PLANT **ROOTS** IN CROPS MODELS : **WHY** WE SHOULD CARE AND **HOW** TO DEAL WITH IT?

Xavier Draye & Guillaume Lobet
UCLouvain - Earth and Life Institute

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European Research Council
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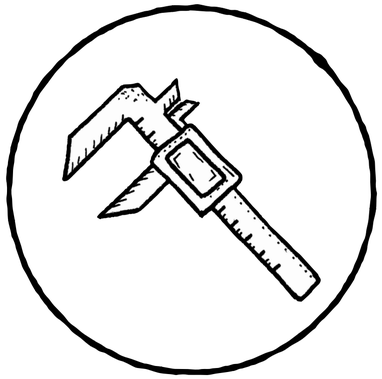
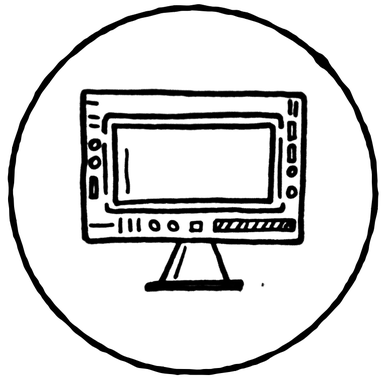
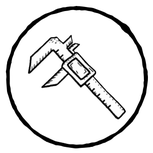


EXPERIMENTAL RESULT



MODELLING RESULT



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PART 1

WHY

ROOTS

MATTER

PART 2

FROM

FIELD TO

MODELS

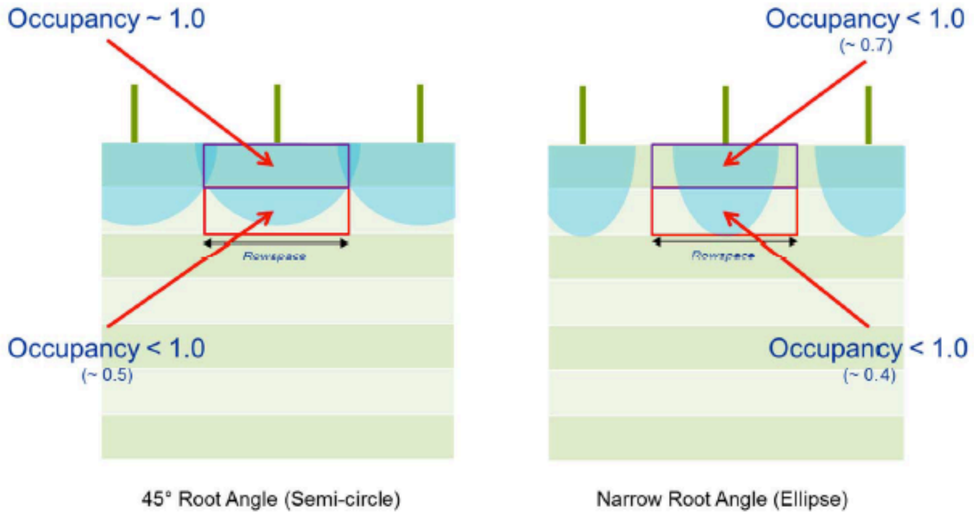
PART 1
WHY **ROOTS** MATTER

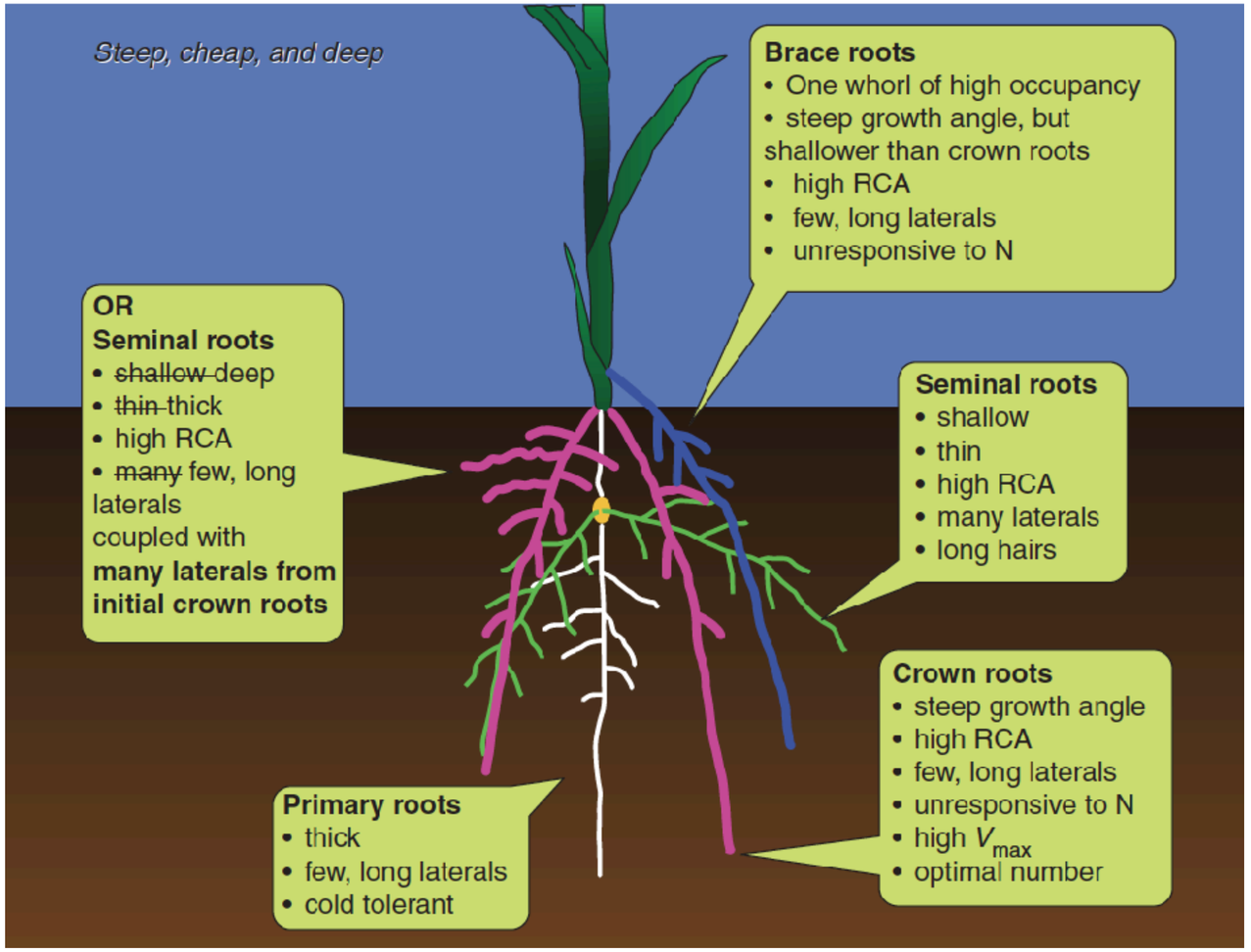
CURRENT ROOT IDEOTYPES FOR TOLERANCE TO WATER DEFICIT

Largely spatial and built on constitutive phenes

Shallow *vs* Deep
Constitutive phenes
Match RLD(z) with SWC(z)

$$\text{Potential Uptake} = \sum_{\text{Layer}=1}^{\text{nLayers}} (\text{ESW}_{\text{Layer}} * \text{KL}_{\text{Layer}} * \text{Occupancy}_{\text{Layer}})$$

