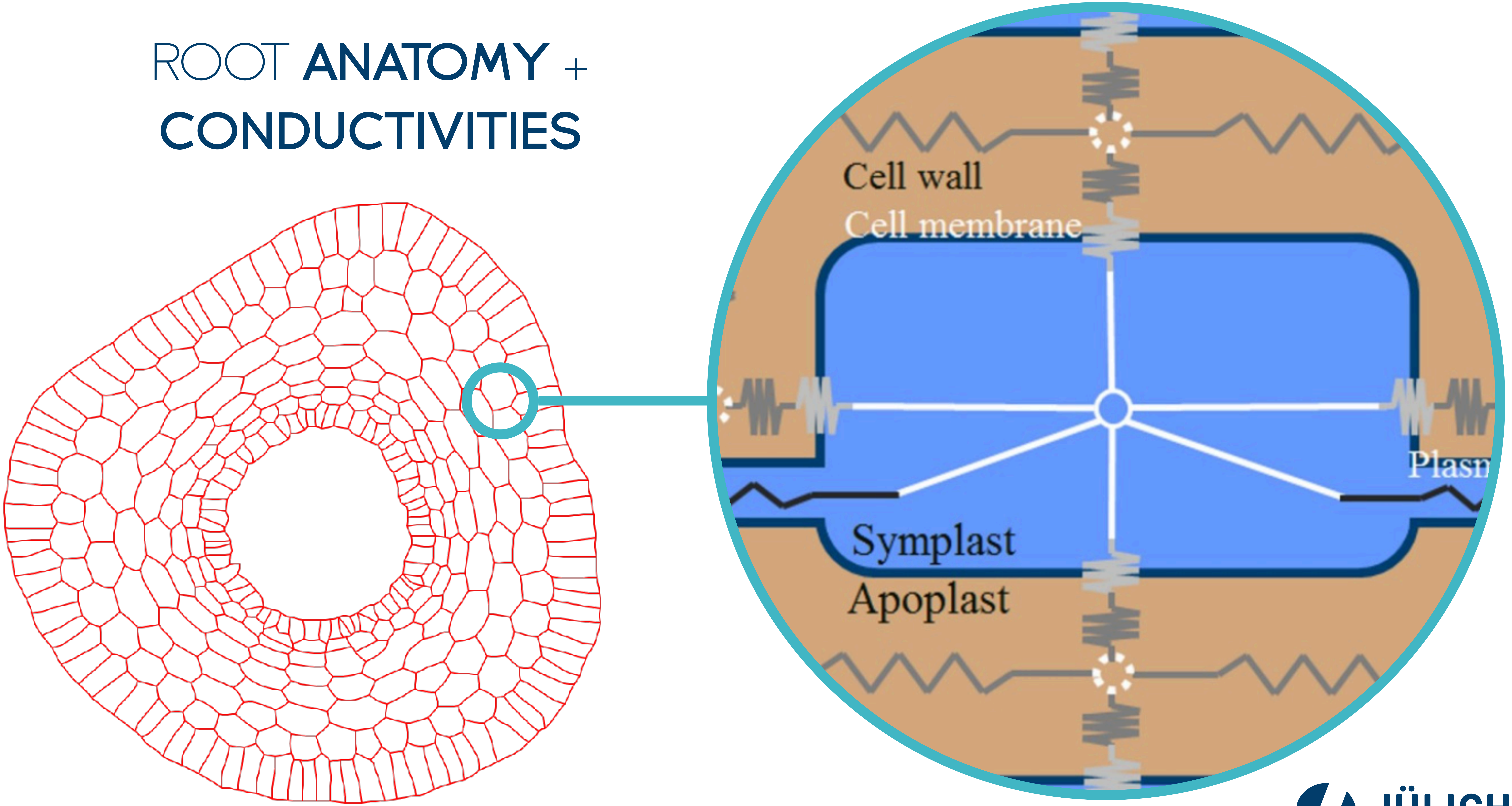


ROOT CONDUCTIVITY = ANATOMY + CONDUCTIVITIES



Pound et al, 2012
Plant Cell

ROOT **ANATOMY** + **CONDUCTIVITIES**



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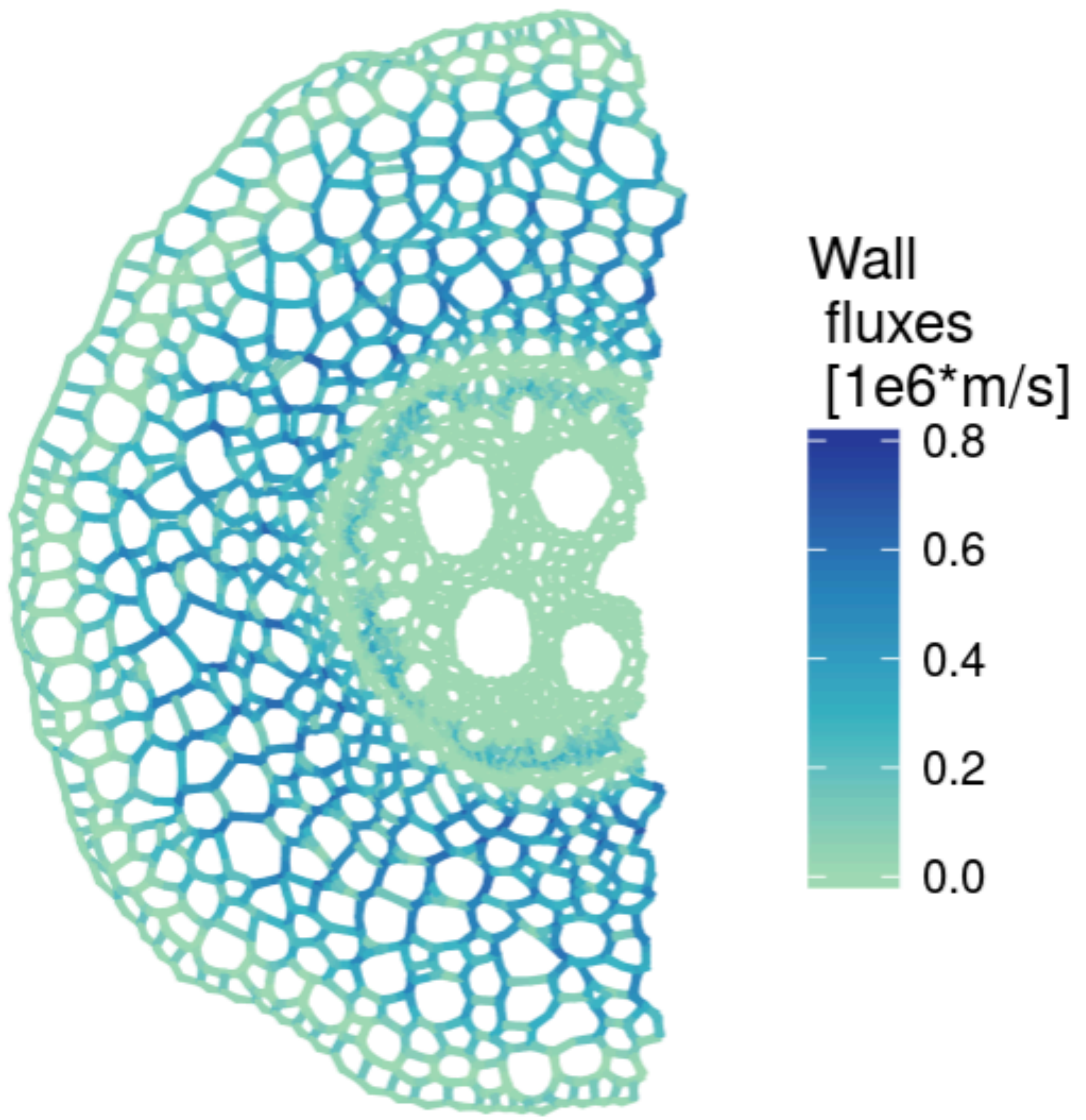
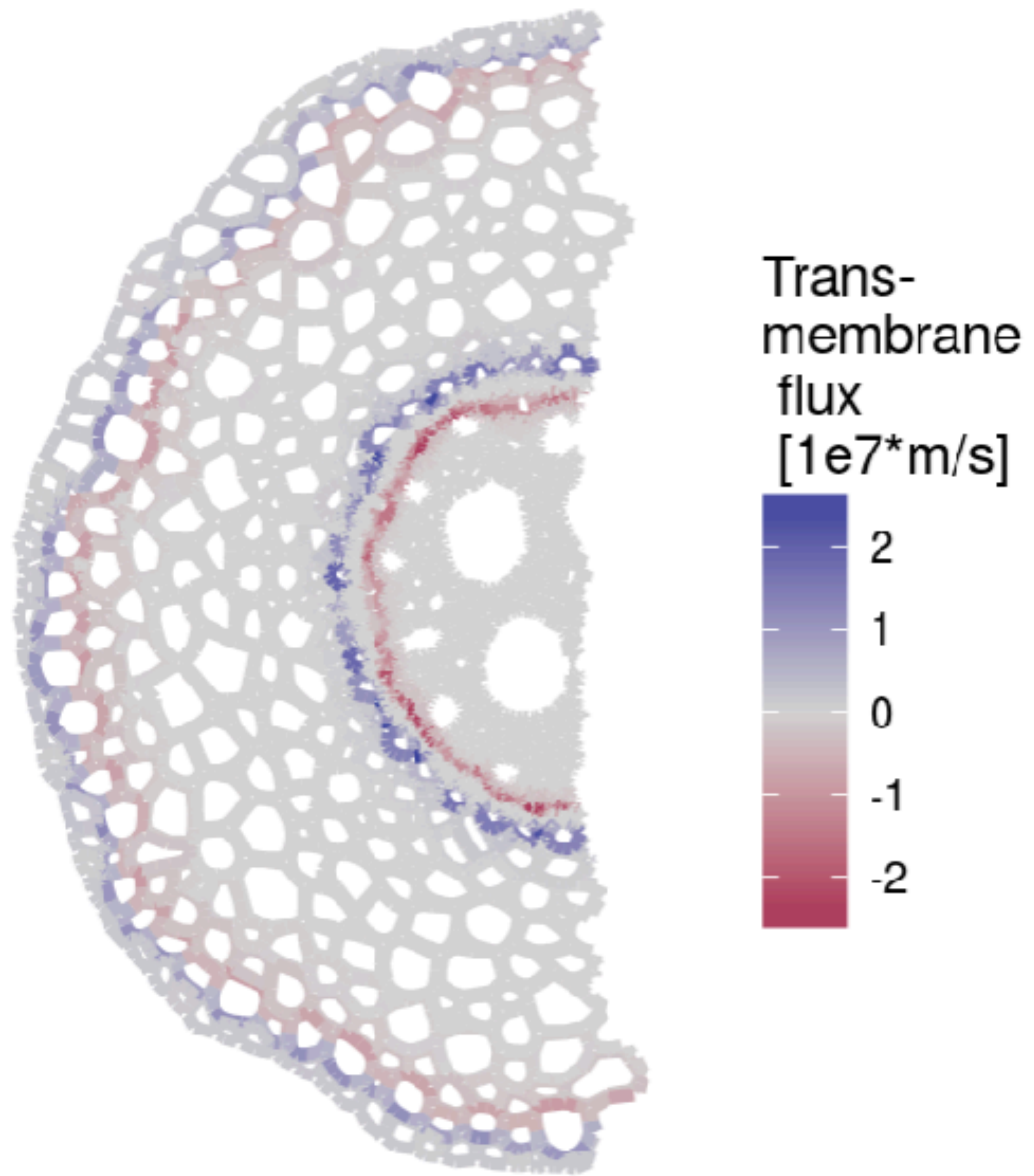
MODELLING **WATER** FLOW AT THE **ORGAN** SCALE

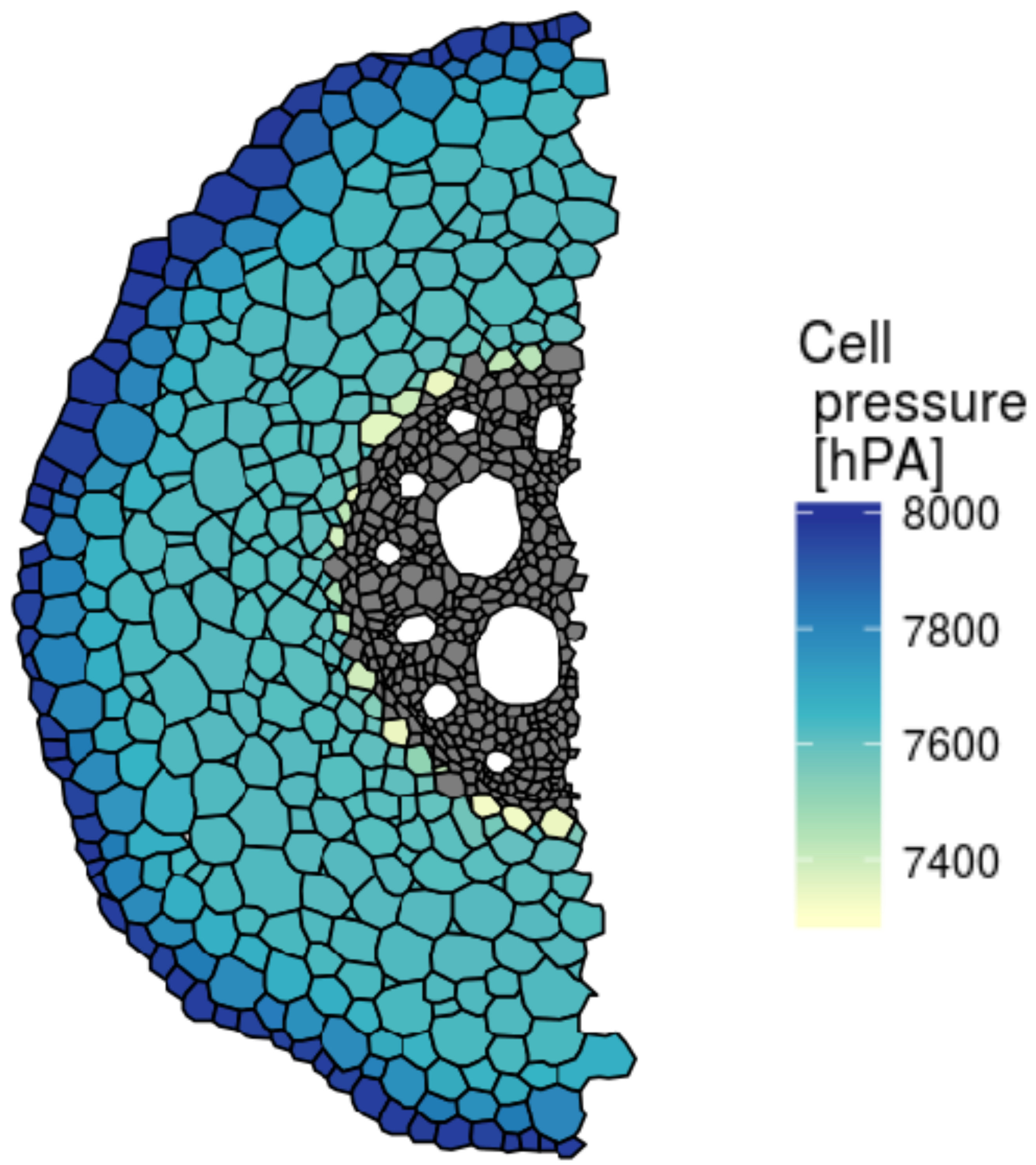
– MECHA –



FLUXES IN
CELL WALLS



FLUXES IN
CELL MEMBRANES



PRESSURES IN
CELLS

RADIAL CONDUCTIVITY

AXIAL CONDUCTIVITY

PARTIAL SOIL CONTACT

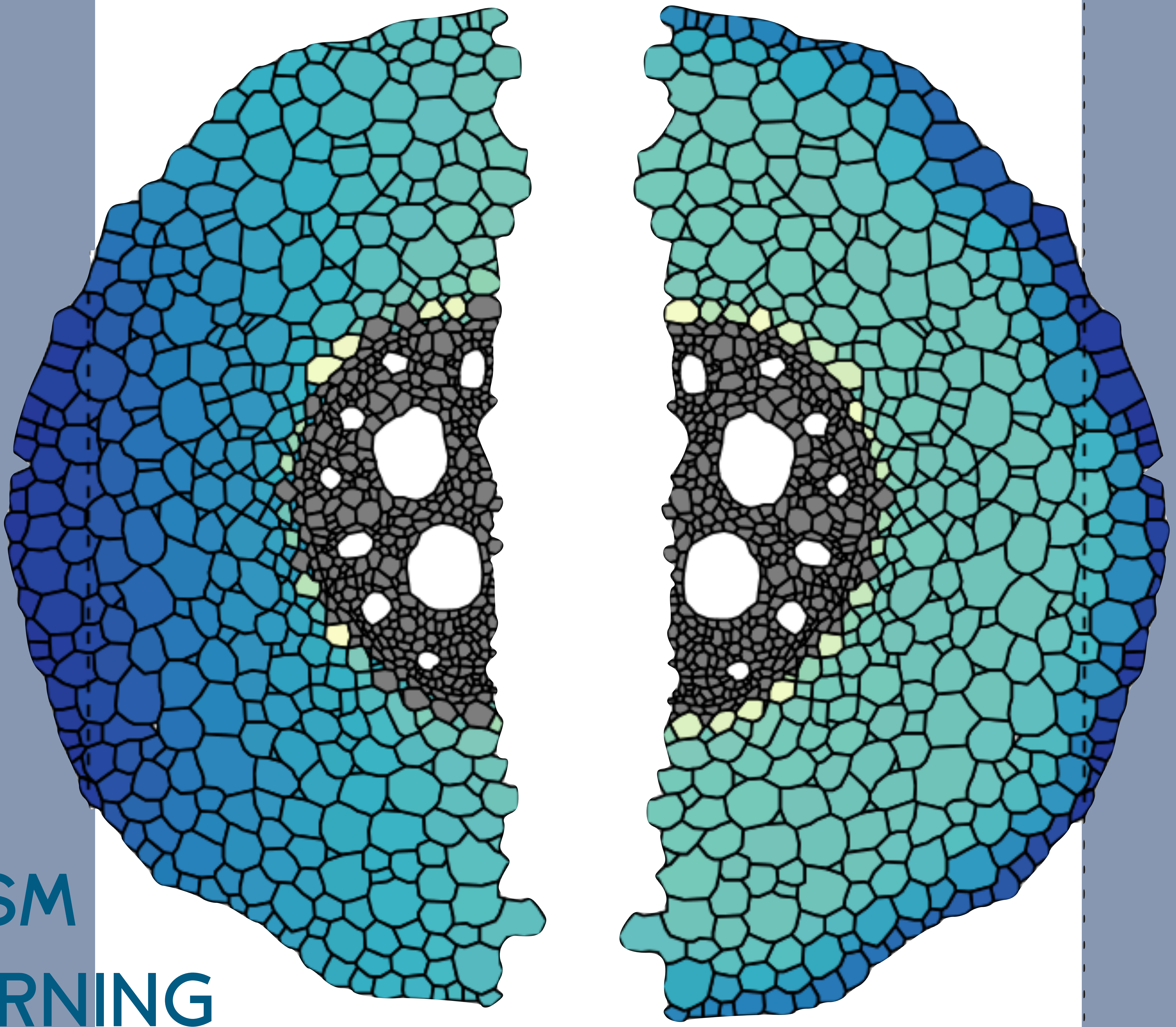
– ENDODERMIS
– EXODERMIS

↓

WATER POTENTIAL GRADIENT

↓

HYDROTROPISM
HYDROPATTERNING



+ ENDODERMIS
+ EXODERMIS

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MECHA - Model of Explicit Cross-section Hydraulic Anatomy