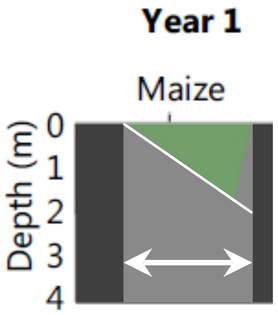




LYNCH ET AL (2016)

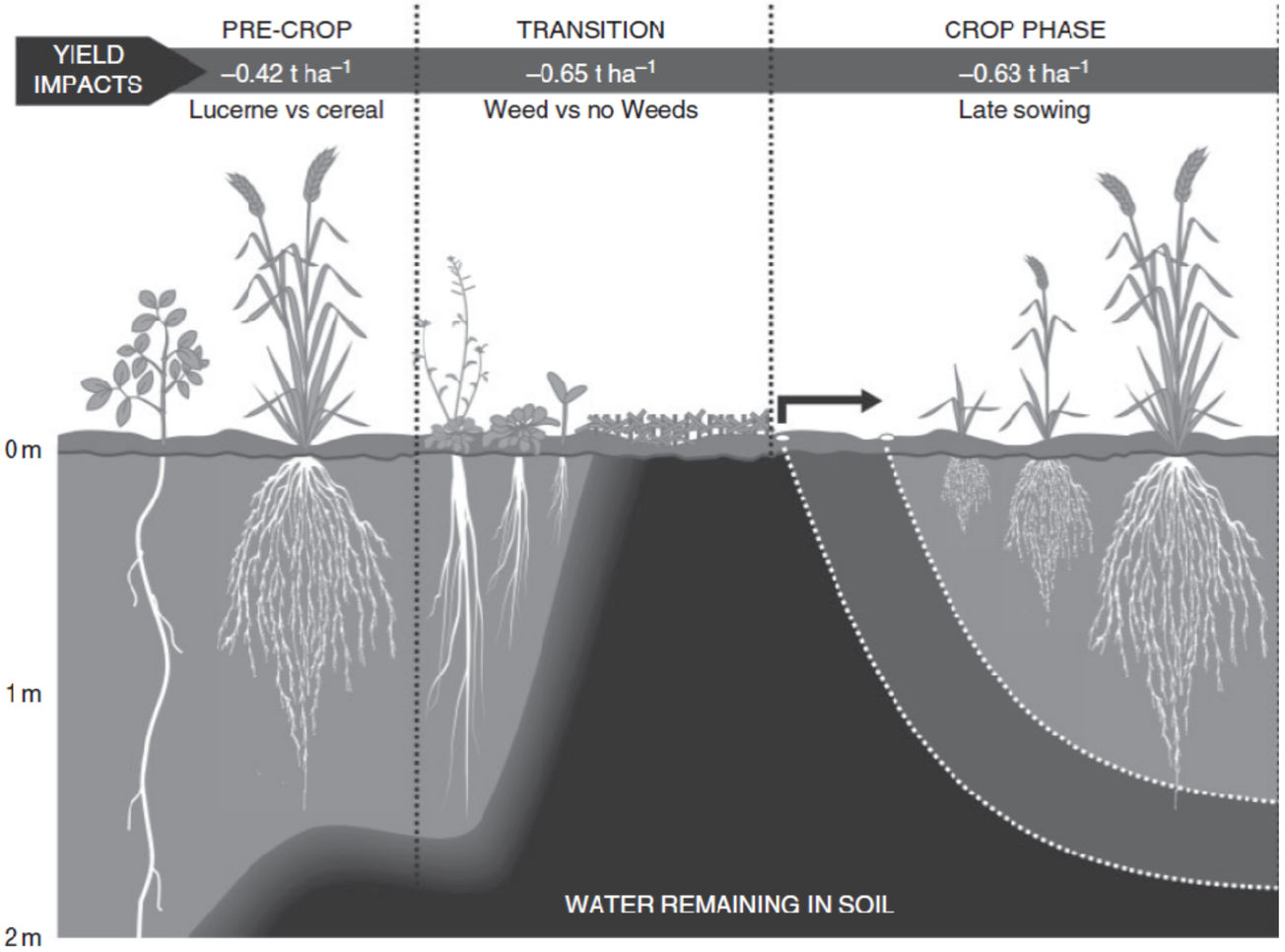
CONSIDERING TIME BRINGS NEW PERSPECTIVES

E.g. the importance of crop duration and root penetration rate



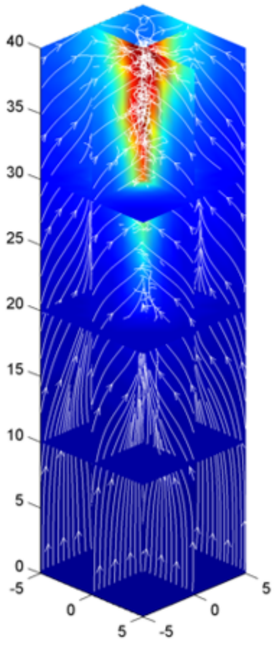
ROOTING DEPTH-BASED OPTIONS FOR PRODUCTIVITY AND RESILIENCE

Based on data and simulations (southern NSW, Australia)

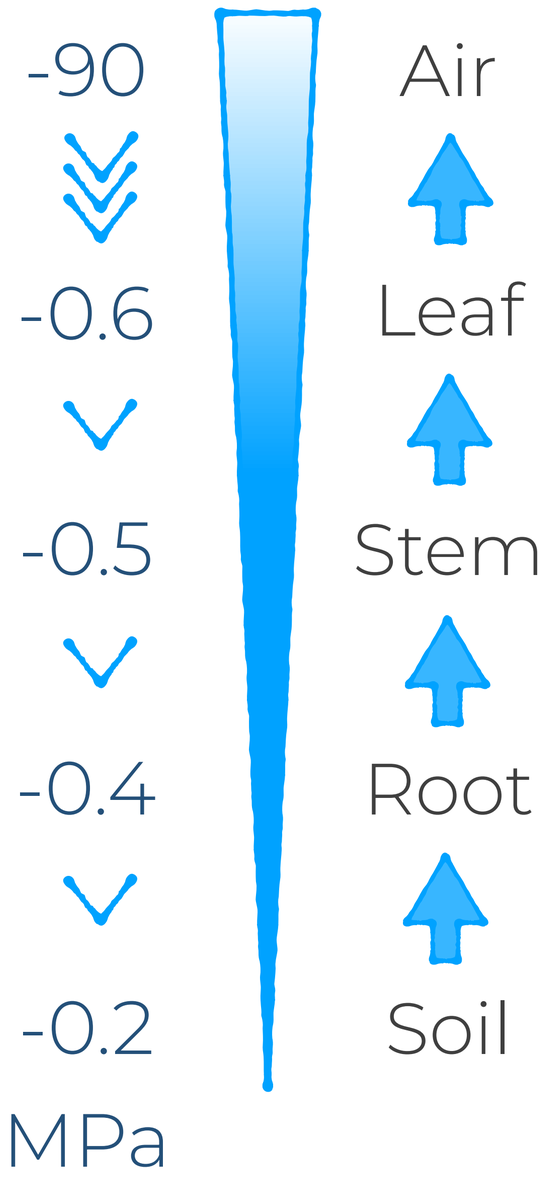


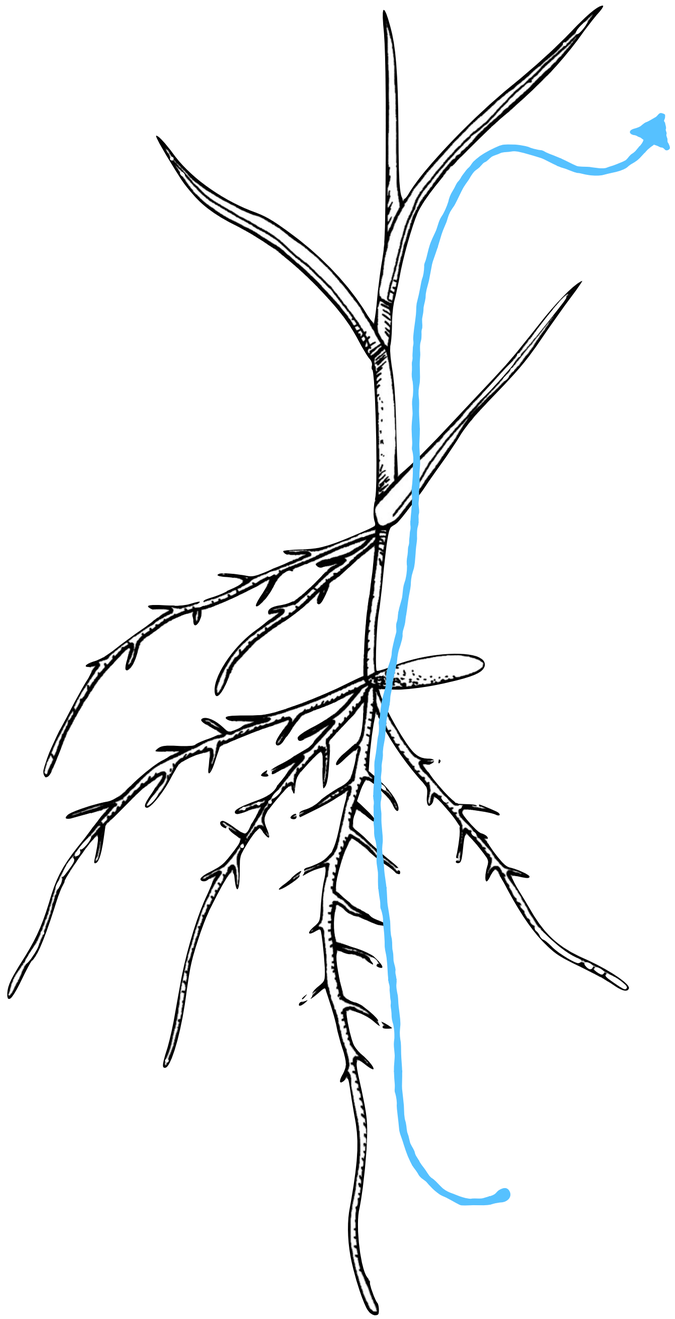
(ADAPTIVE) HYDRAULIC ARCHITECTURE & ANATOMY

??