Valentin Couvreur, Marc Faget, Guillaume Lobet, Mathieu Javaux, François Chaumont and Xavier Draye

Université catholique de Louvain, Forschungszentrum Juelich GmbH

Choose plant | Change parameters | About

Choose a simulation to visualize

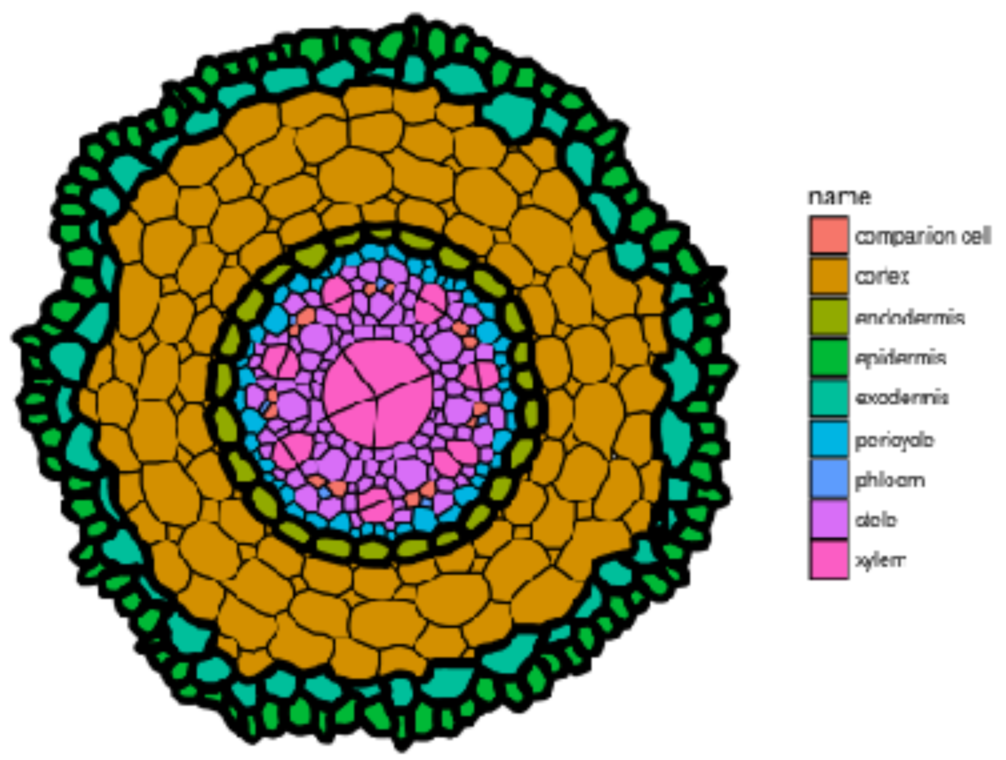
1. Select a plant type

MilletPR1

MECHA was run for different cross section geometries and plant type. Te results were pre-processed to be easily visualised here.

Tissue layers

Visualisation of the different cell layers used in the simulation



Select the information to visualize

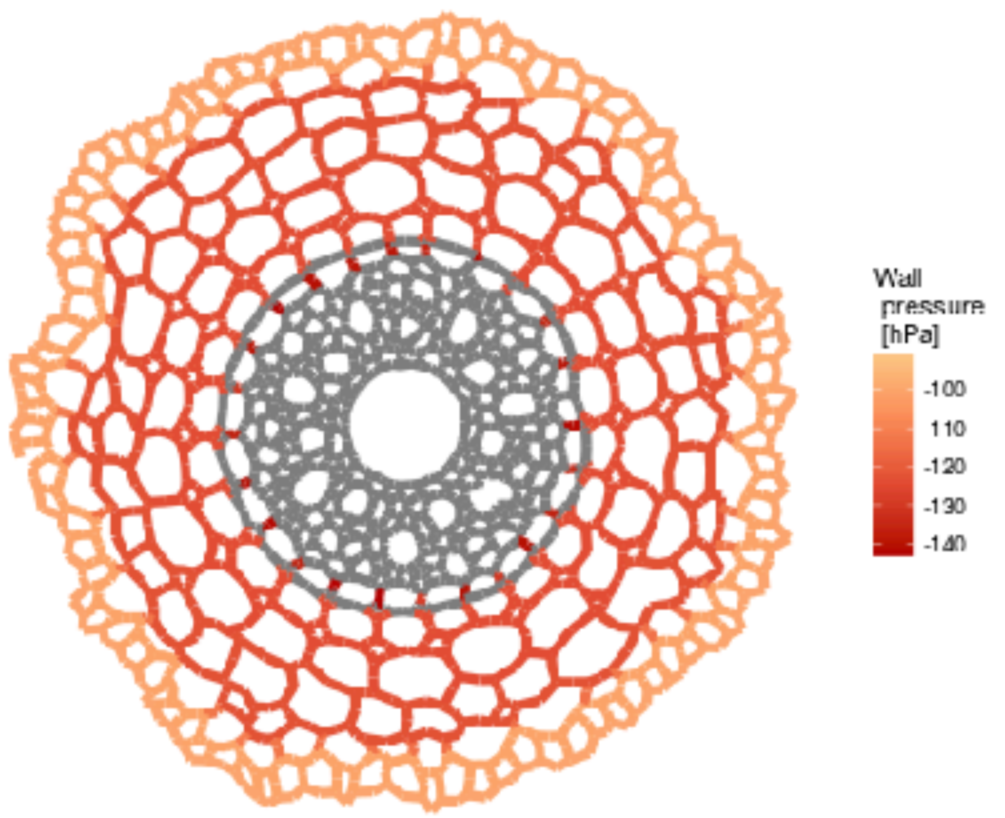
potentials

Synthetic information about the simulation

param	value	unit
Cross-section height	0.008	cm
Cross-section perimeter	0.0863	cm
Cross-section radial conductivity	2.93e-04	cm/hPa/d
Xylem pressure potential	1100	hPa
Soil pressure potential	-100	hPa
Xylem osmotic potential	-1500	hPa
Soil osmotic potential	-200	to
Soil contact	0e+00	microns
Wall conductivity	0.0066	cm^2/hPa/d
Plasmodesmata conductivity	3.1e-11	cm^3/hPa/d
Aquaporin conductivity	4.3e-04	cm/hPa/d
Cortex osmotic potential	-8000	hPa

Cell walls pressure

Pressure within the cell walls of the cross section

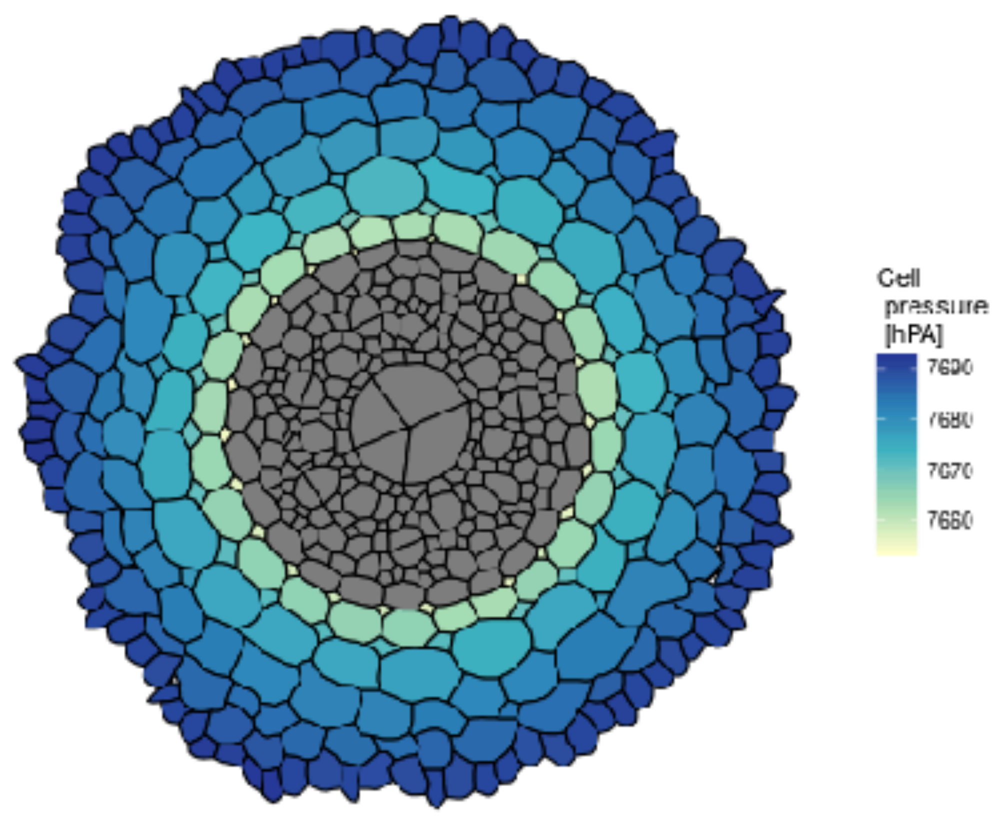


Display range:

-142.25 — -90.01

Cells potentials

Pressure within the cell of the cross section

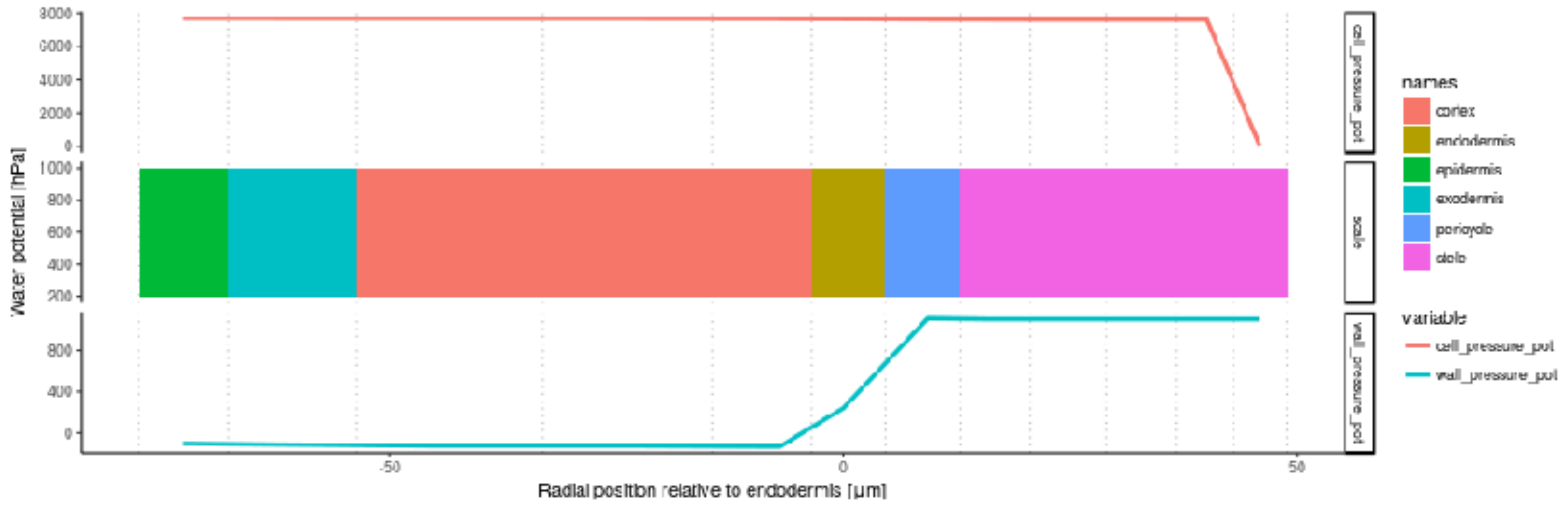


Display range:

7,654 — 7,693

Average cell and wall pressure

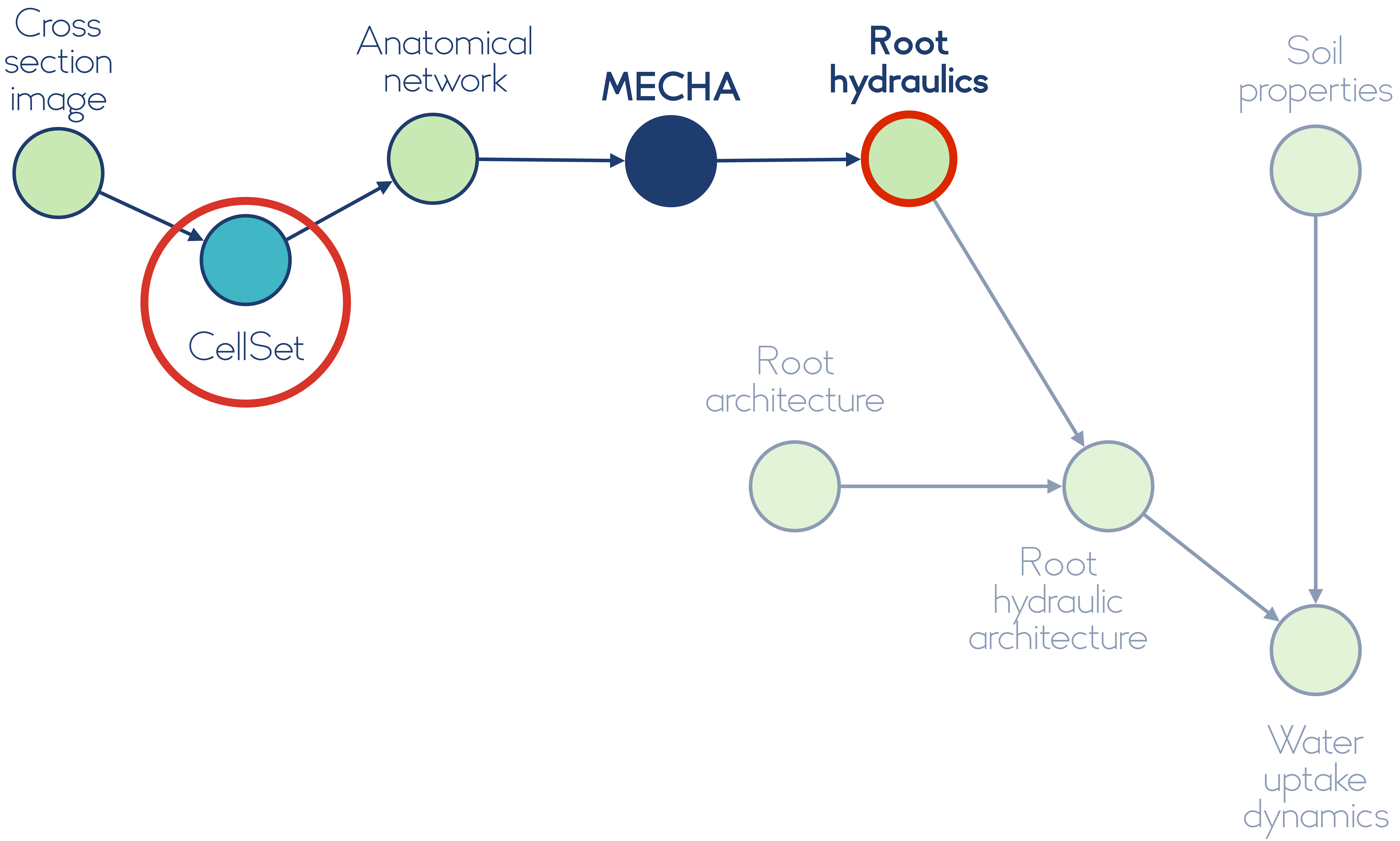
Visualisation of the average cell and wall pressure across the cross-section



Open Source

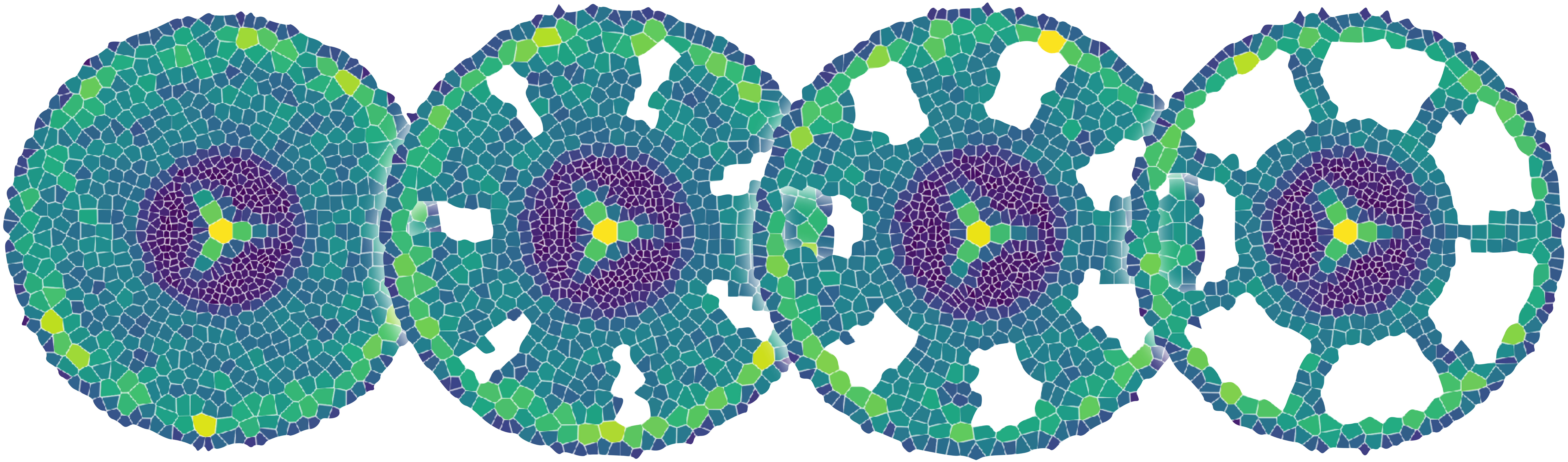
mecharoot.github.io

Couvreur et al, 2018
Plant Physiology


Cross section image
CellSet
Anatomical network
MECHA
Root hydraulics
Soil properties
Root architecture
Root hydraulic architecture
Water uptake dynamics

GENERATOR OF ANY TYPE OF ROOT ANATOMY

– GRANAR –



XYLEM POLES / CORTEX / AERENCHYMA / ...