Thorup-Kristensen & Kirkegaard (2016) Ann Bot 118:573

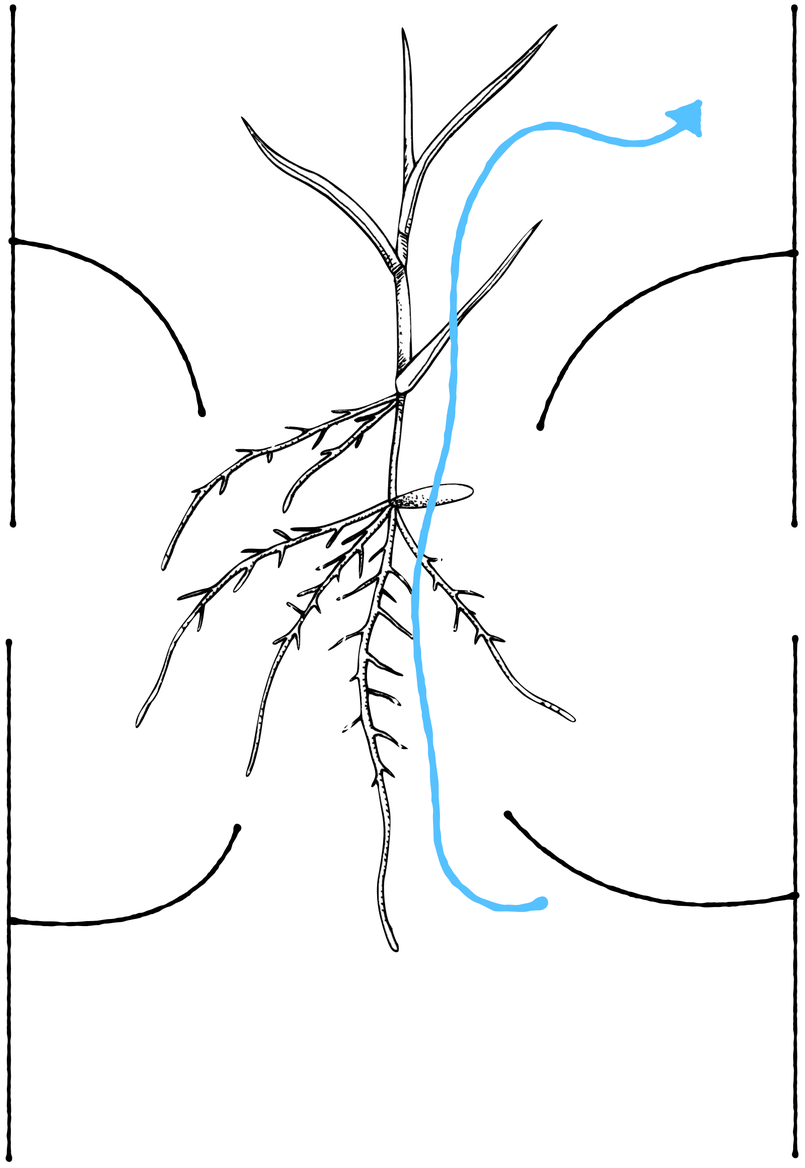


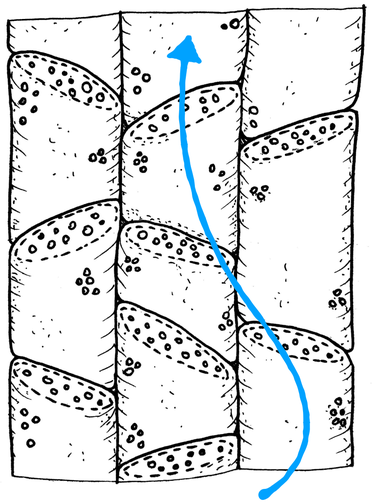


WATER FLOW IN THE SOIL-PLANT-ATMOSPHERE IS A PASSIVE PROCESS

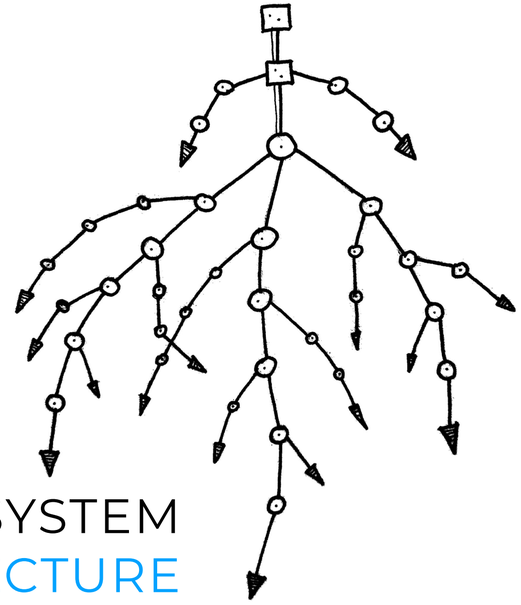
BUT IS ACTIVELY REGULATED

SOIL
PROPERTIES

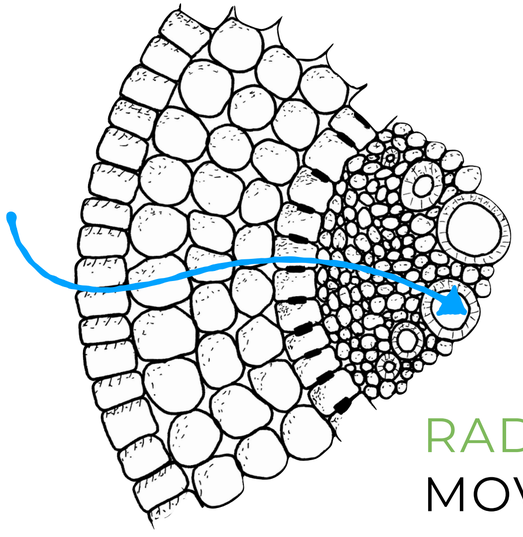




AXIAL
MOVEMENT

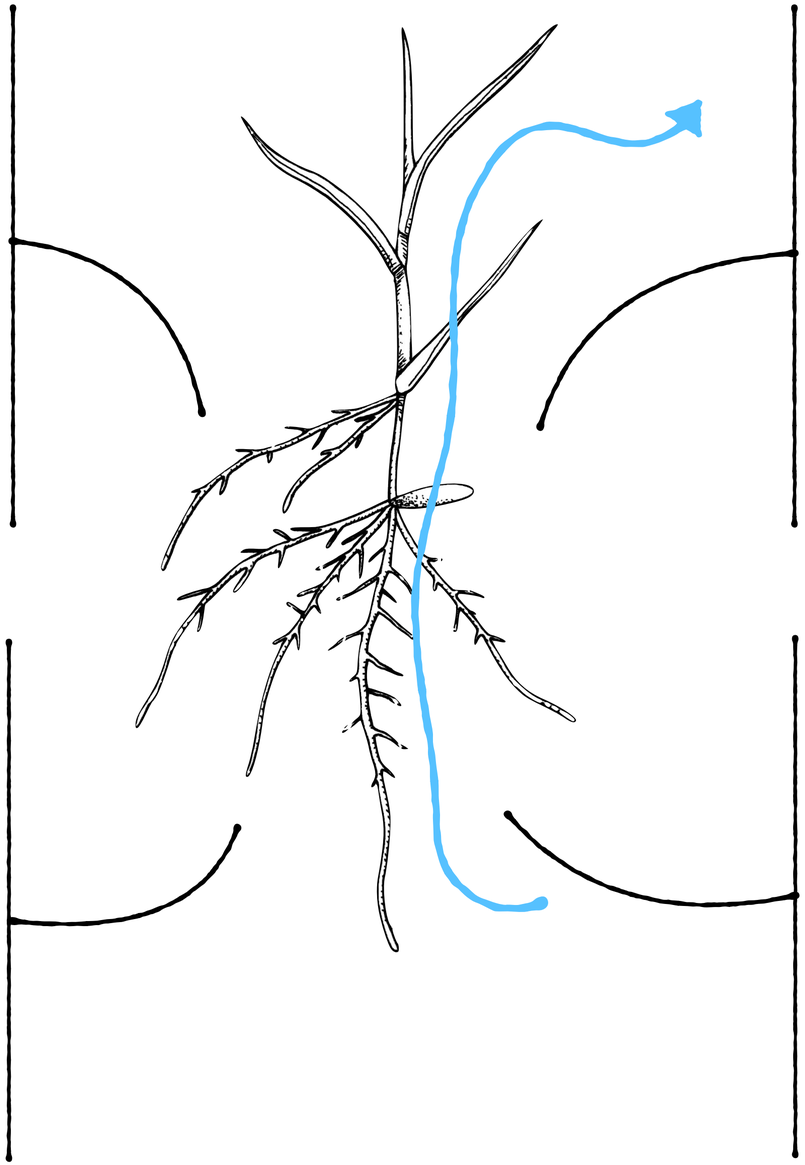