Heymans et al, 2019,
bioRxiv

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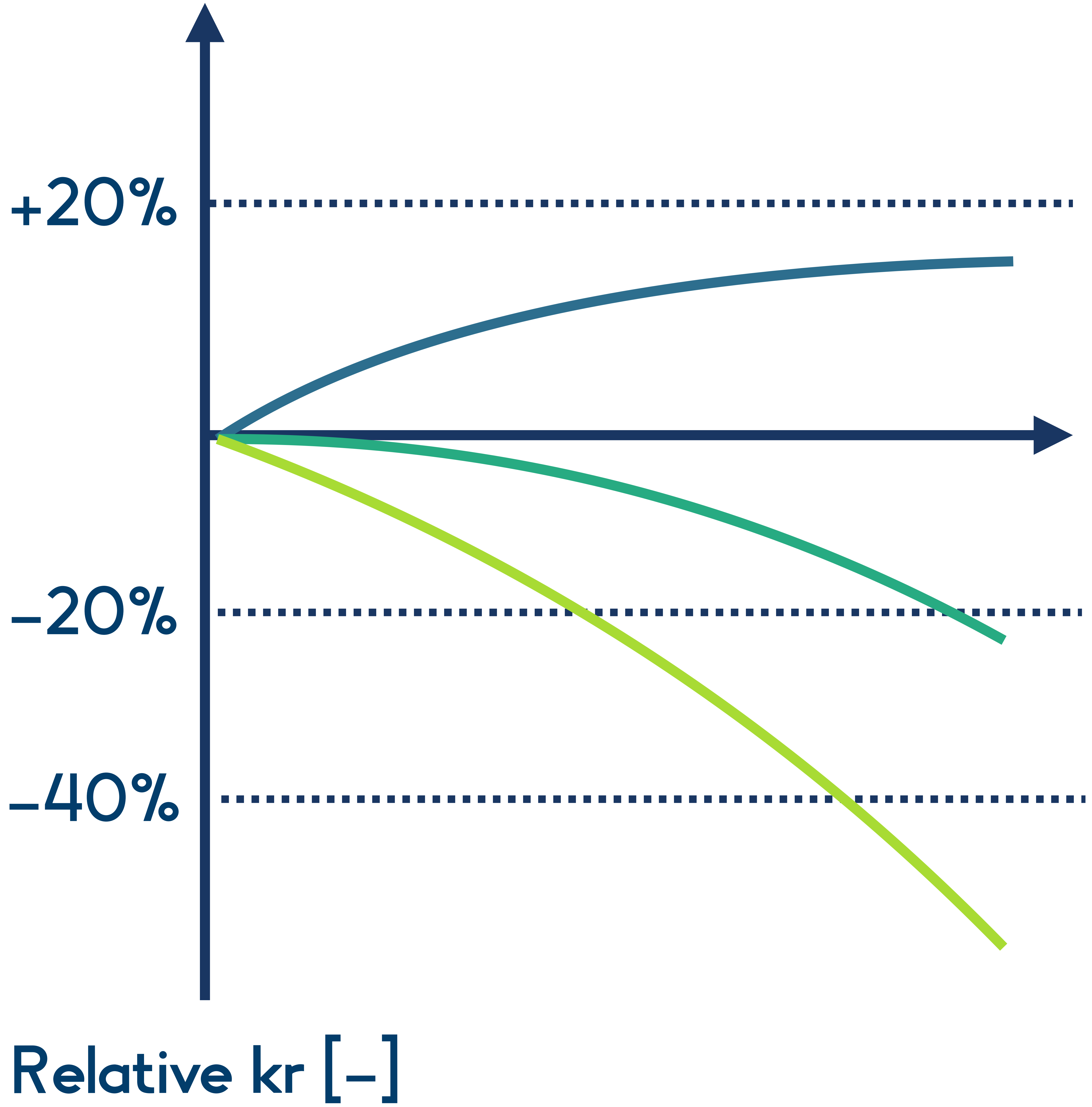
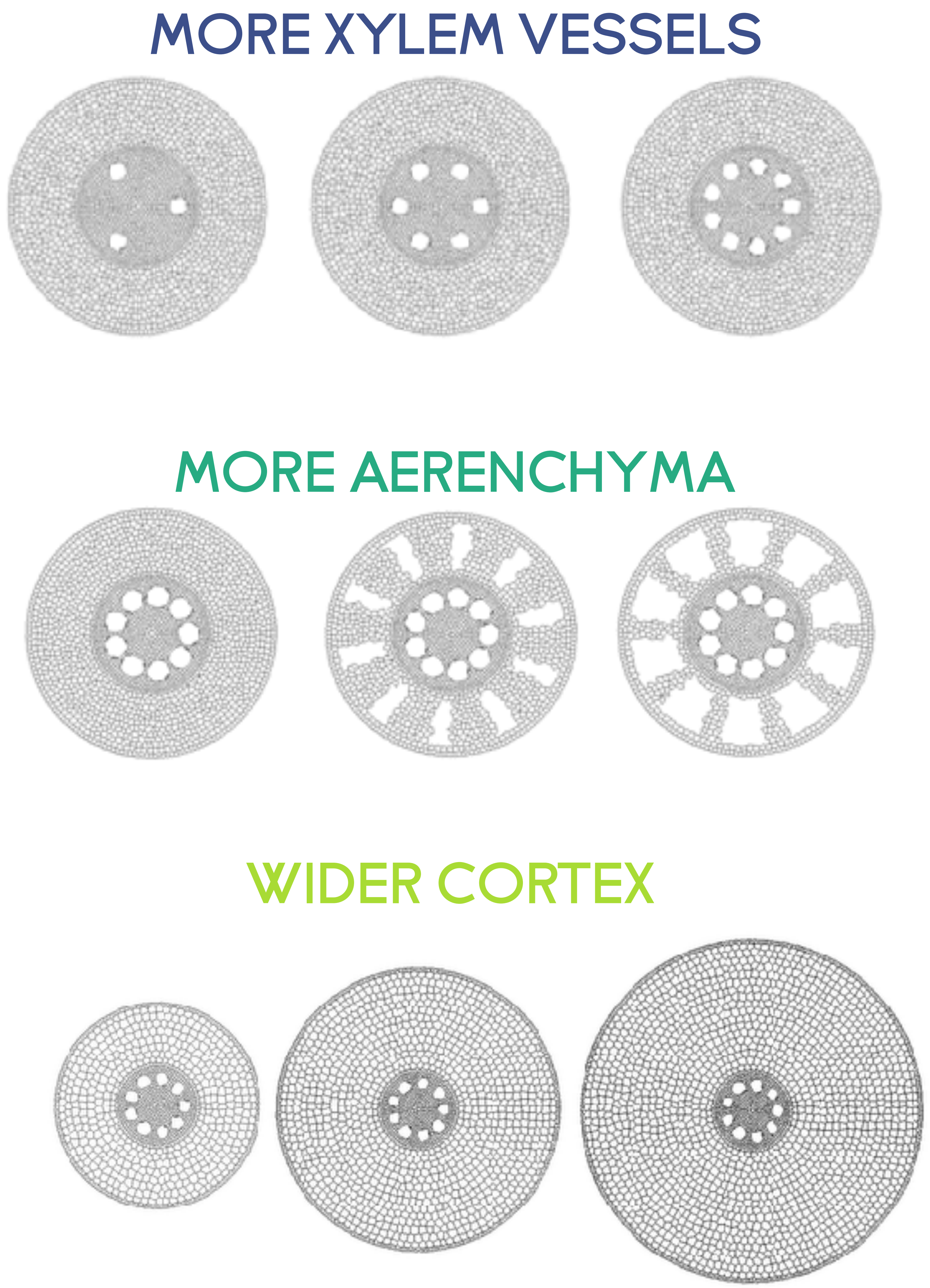
EFFECT OF ANATOMY ON RADIAL CONDUCTIVITY





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Generator of Root ANAtomy in R [GRANAR] | The model | About

Cortex | Stele | Xylem | Aerenchyma

Parameters for the cortex. You can adjust the number of cell layers and the size of individual cells

Layers: 1 — 6 — 15

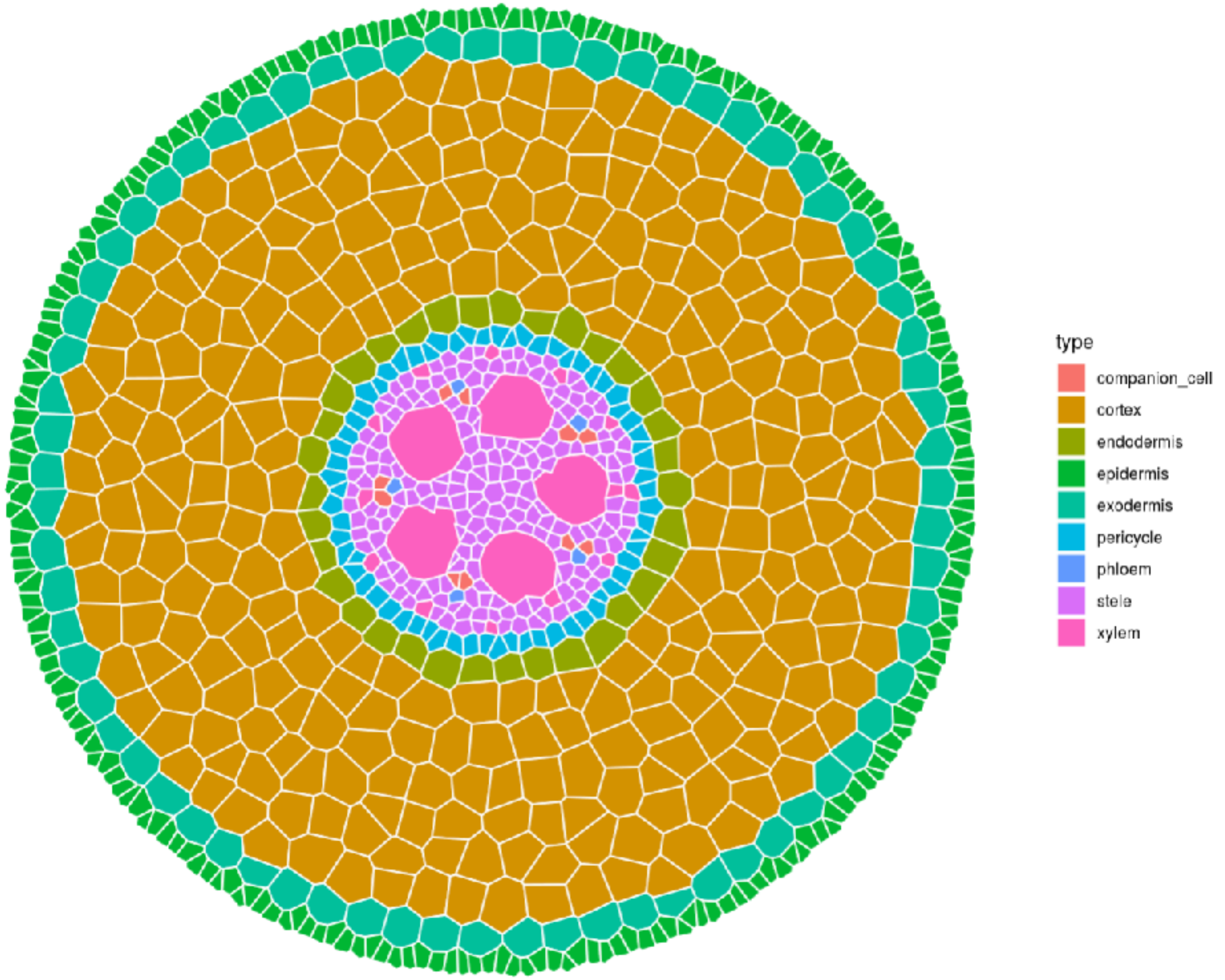
Diameter: 0.01 — 0.03 — 0.06

Plant type

monocot

Variable to display

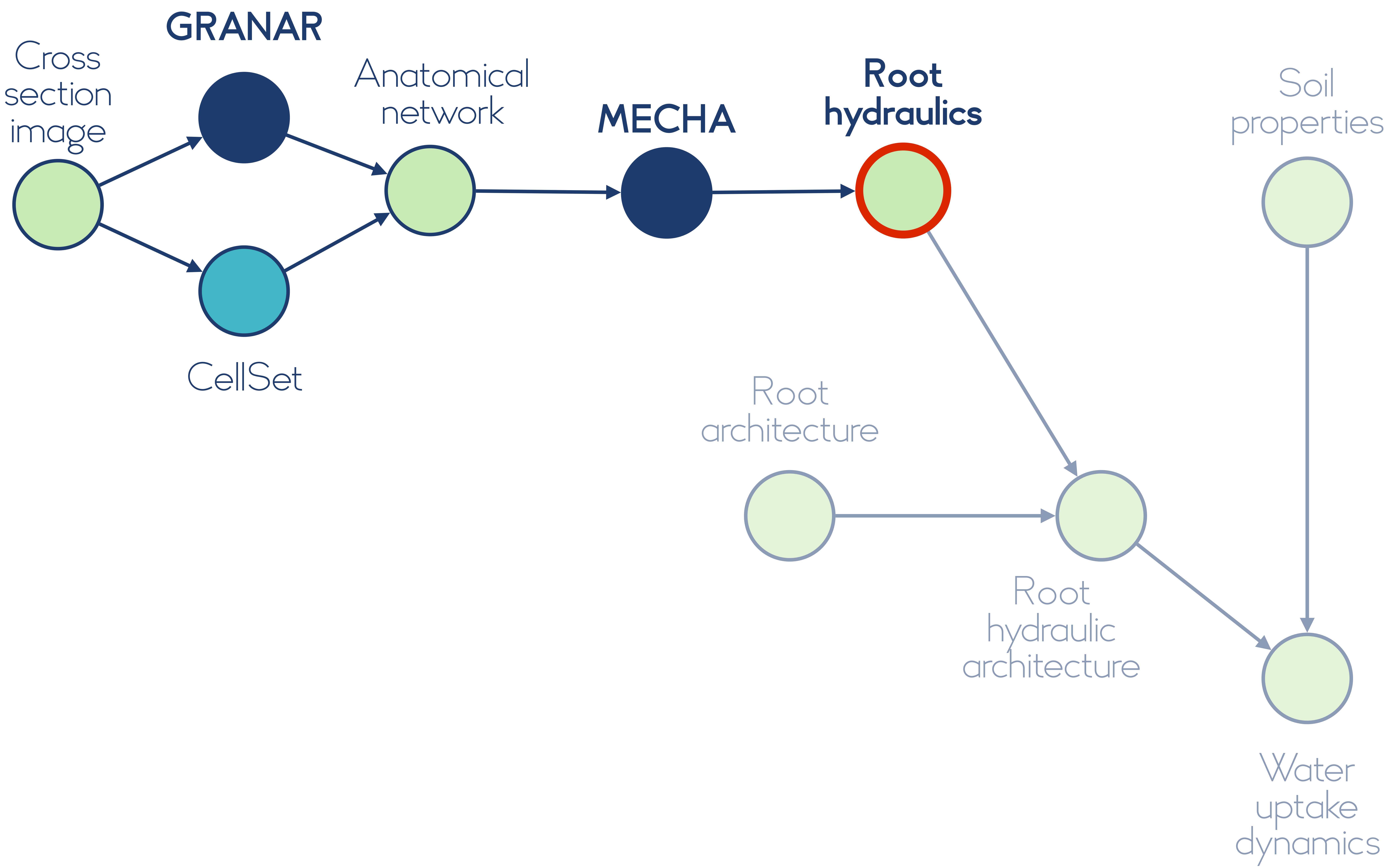
Type



Open Source

granar.github.io

Heymans et al, 2019
bioRxiv



GRANAR
Cross section image
Anatomical network
MECHA
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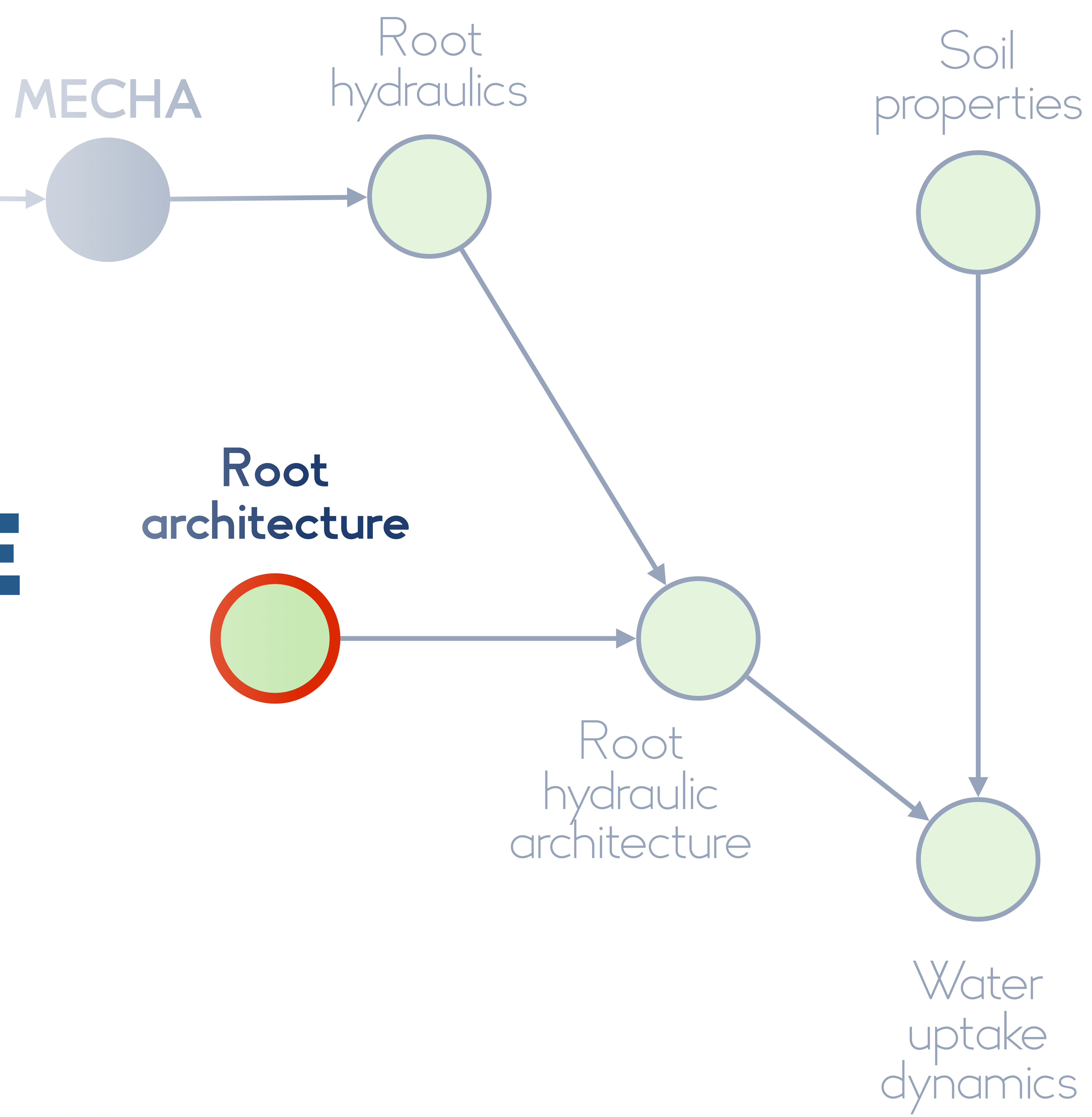
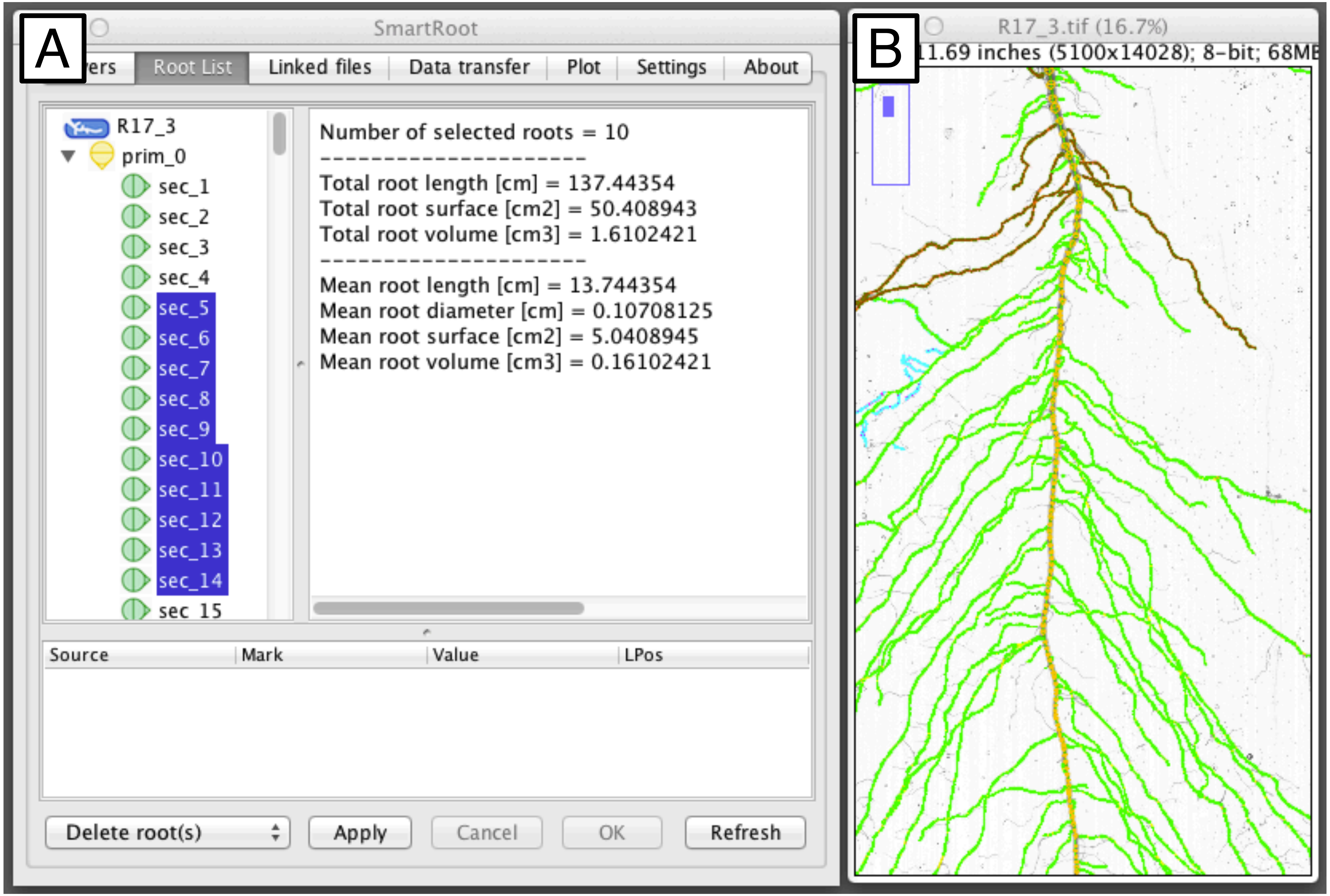
Soil properties
CellSet
Root architecture
Root hydraulic architecture
Water uptake dynamics

2 ROOT SYSTEM ARCHITECTURE



Andrea **Schnepf**   Daniel **Leitner**   Guillaume **Lobet**





MANUALLY DIGITALIZE

HIGH DEDICATION

SMARTROOT

ROOTNAV

ROOTSYSTEM ANALYSER

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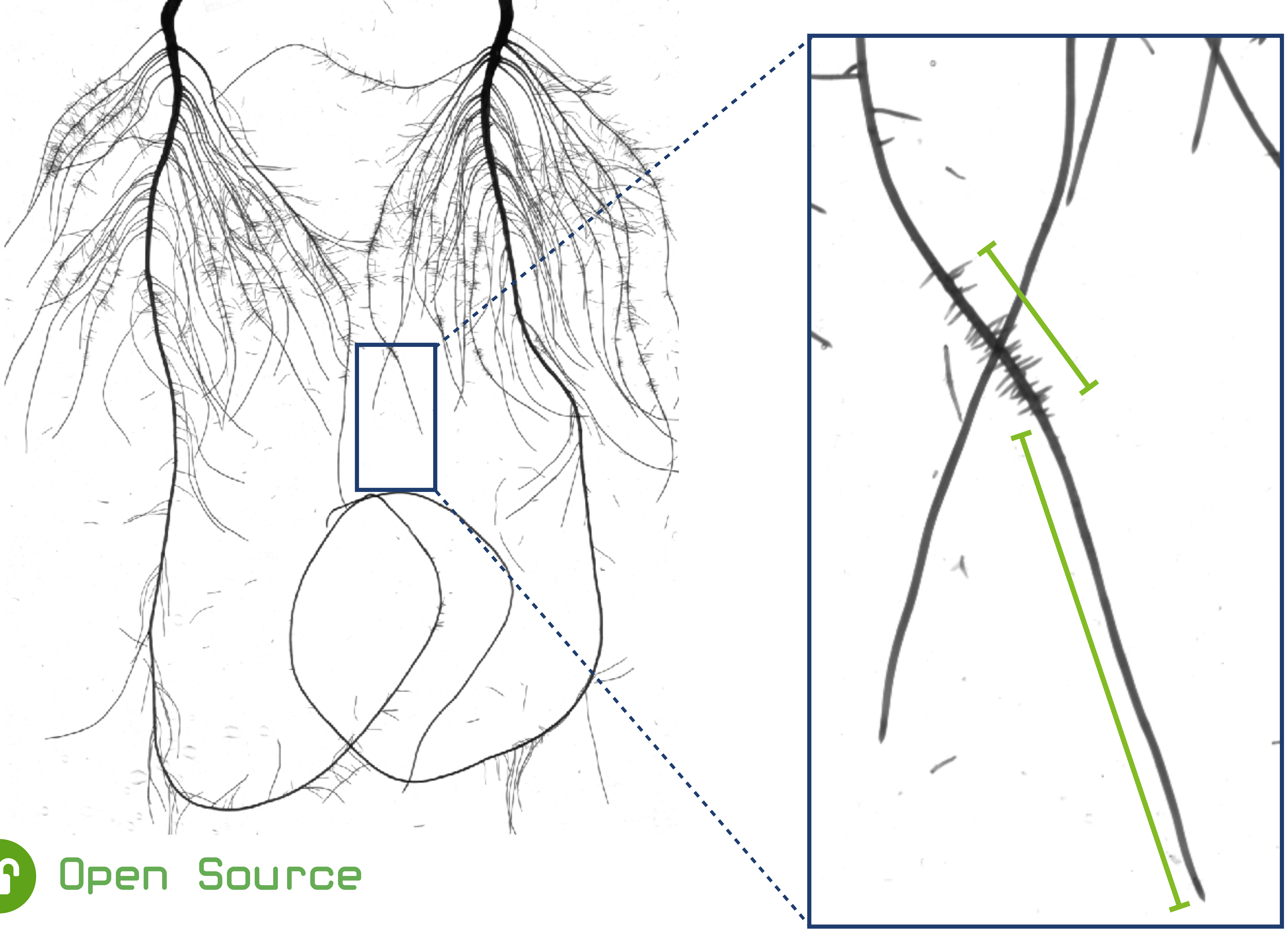


SAMPLE
THE IMAGE

PARAMETERS
FOR ROOT
MODEL

Open Source

smartroot.github.io

Lobet et al, 2011
Plant Physiology

– SMARTROOT –

– CROOTBOX –

Anagallis femina	Brassica oleracea	Heliantus	Pisum sativum a	Zea mays 4

"SMALL" SET OF PARAMETERS

➔ DYNAMIC ROOT ARCHITECTURE

CRootBox

This app displays the capabilities of the CRootBox model. Choose a dataset, unleash CRootBox, then try changing the parameters.

Daniel Leitner, Guillaume Lobet, Magdalena Landl, Mirjam Zorner, Shehan Morandage, Trung Hieu Mai, Cheng Sheng, Jan Vanderborgth, Andrea Schnepf

Forschungszentrum Juelich GmbH

1. Load parameter set

1. Select root system dataset

Brassica napus a

The algorithmic beauty of plant roots – an L-System model for dynamic root growth simulation
Leitner D, Klepsch S, Knieß A, Schnepf A
Mathematical and Computer Modelling of Dynamical Systems, 16, 575-587, 2010
View paper

Black and white root system

Unleash CRootBox

2. Update parameters

2. Select root type

taproot

Select parameter to change

Length of basal zone [cm]

Parameter mean:

0 4 8

0 0.8 1.6 2.4 3.2 4 4.8 5.6 6.4 7.2 8

Parameter deviation [%]:

0 5 50

0 5 10 15 20 25 30 35 40 45 50

Length of basal zone [cm]
Length of the unbracnhed basal zone of the root

3. Select plant parameter to change

Planting depth [cm]

Parameter value:

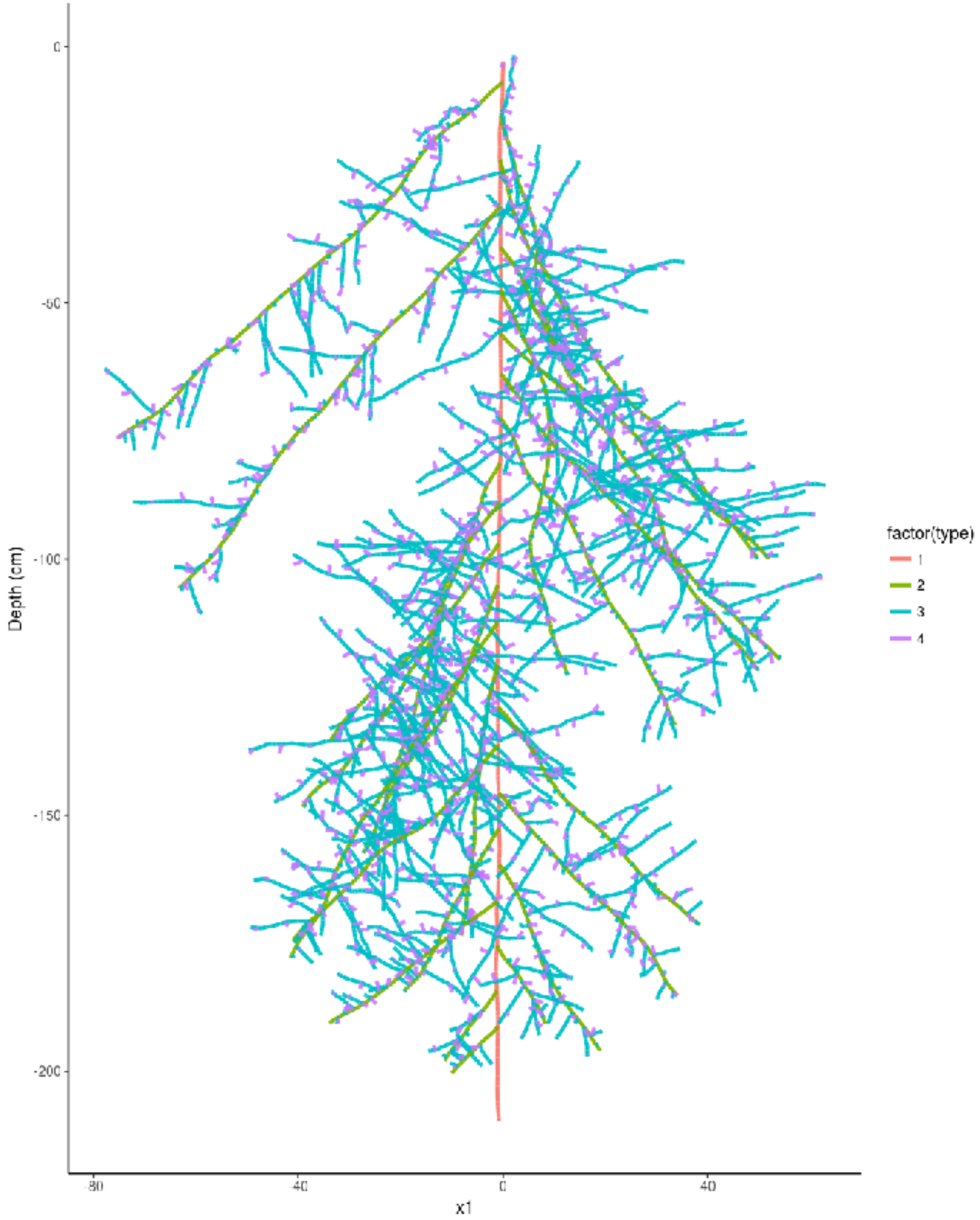
0 3 6

0 0.6 1.2 1.8 2.4 3 3.6 4.2 4.8 5.4 6

Planting depth [cm]
The depth, in cm, at which the seed is placed in the soil

Update root system

Root system representation | Root length profile



Open Source

bit.ly/crootbox

Schnepf et al, 2018
Annals of Botany

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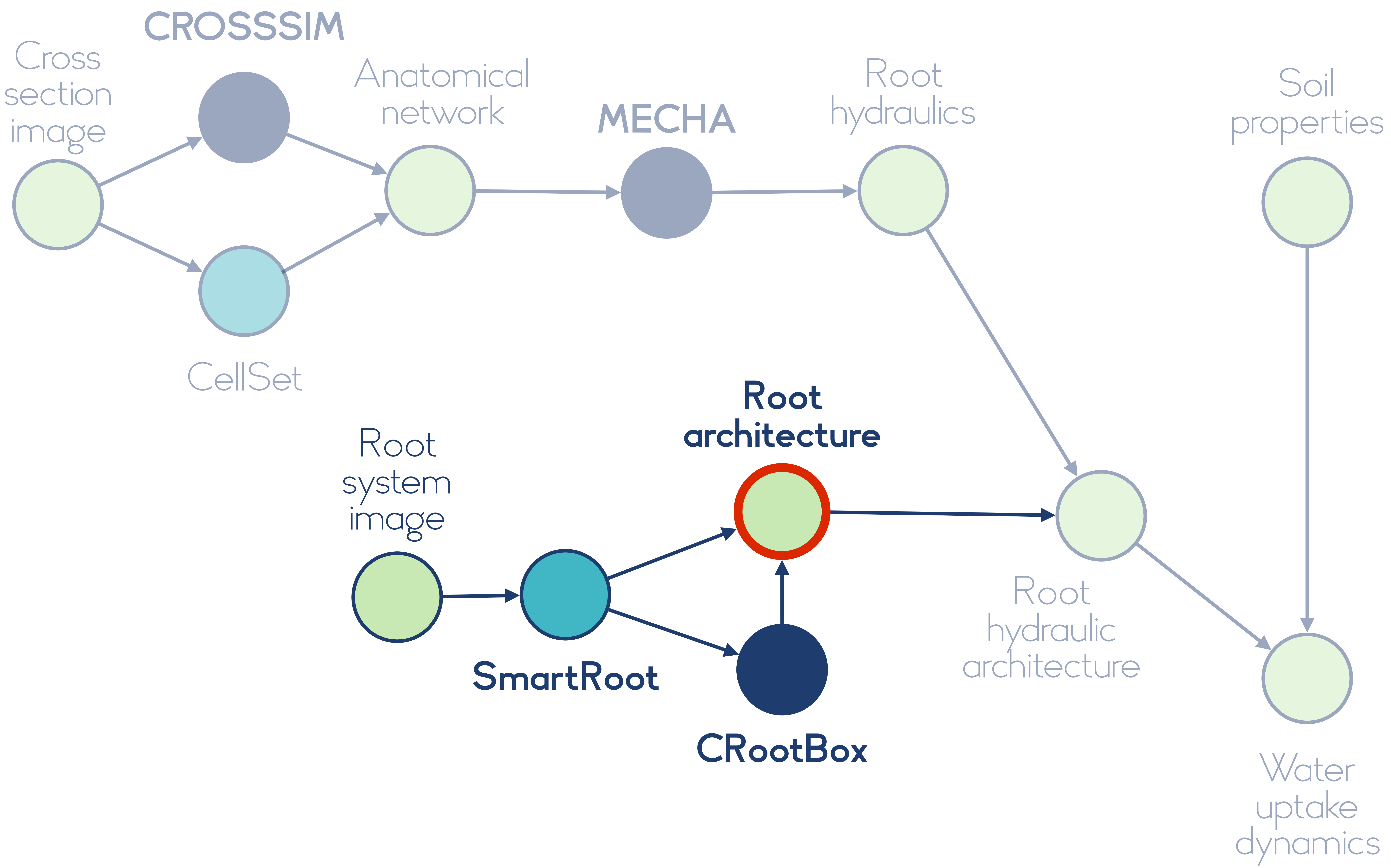
CROSSSIM
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Anatomical network
MECHA
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Soil properties
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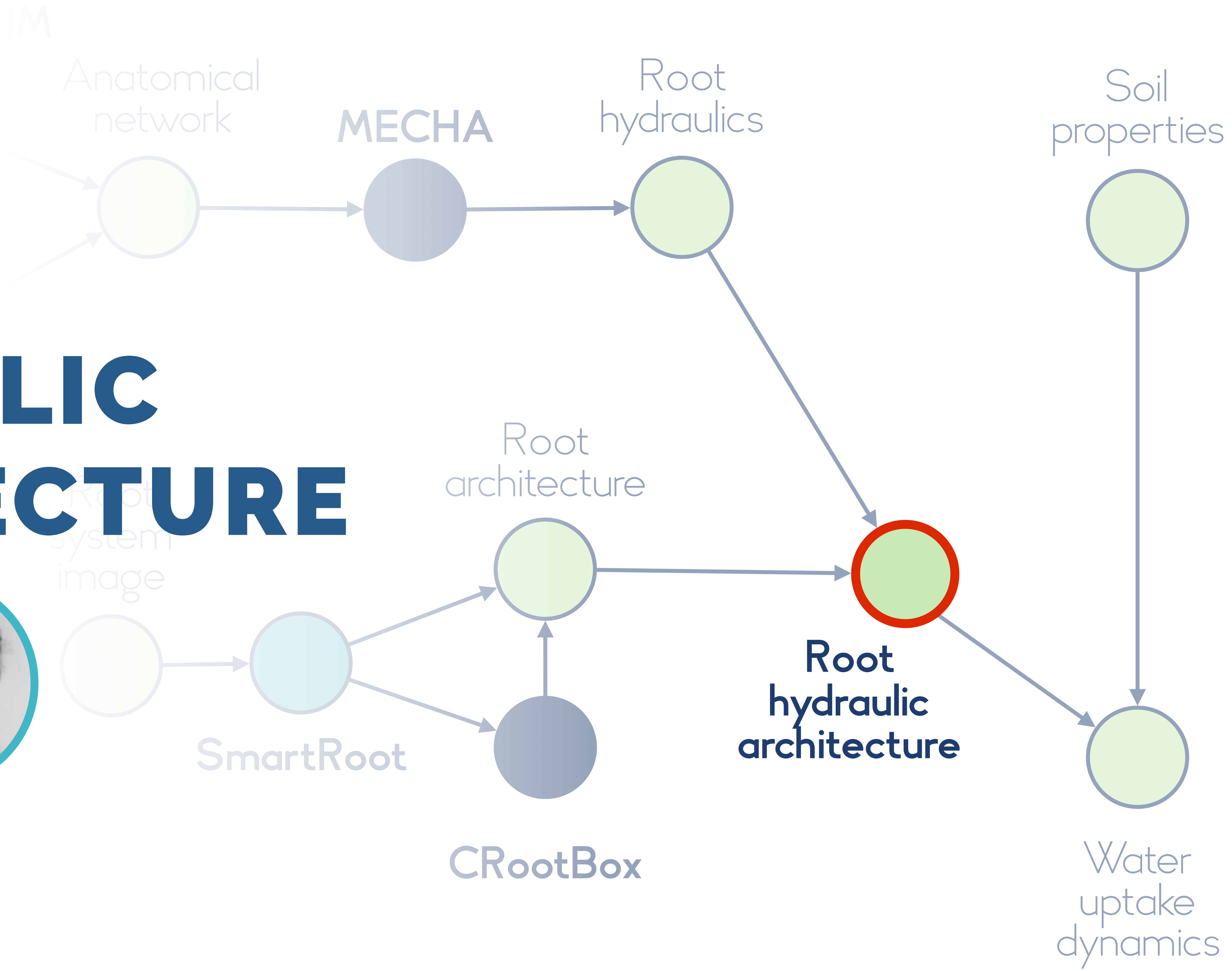
Root architecture
Root system image
SmartRoot
CRootBox
Root hydraulic architecture
Water uptake dynamics