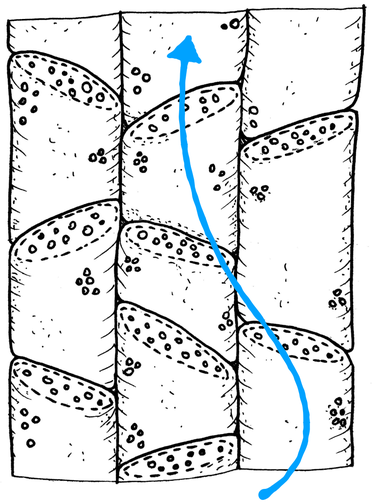
ROOT SYSTEM
ARCHITECTURE



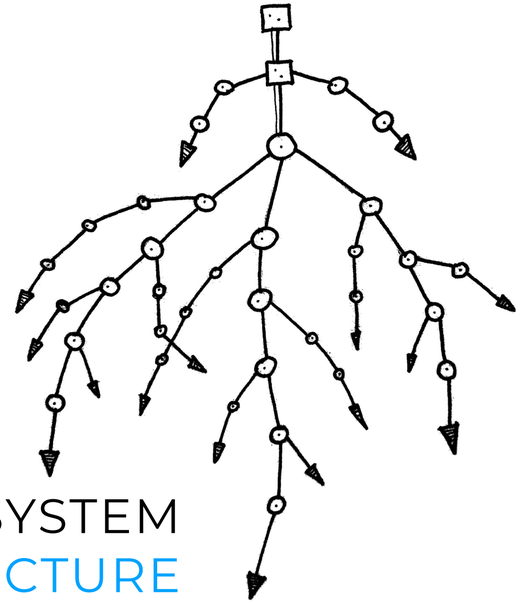
RADIAL
MOVEMENT

SOIL
PROPERTIES

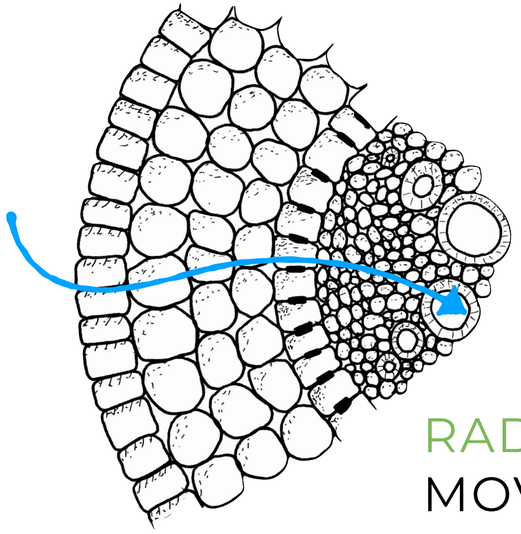




AXIAL
MOVEMENT



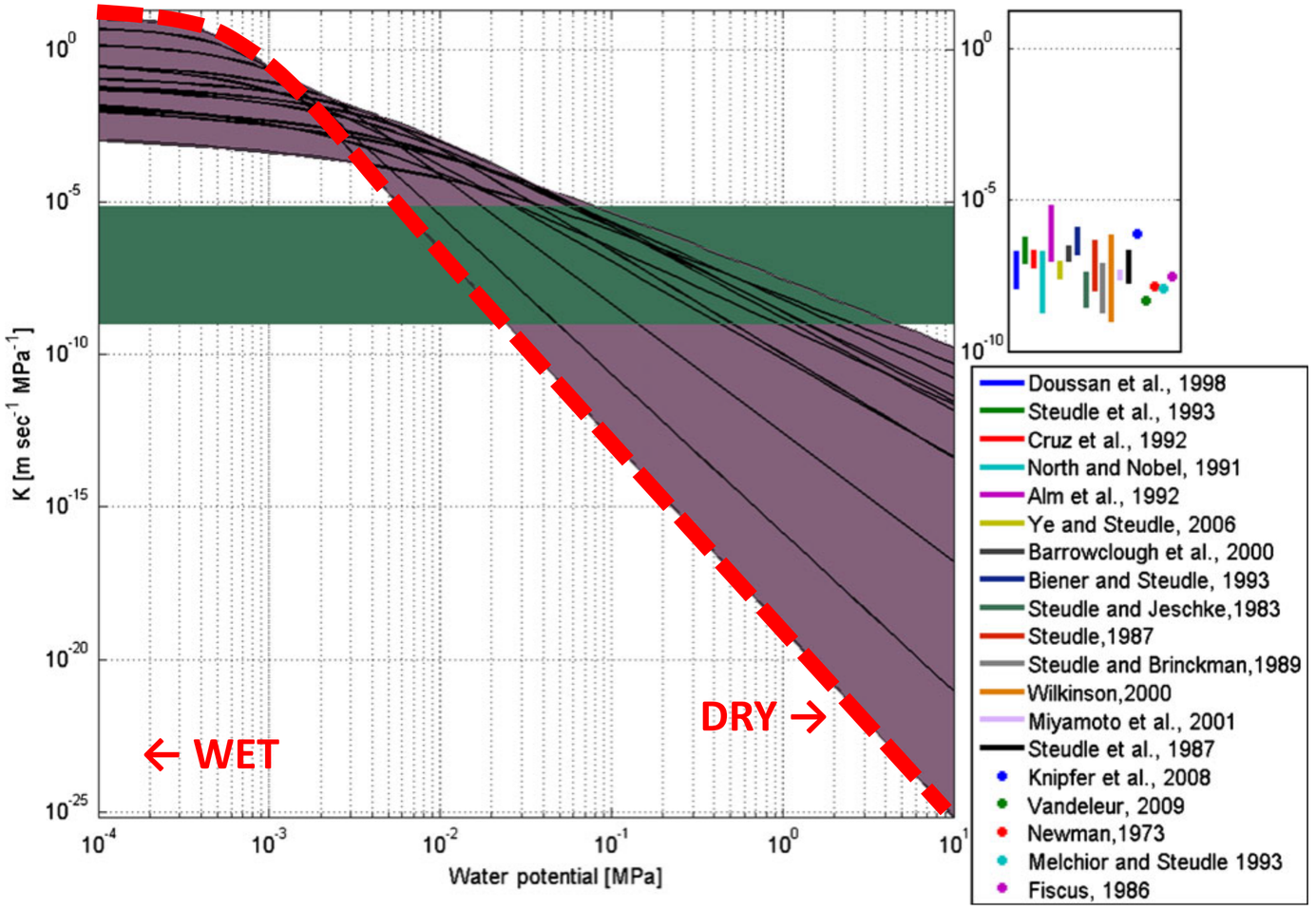
ROOT SYSTEM
ARCHITECTURE



RADIAL
MOVEMENT

WATER FLOW RELIES ON CONDUCTIVE PATHS IN THE SOIL