3

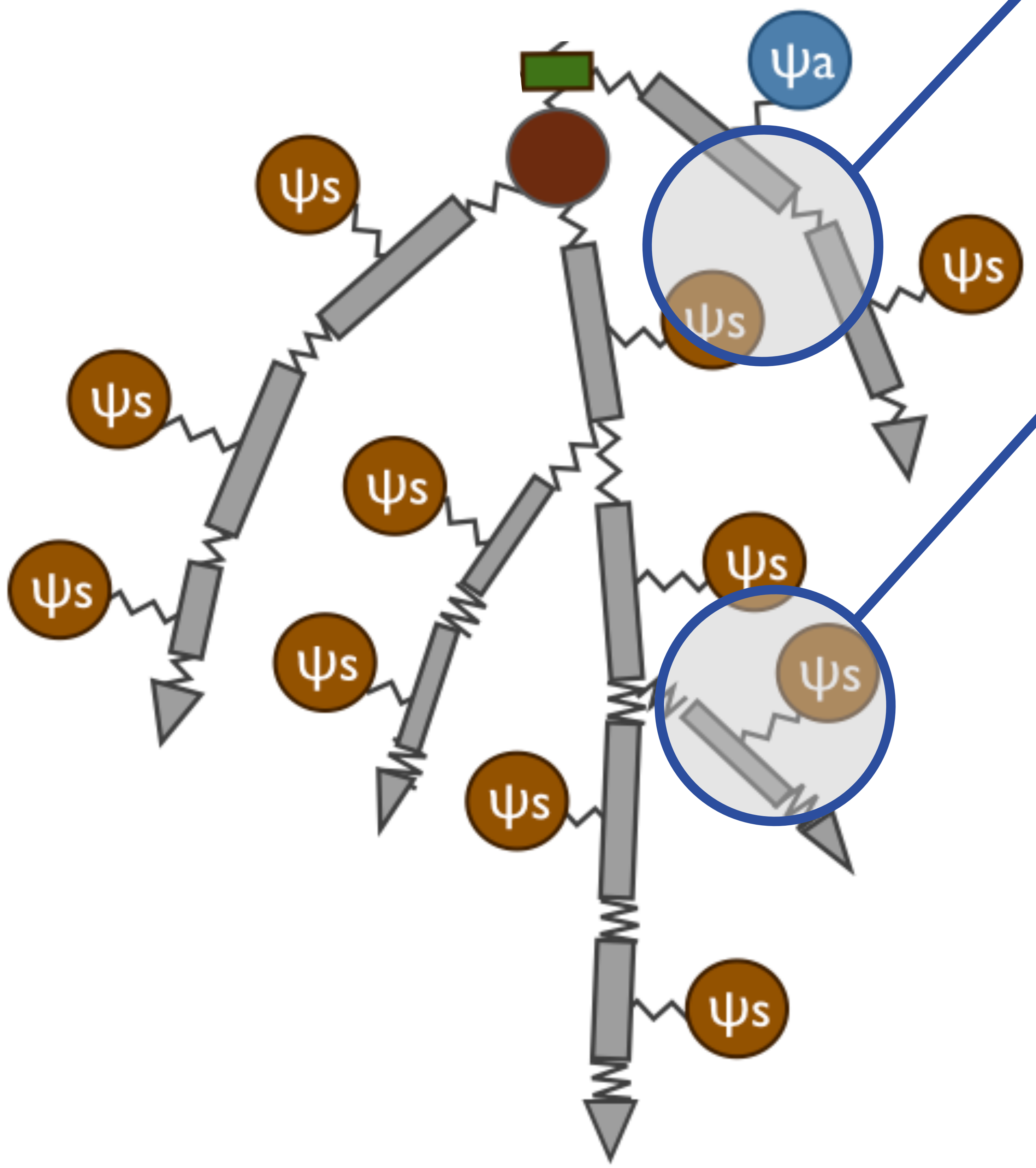
ROOT HYDRAULIC ARCHITECTURE

Mathieu **Javaux**

Félicien **Meunier**



ROOT SYSTEM +
CONDUCTIVITIES =
HYDRAULIC ARCHITECTURE



Axial flux

$J = K_x . (P_{r1} - P_{r2})$

Radial flux

$J = K_r . (P_{r1} - P_{soil})$

FLUXES

➜ ROOT SYSTEM CONDUCTIVITY [Krs]

INTRINSIC UPTAKE CAPABILITY

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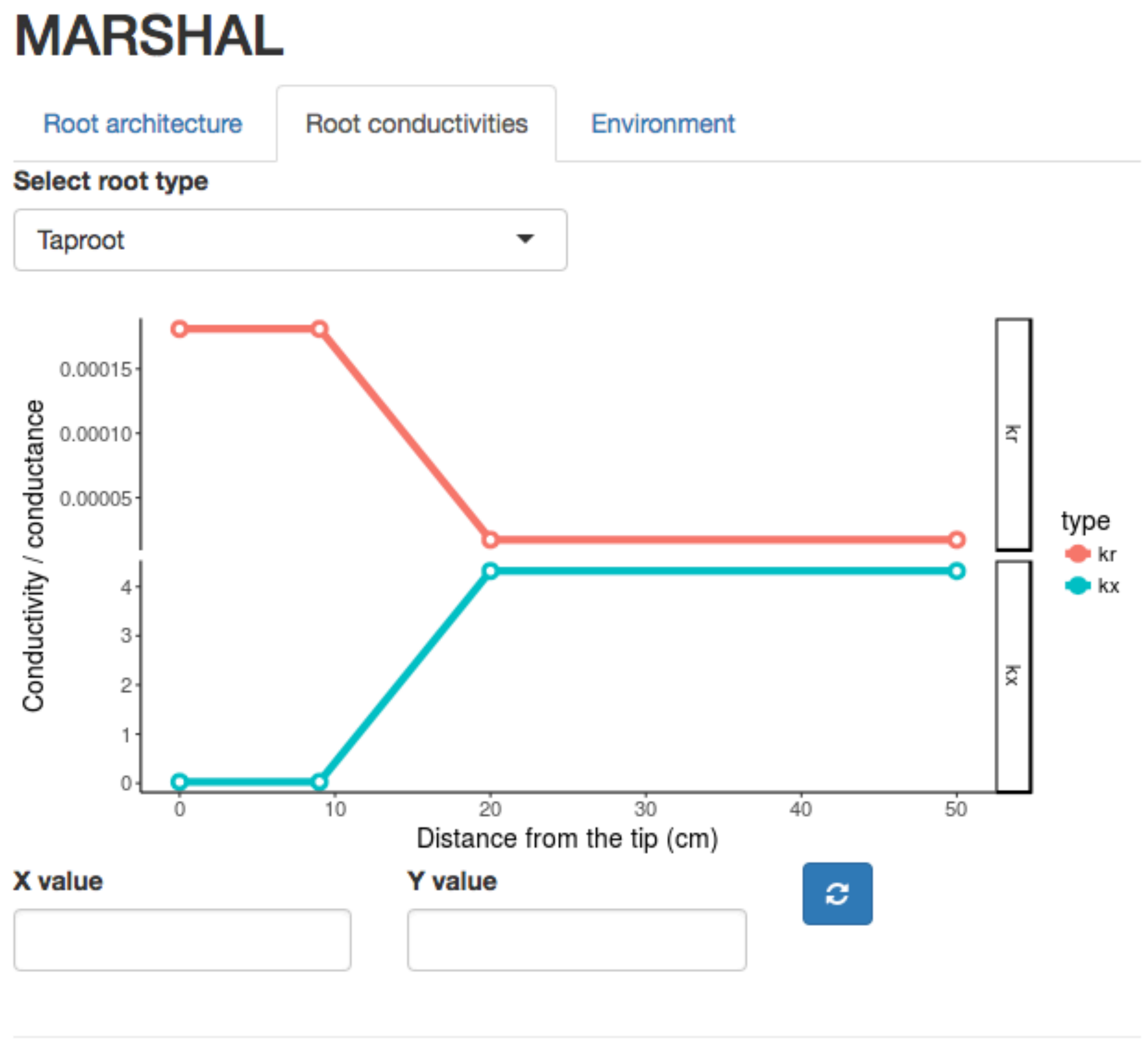

– MARSHAL –

Open Source

marshal-root.github.io

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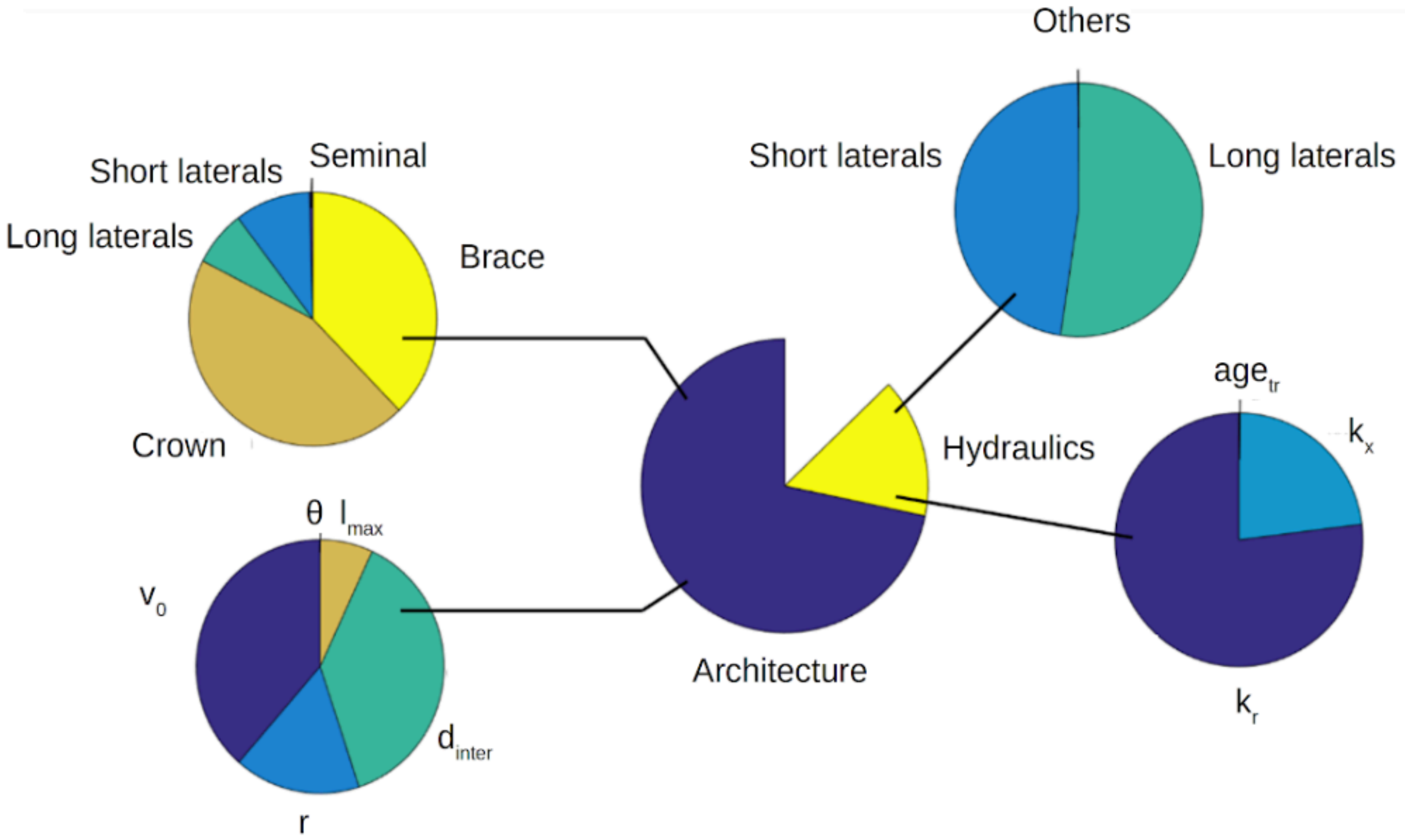
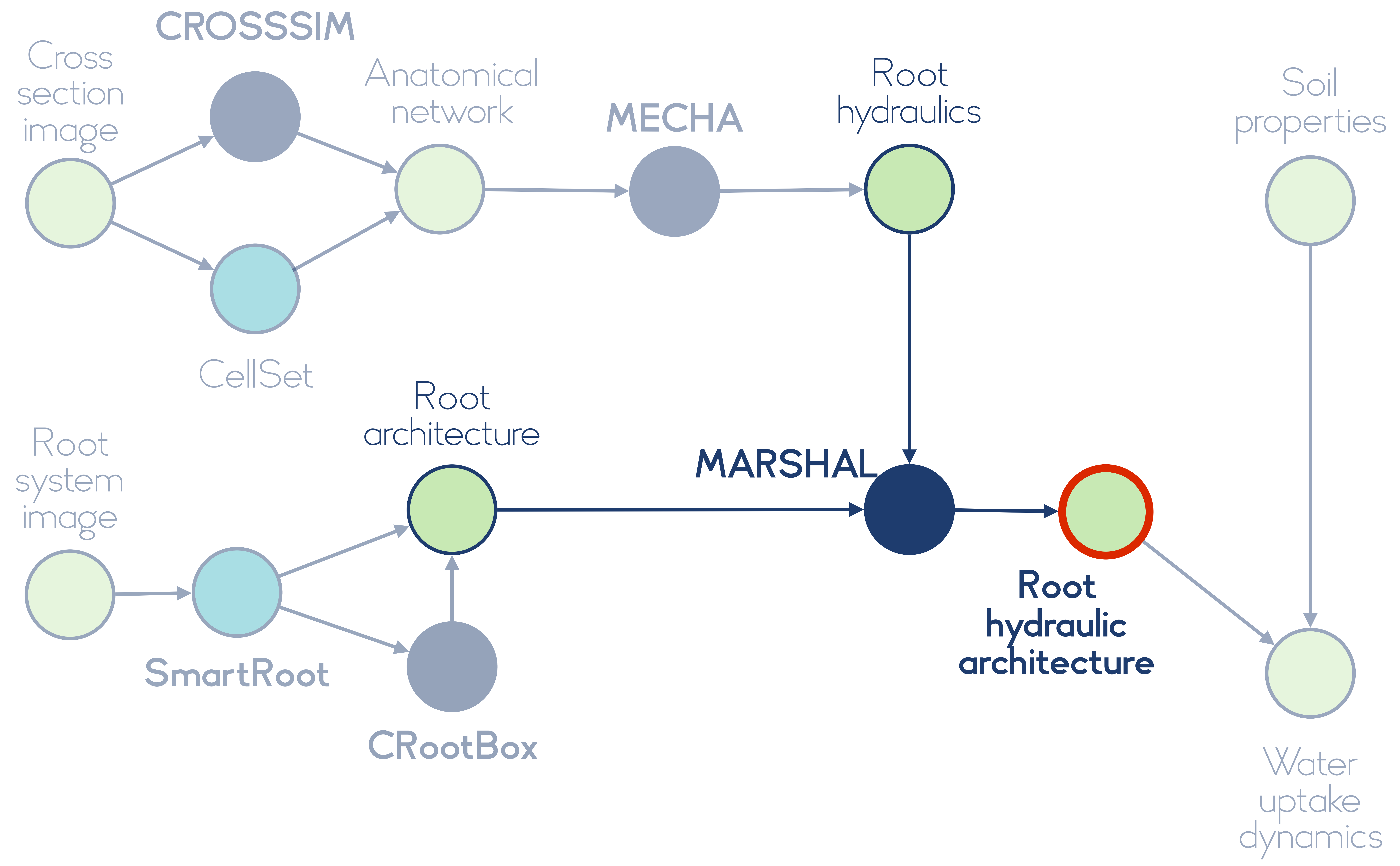
NOT ALL TRAITS HAVE THE SAME **QUANTITATIVE EFFECTS**