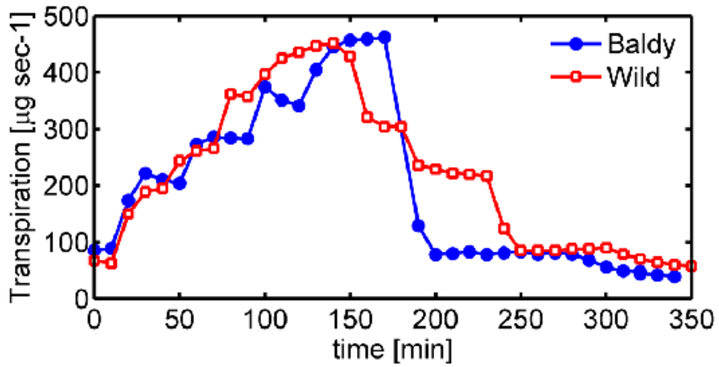
Roots and soil share the control of water flow:
« it depends »

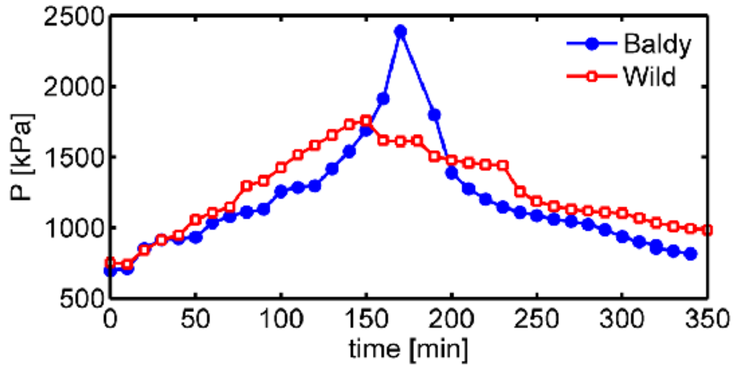


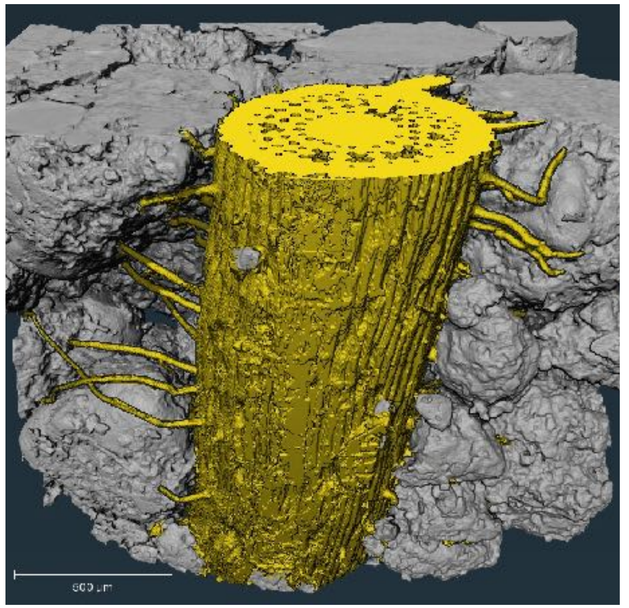
DRAYE ET AL 2010

SOIL-ROOT INTERFACE

Root hairs: engineers of rhizosphere hydraulics



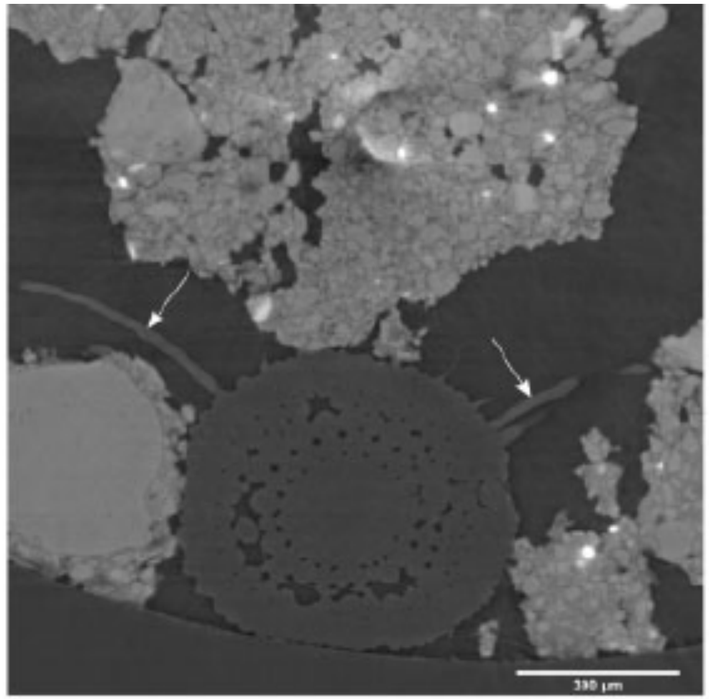




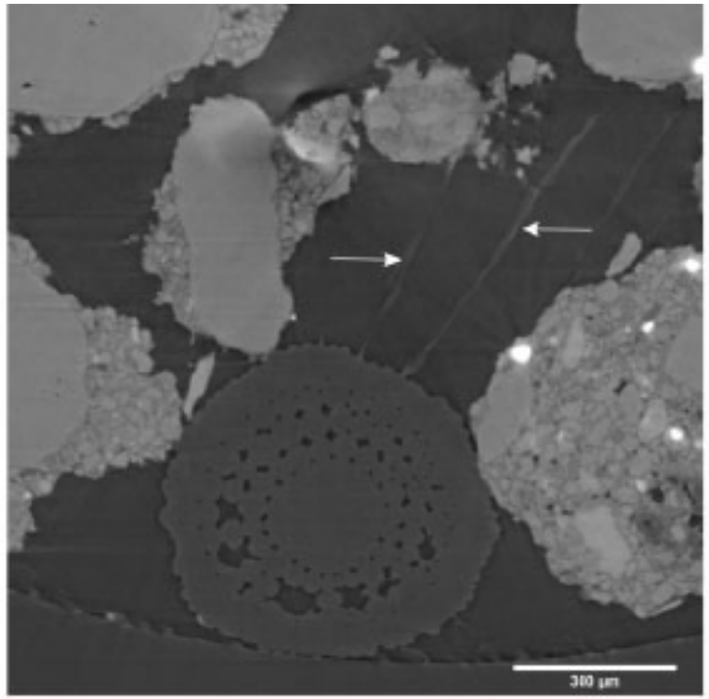
CARMINATI ET AL (2017)

SOIL-ROOT INTERFACE: LIMITS OF ROOT HAIR BENEFITS

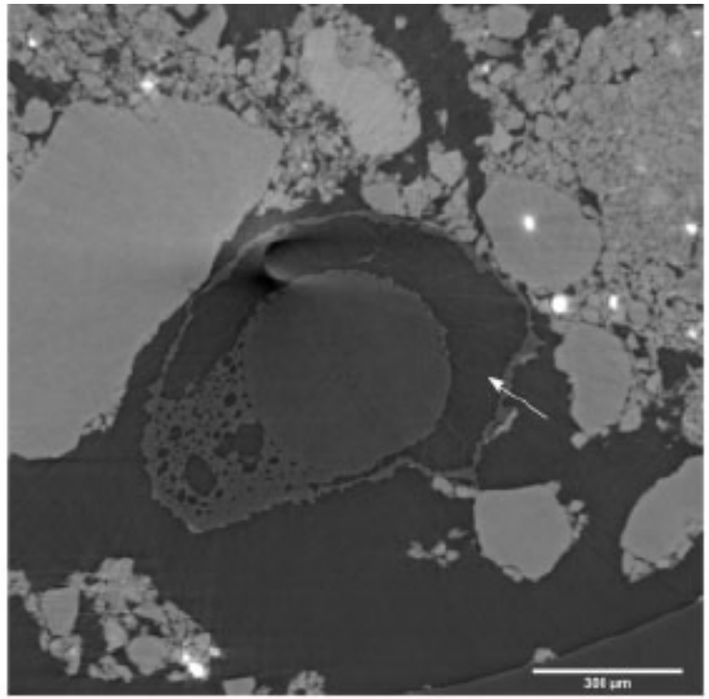
At low soil water potential, root hairs, then root shrinks and lose contact



Root Hairs Turgid



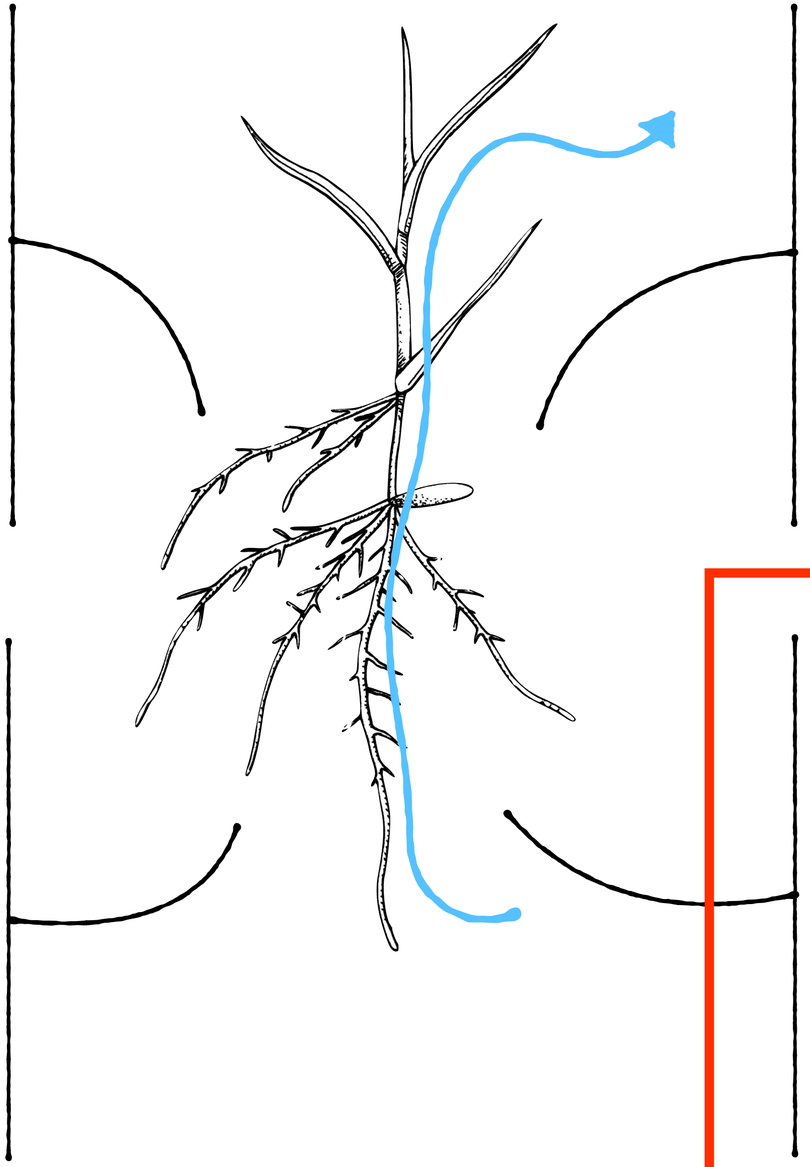
Root Hairs Shrunk

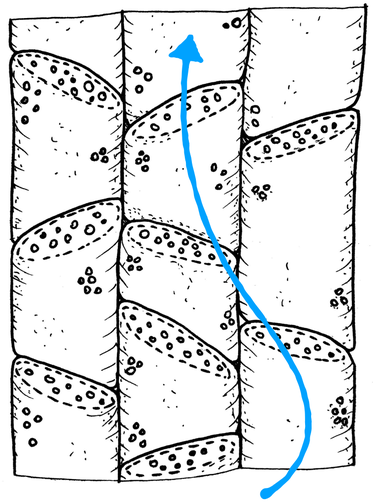


Major Cortex Drying

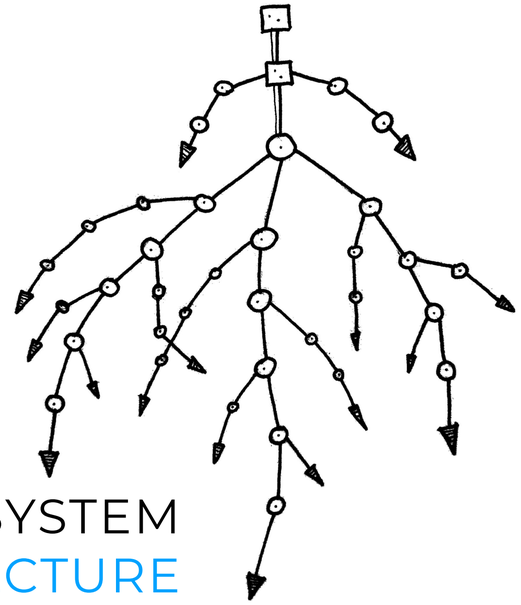
DUDDEK ET AL (2022)