Root system conductance at 60 days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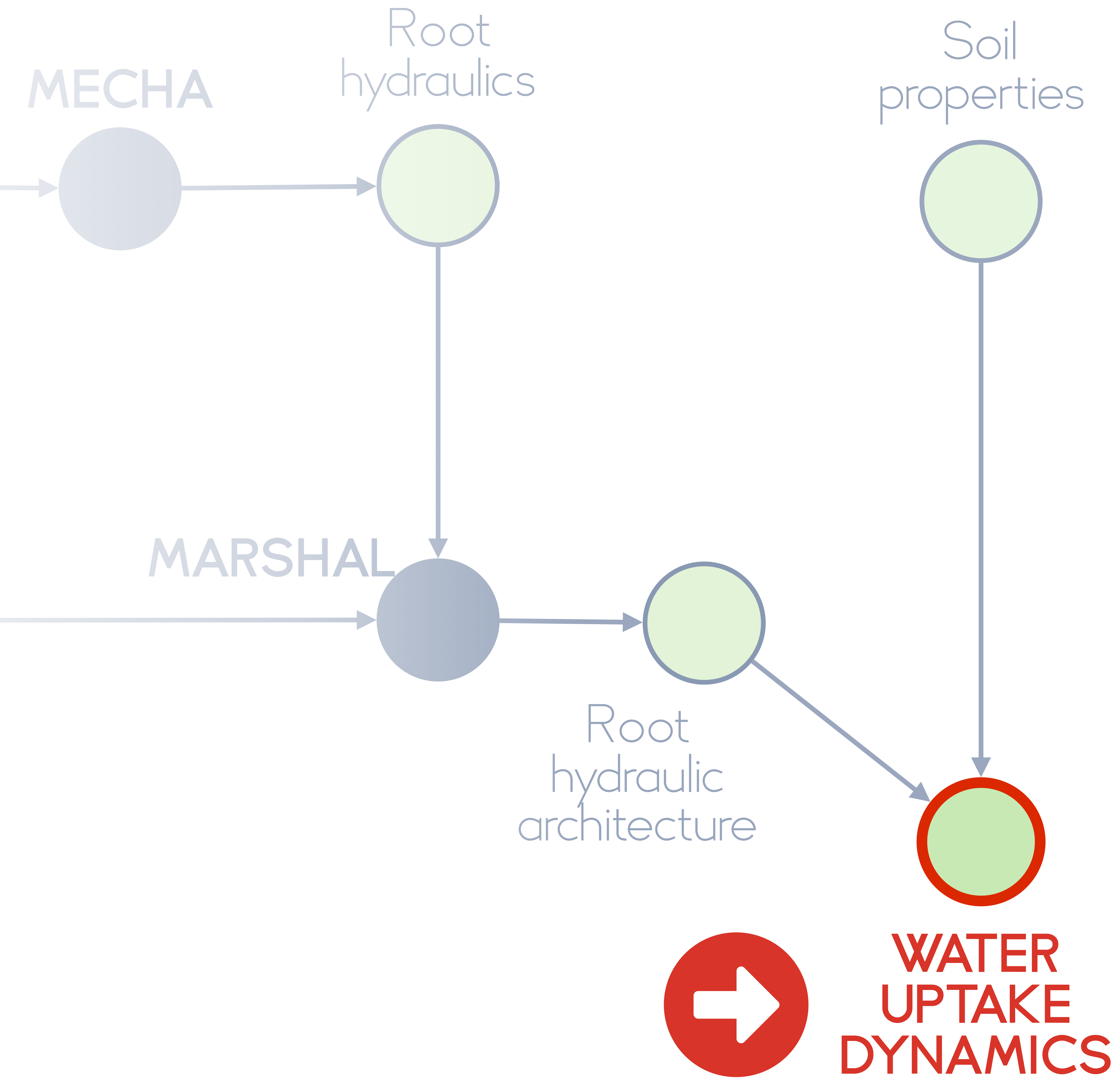
Root architecture
Root system image
MARSHAL
SmartRoot
CRootBox
Root hydraulic architecture
Water uptake dynamics

4

WATER UPTAKE DYNAMICS

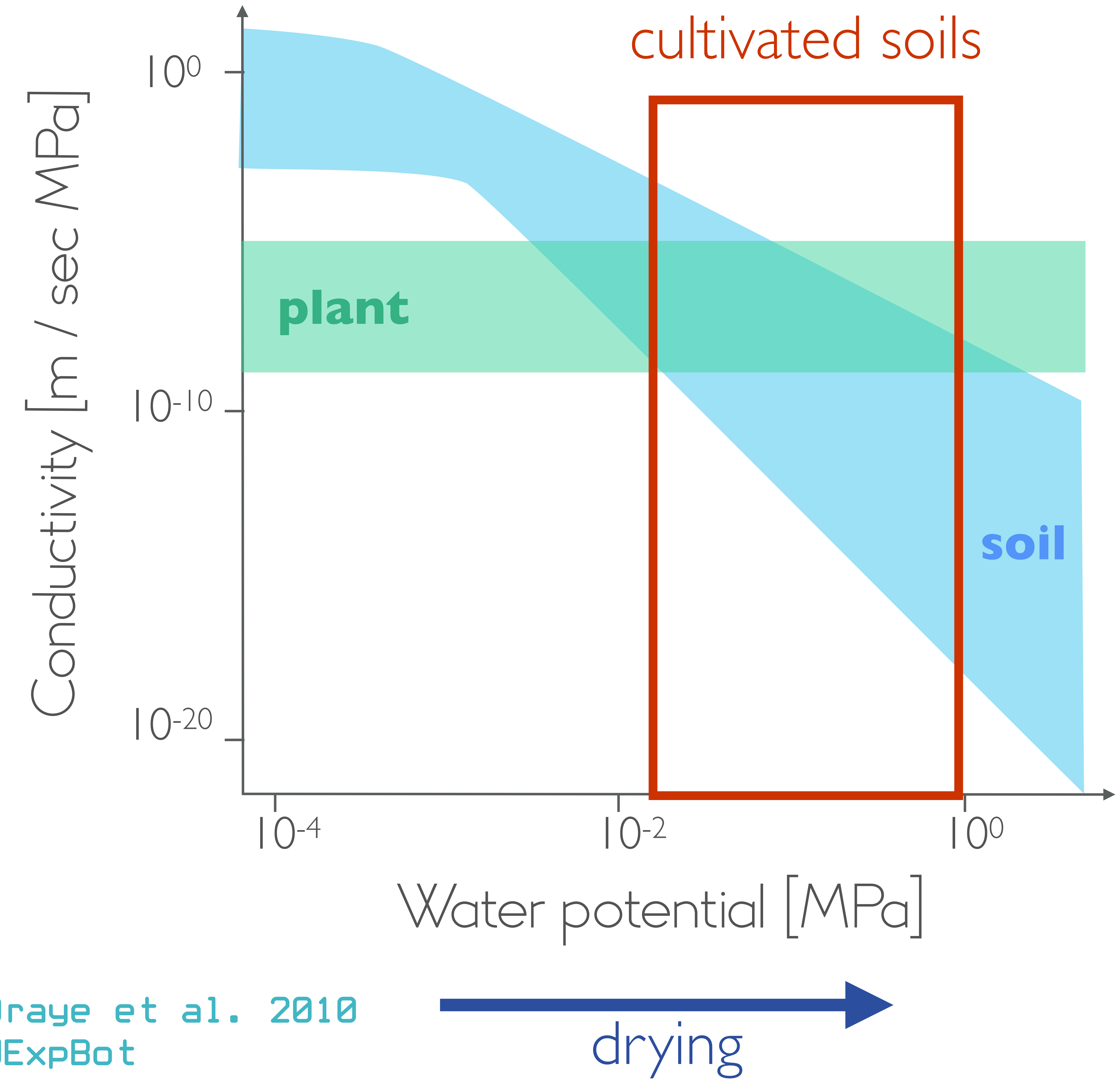


Mathieu **Javaux**

Félicien **Meunier**

Valentin **Couvreur**

DOES THE **SOIL MATTERS**?



"When the soil is wet it has little influence on the uptake of water from it by the plant. When it is dry it has a large influence. When it is neither wet nor dry, the extent of influence is a matter of controversy."

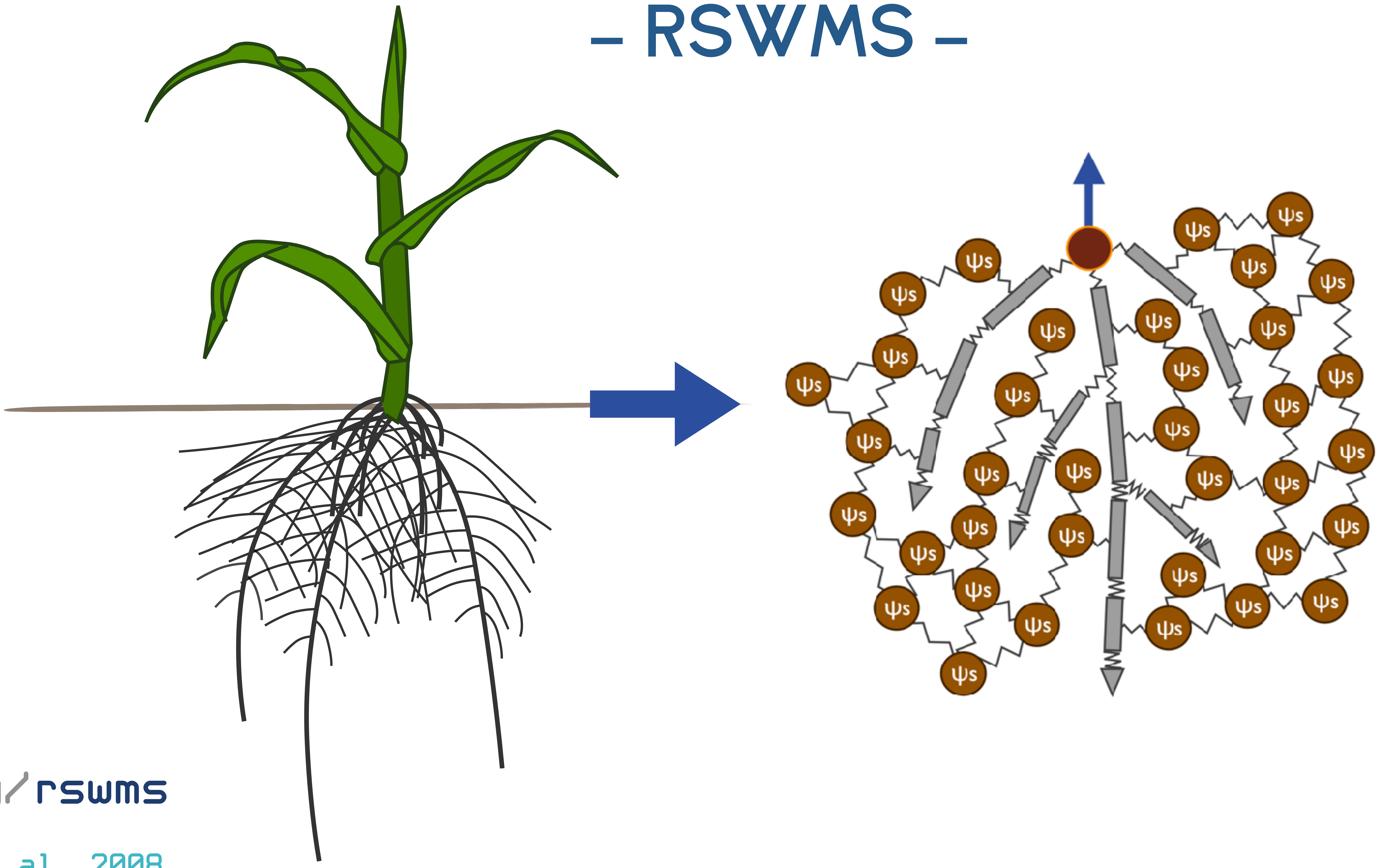
Passioura, 1980

Draye et al. 2010 JExpBot

JÜLICH Forschungszentrum

MODELLING **SOIL-PLANT** WATER MOUVEMENT

- RSWMS -



bit.ly/**rswms**

Javaux et al, 2008
Vadose Zone Journal

JÜLICH
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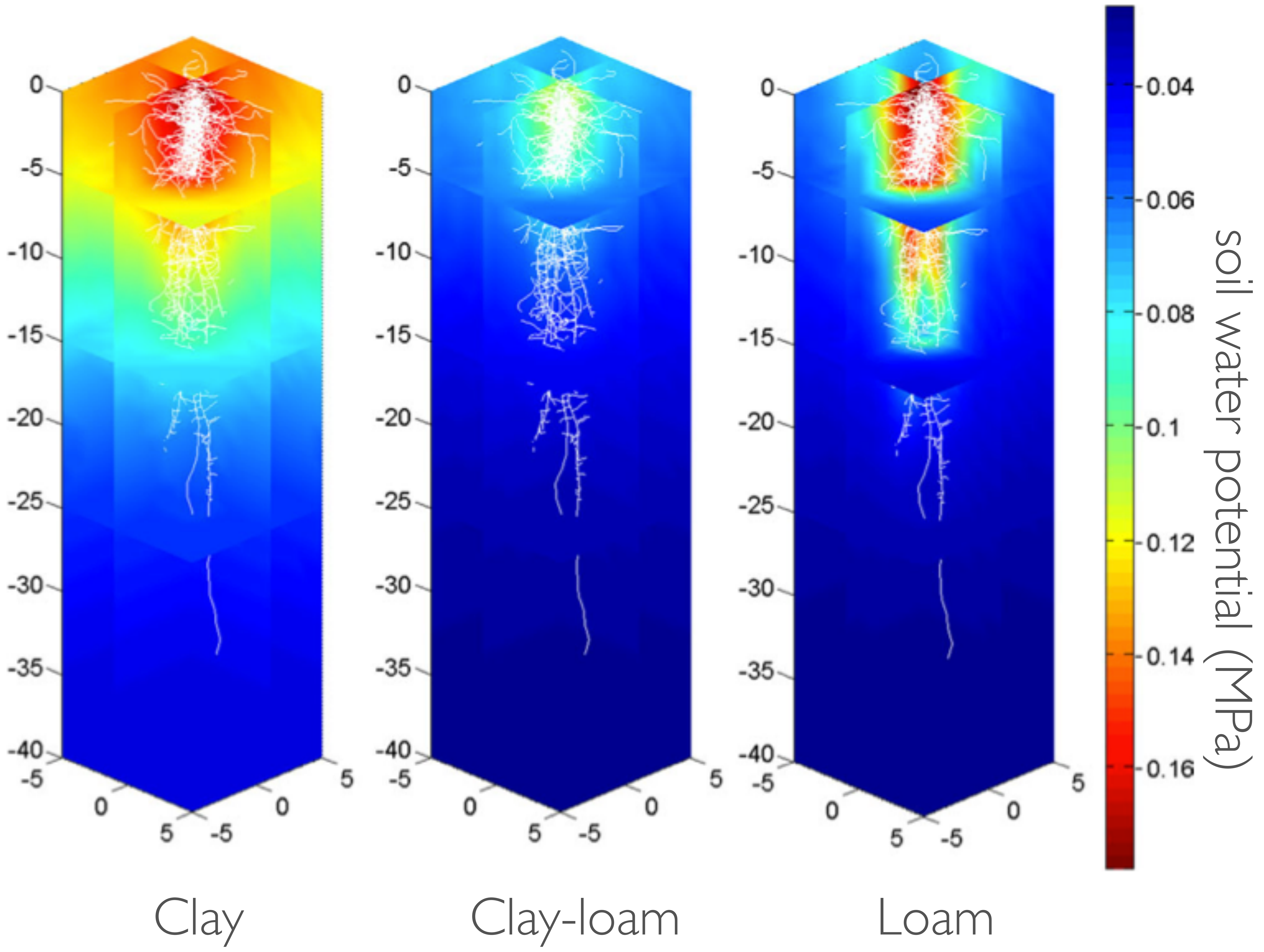
SOIL PROPERTIES SHAPE THE WATER UPTAKE

= ROOT ARCHITECTURE

= HYDRAULIC PROPERTIES

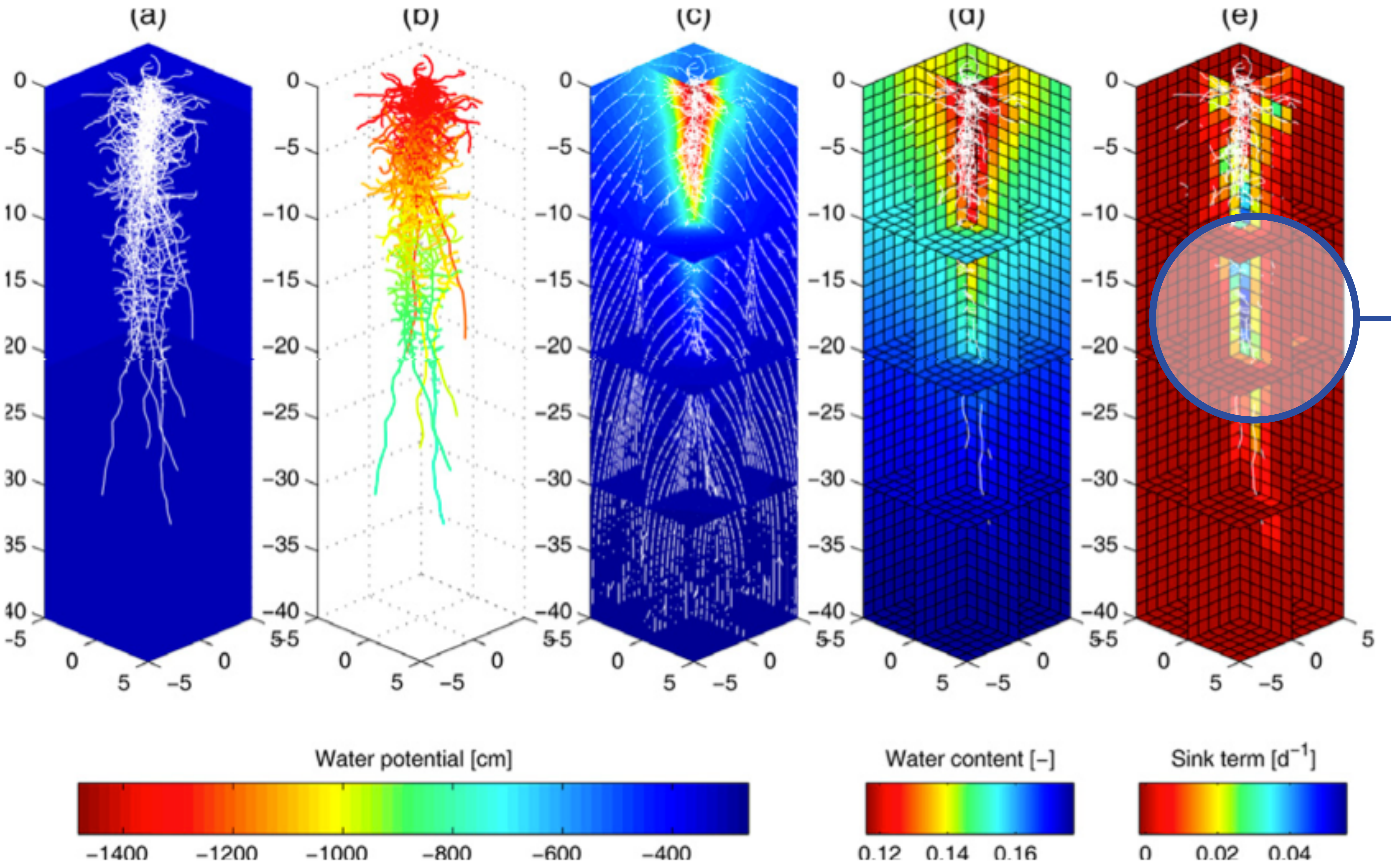
= INITIAL WATER CONTENT

DIFFERENT SOIL TYPES

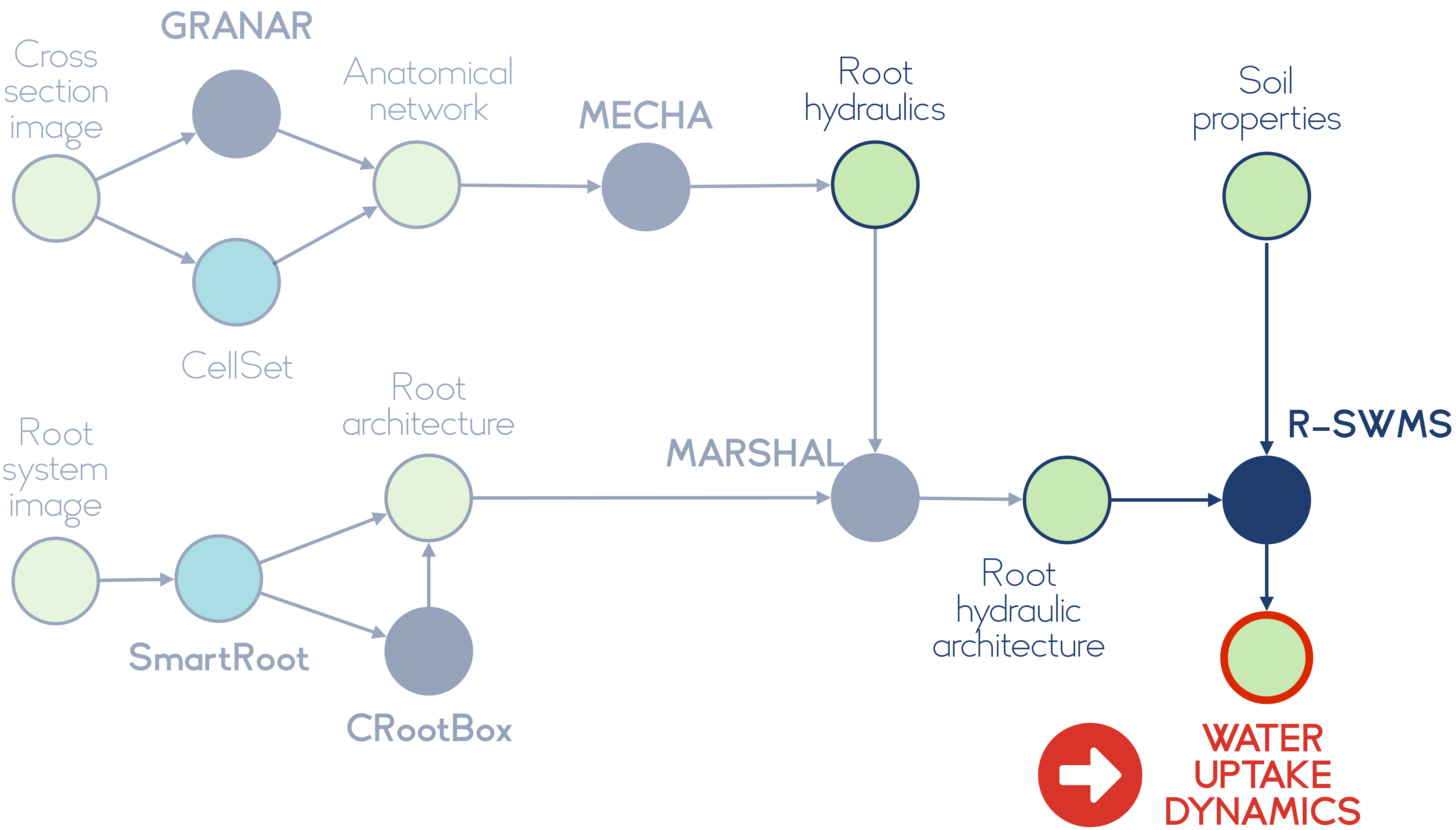


Draye et al, 2010
JExpBot

SOIL WATER CONTENT SHAPES THE WATER UPTAKE



COMPENSATORY UPTAKE



GRANAR
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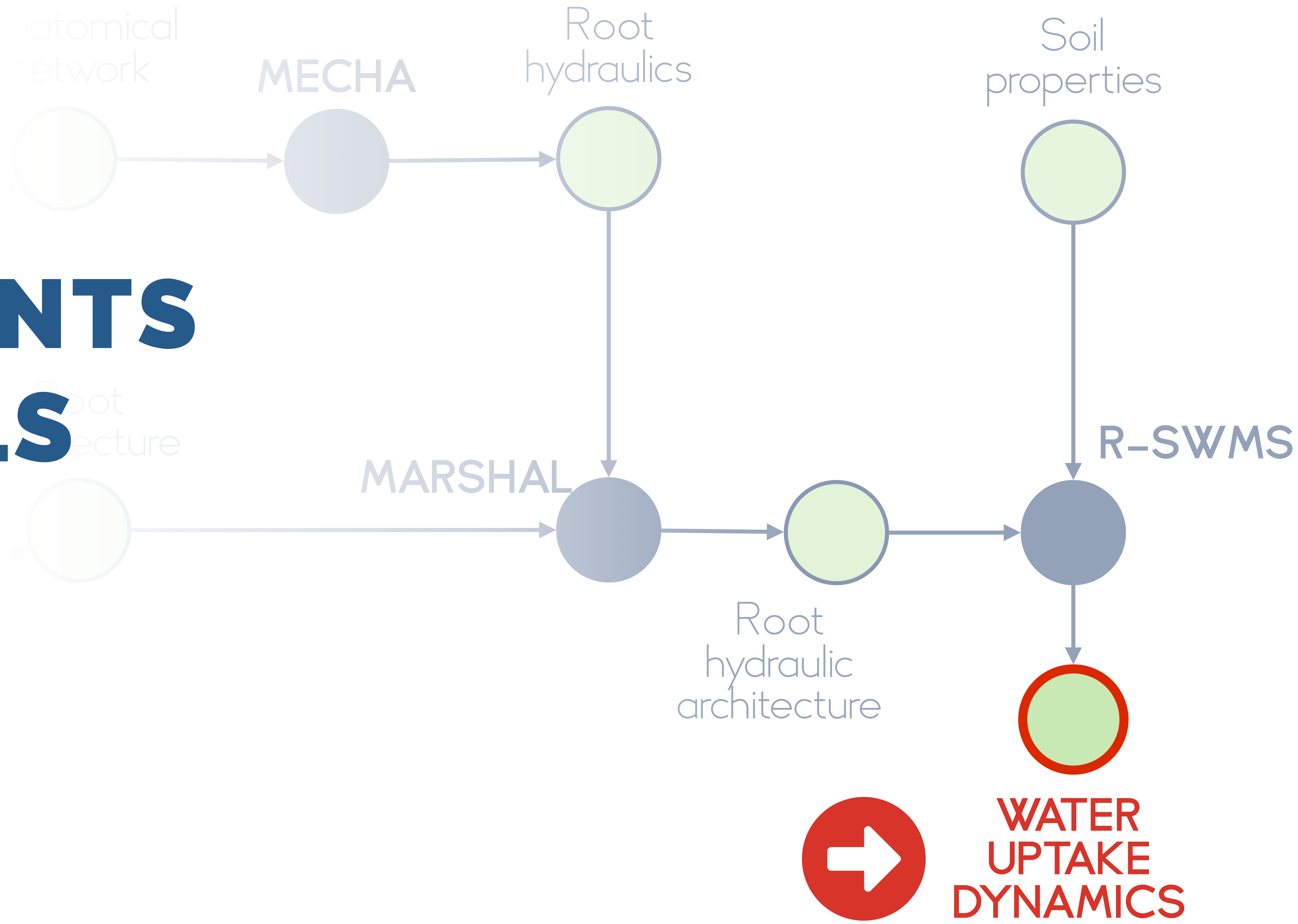
Root architecture
Root system image
MARSHAL
R-SWMS
SmartRoot
CRootBox
Root hydraulic architecture
WATER UPTAKE DYNAMICS

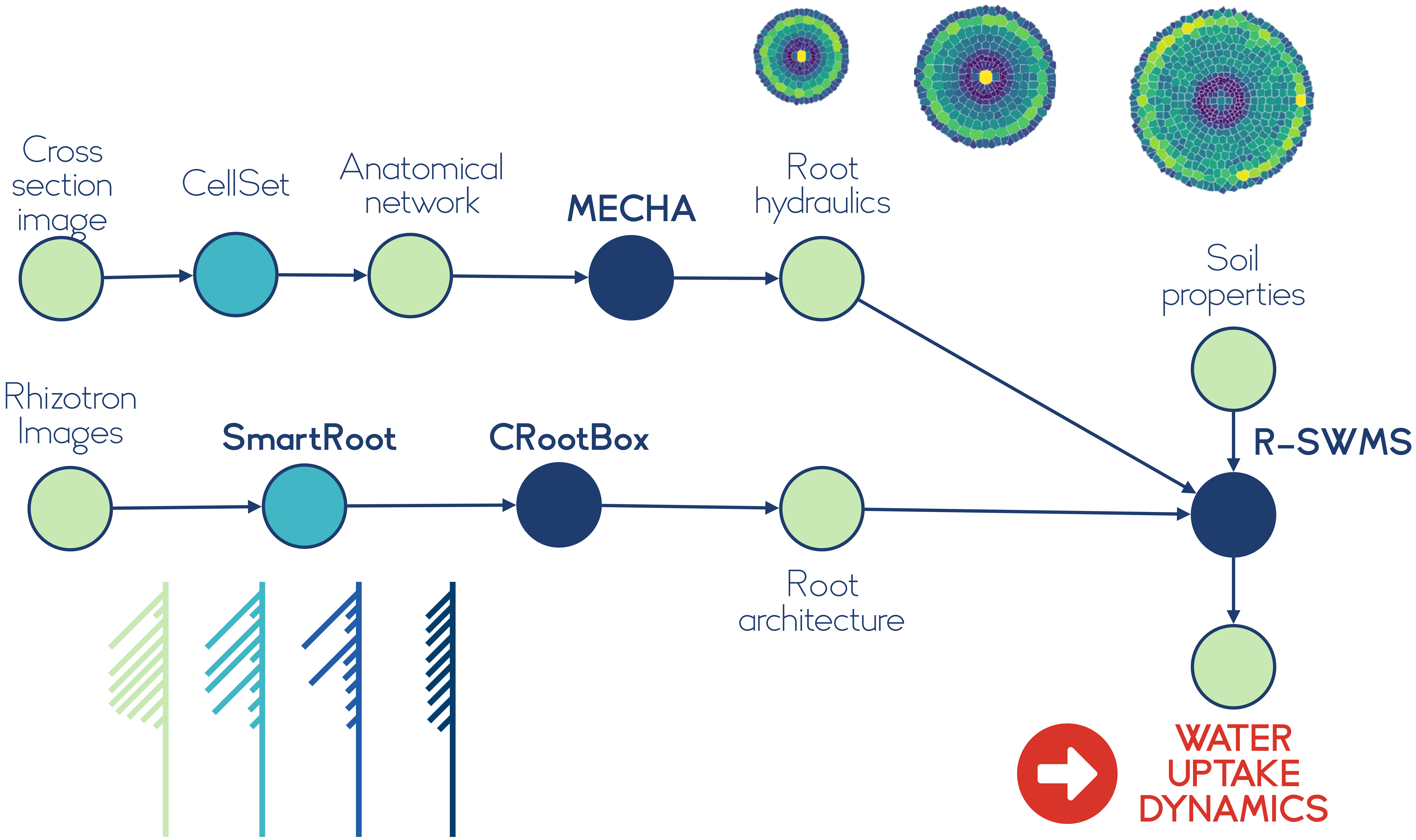
5

FROM EXPERIMENTS TO MODELS

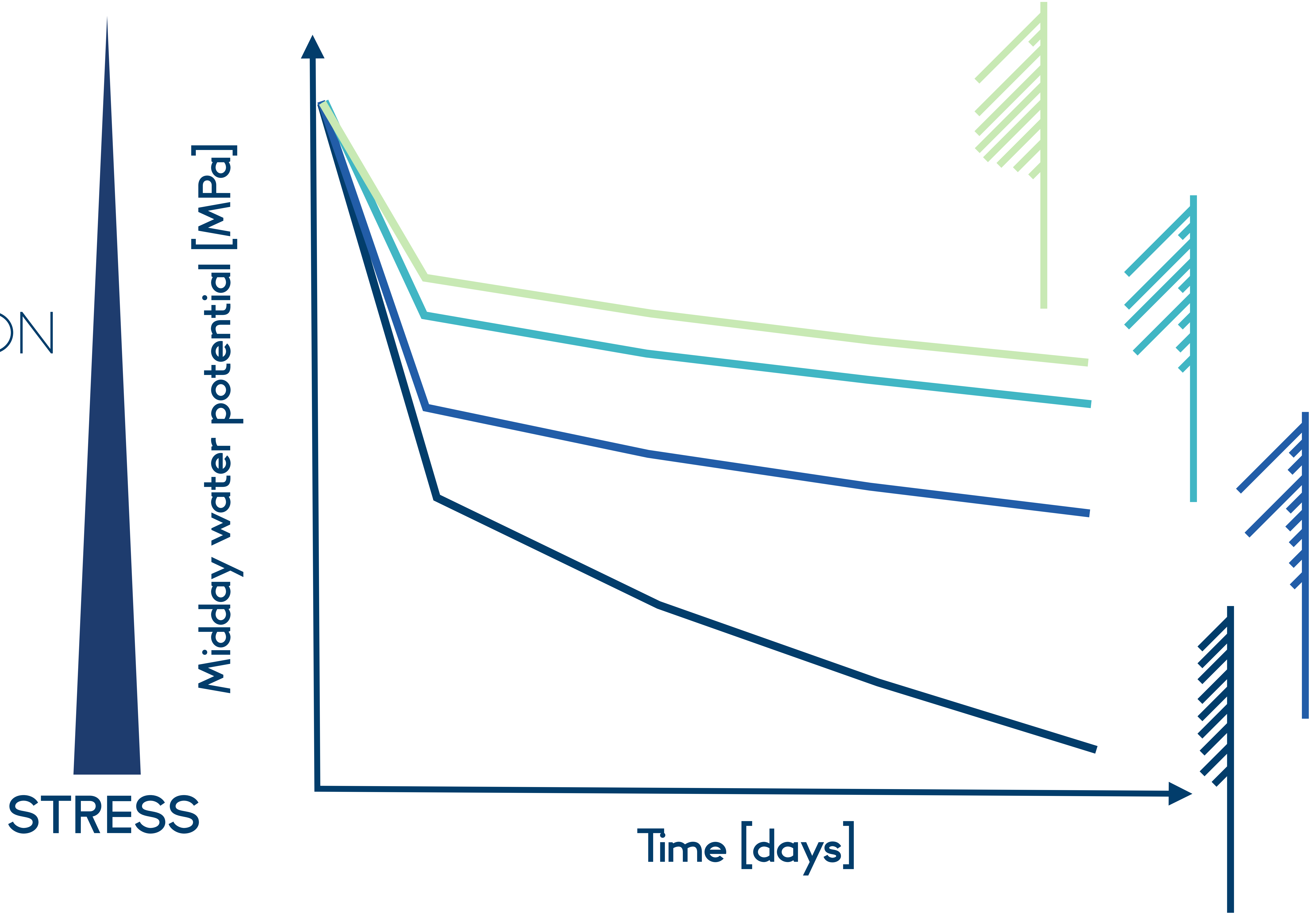


Sixtine
Passot

Adrien
Heymans

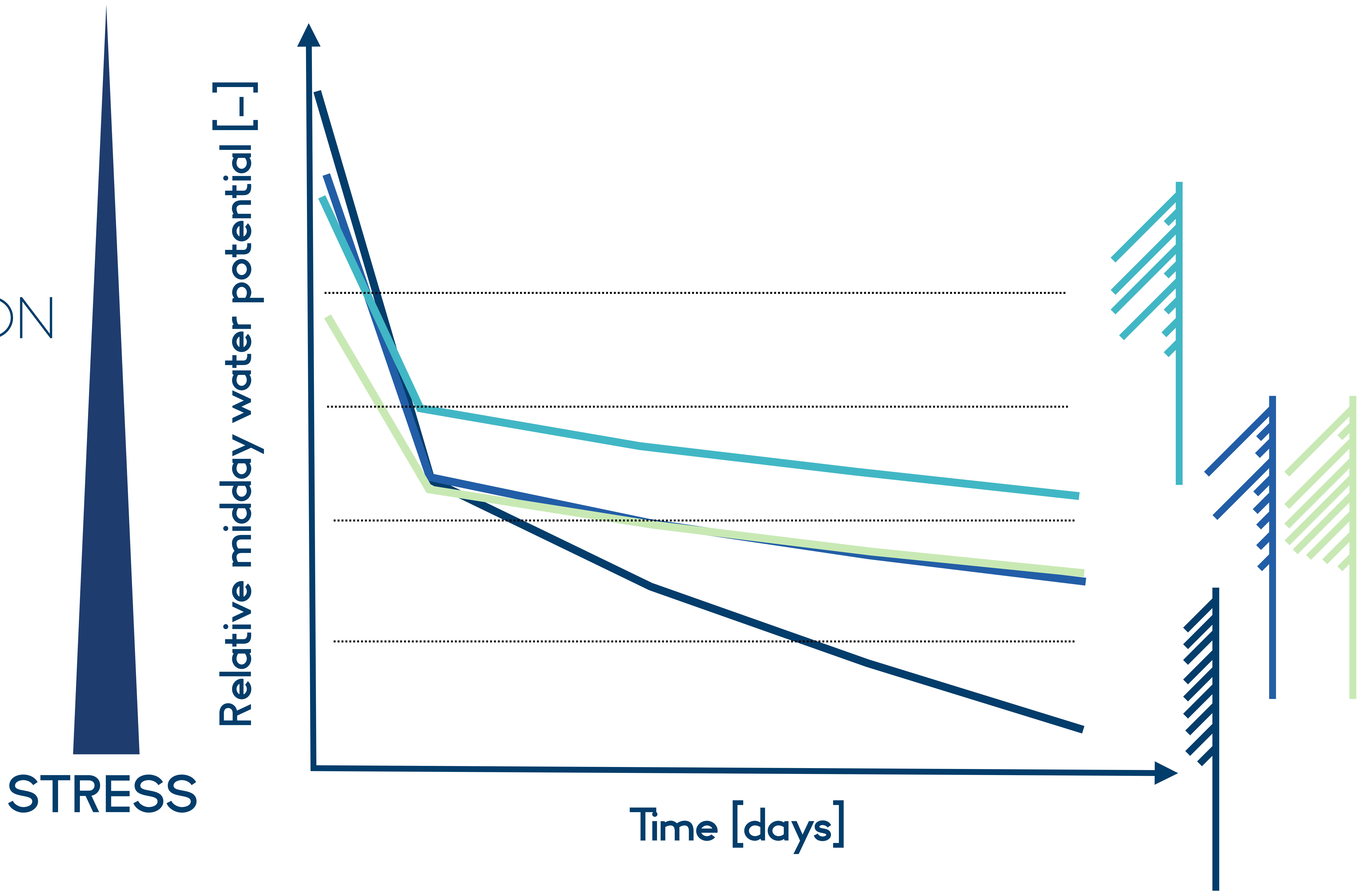

Cross section image
CellSet
Anatomical network
MECHA
Root hydraulics
Soil properties
Rhizotron Images
SmartRoot
CRootBox
R-SWMS
Root architecture
WATER UPTAKE DYNAMICS

EFFECT OF **LATERAL ROOT** DISTRIBUTION ON **WATER UPTAKE** DYNAMICS

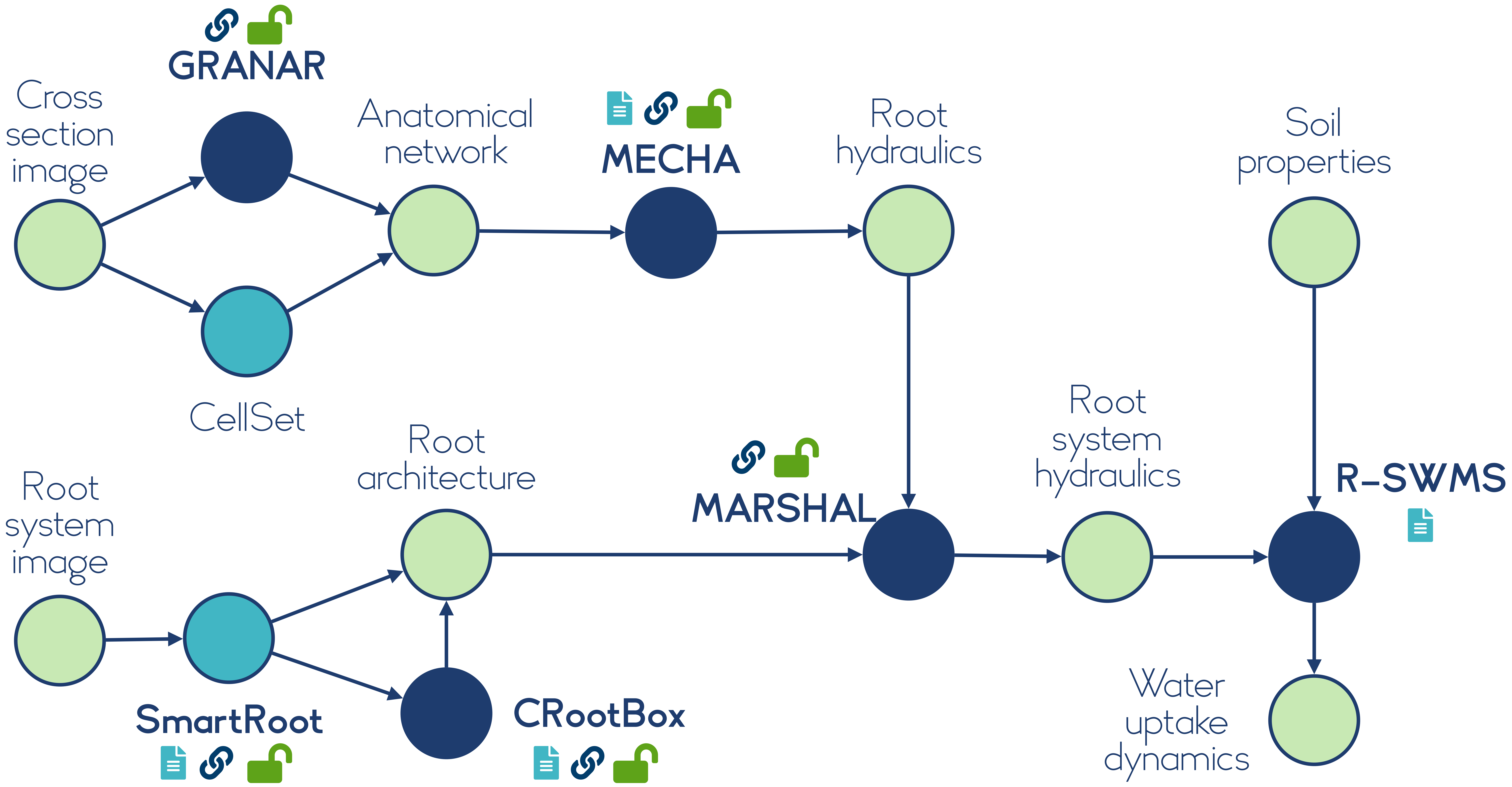


EFFECT OF
LATERAL ROOT
DISTRIBUTION ON
WATER UPTAKE
DYNAMICS

CONSIDERING
CARBON COST

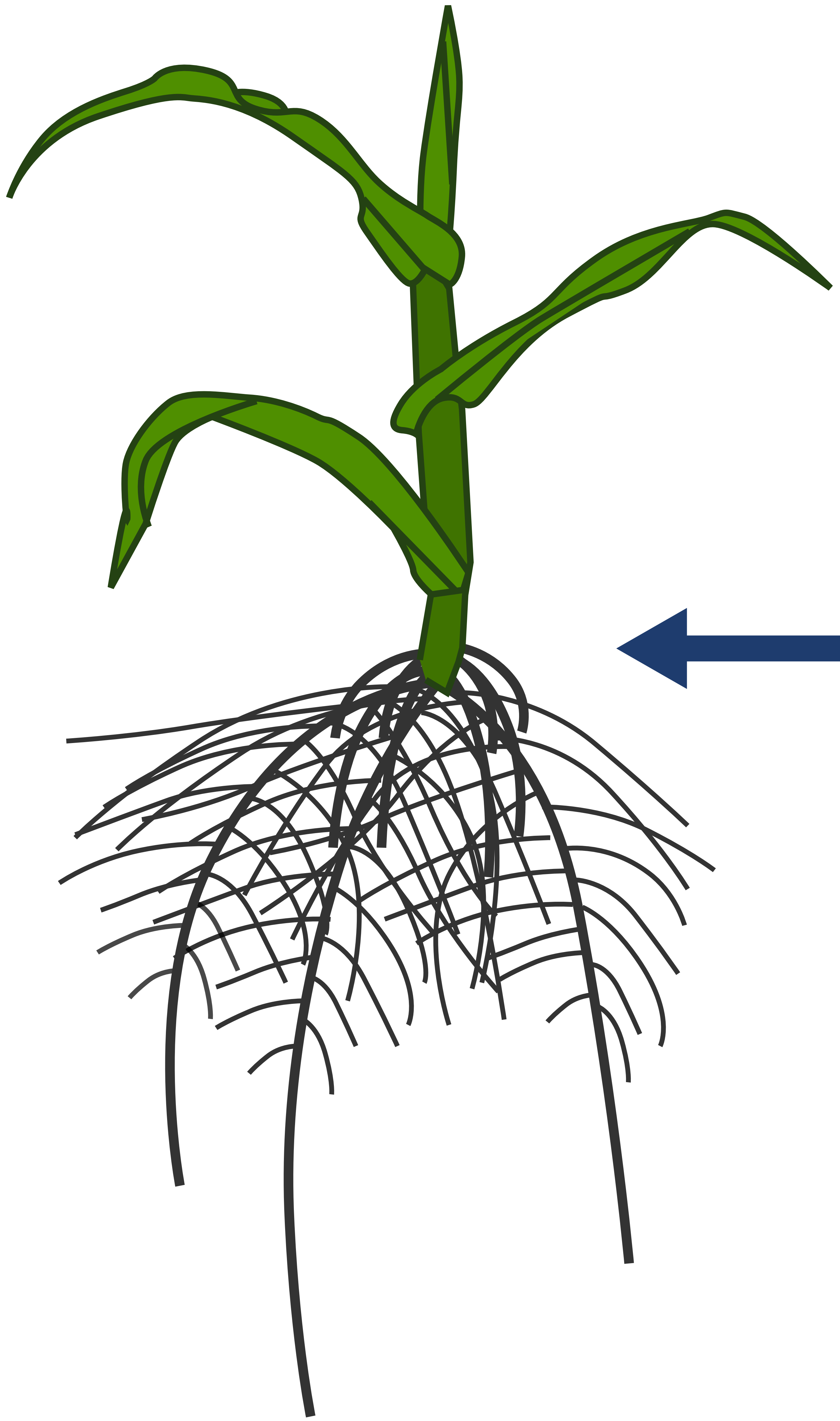



WRAPPING UP



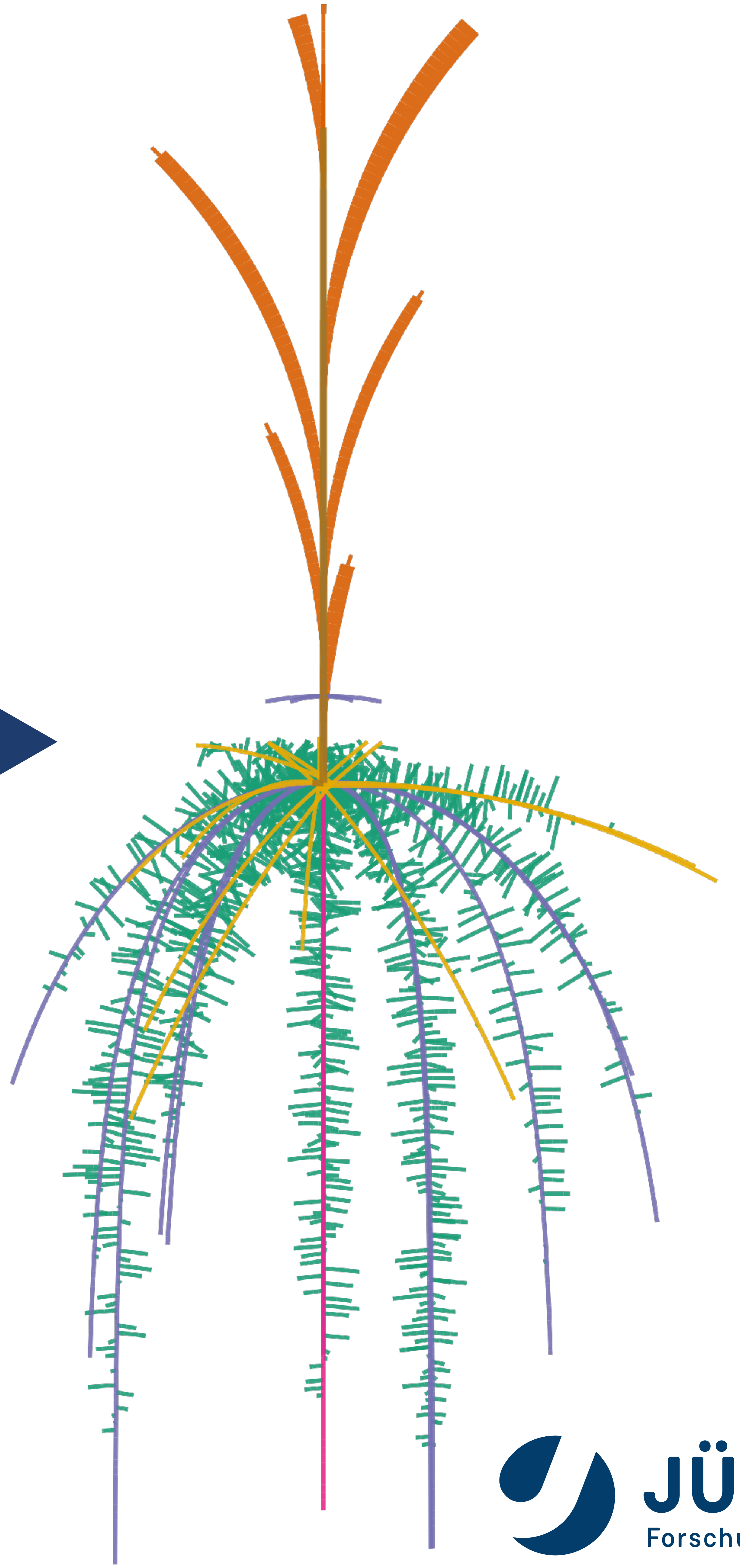
bit.ly/water-network-app

Passot, Couvreur, Meunier et al 2018
JExpBot



WE CAN LINK **MODELS** AND **EXPERIMENTS**

TO GET MORE **FUNCTIONAL** INFORMATIONS



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MAKING MODELS **USABLE** FOR **EVERYONE**

WEB APPLICATION
[R SHINY]
STUDENTS / CURIOUS

LIBRARIES, NOTEBOOKS
[PYTHON, R]
USERS

CORE MODELS
[PYTHON, R, C++]
DEVELOPPERS

USABILITY

CAPABILITIES

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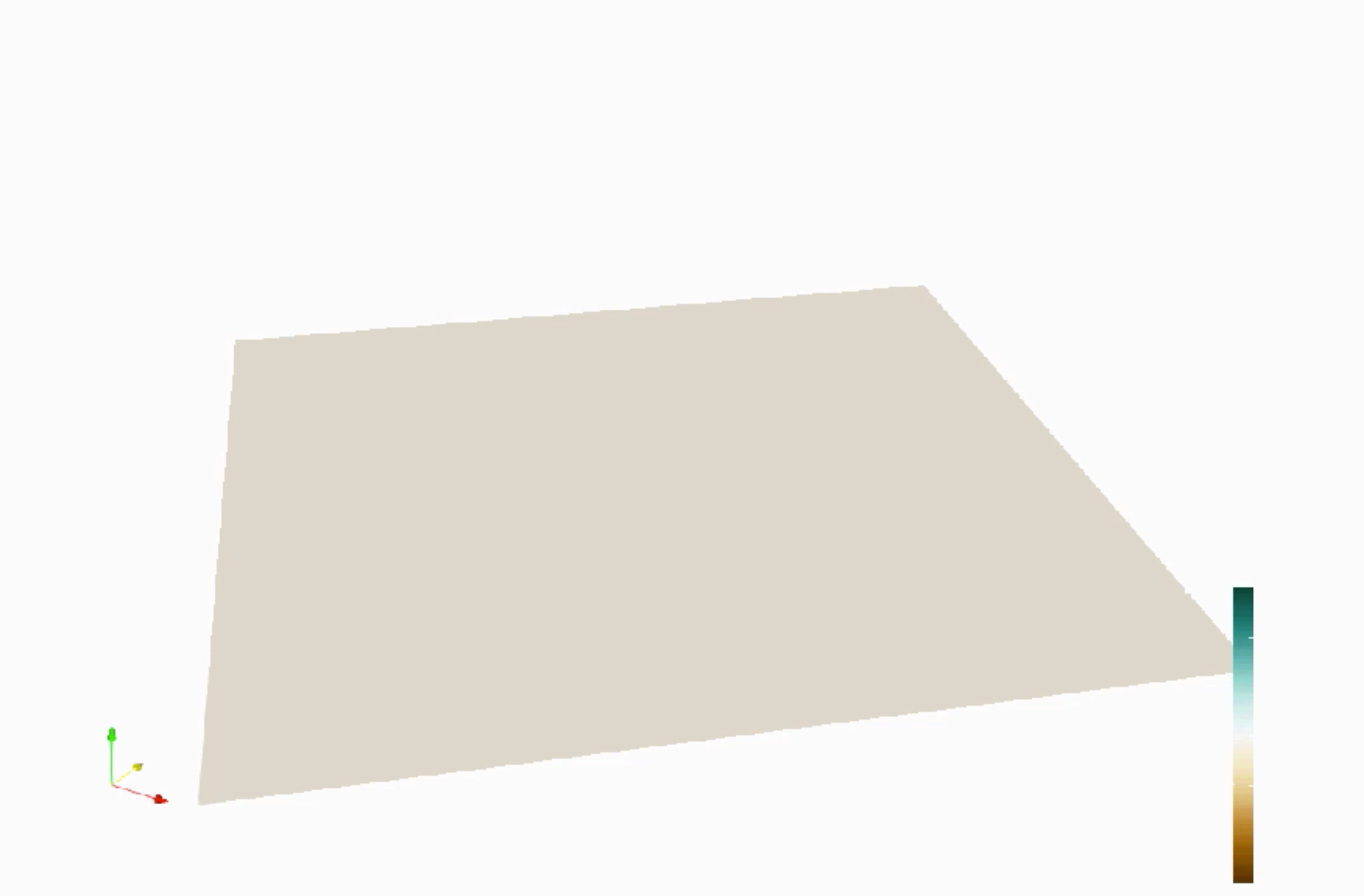
WHAT I **DID NOT** TALK ABOUT

- **NUTRIENT** UPTAKE
- **SOLUTE** DYNAMICS IN THE SOIL
- **SALT** STRESS MODELLING
- GROWTH IN **MACROPORES**
- **CARBON** MODELLING
- **WHOLE PLANT** MODELLING
- …



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UCLouvain


Félicien
Meunier


Mathieu
Javaux


Valentin
Couvreur


Xavier
Draye


Sixtine
Passot


Adrien
Heymans

JÜLICH
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Andrea
Schnepf

SIM WERK
simulationswerkstatt


Daniel
Leitner

www.rosi.science

ALL MODELS ARE WRONG BUT SOME ARE USEFUL

G. BOX [1978]

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