SOIL
PROPERTIES

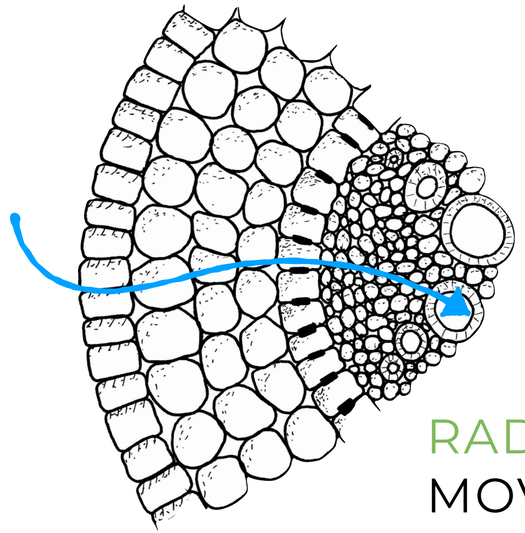




AXIAL
MOVEMENT



ROOT SYSTEM
ARCHITECTURE

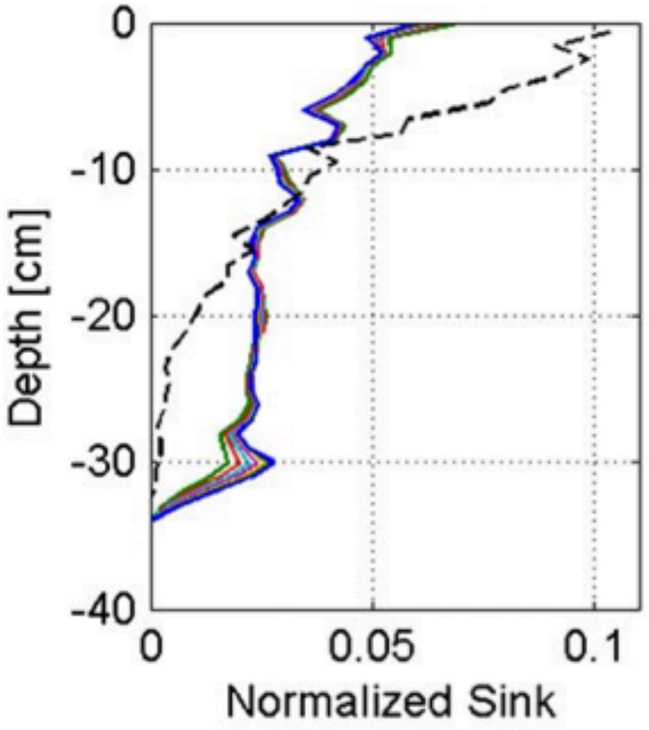


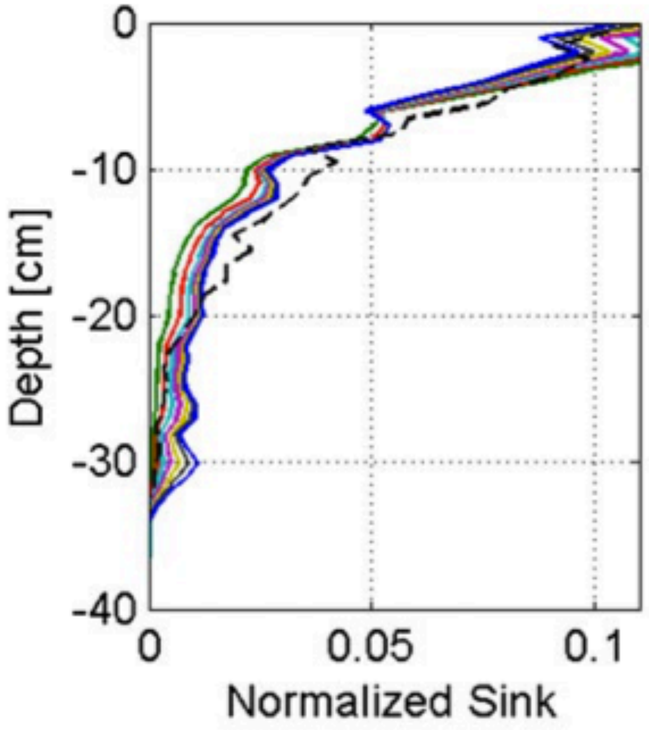
RADIAL
MOVEMENT

ROOT HYDRAULIC ANATOMY

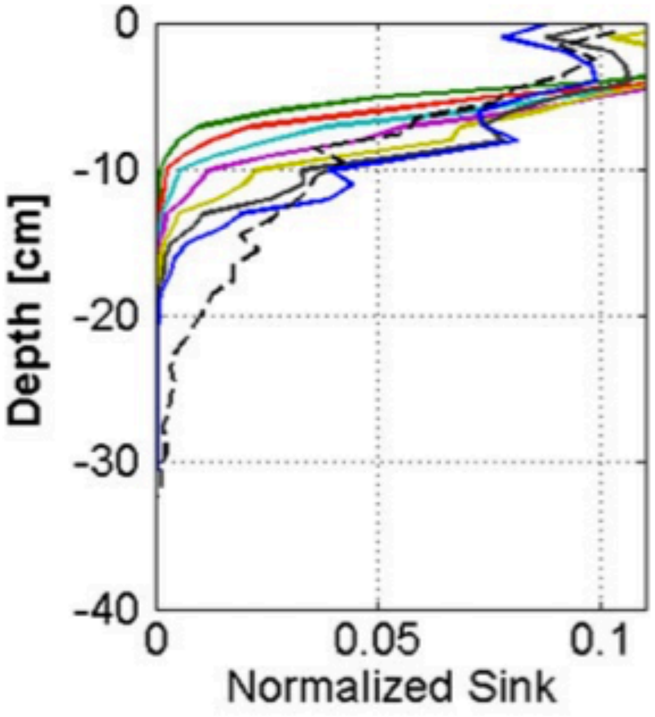
Simple hydraulic property changes might drive uptake redistribution

low
Kr / Kx





large
Kr / Kx

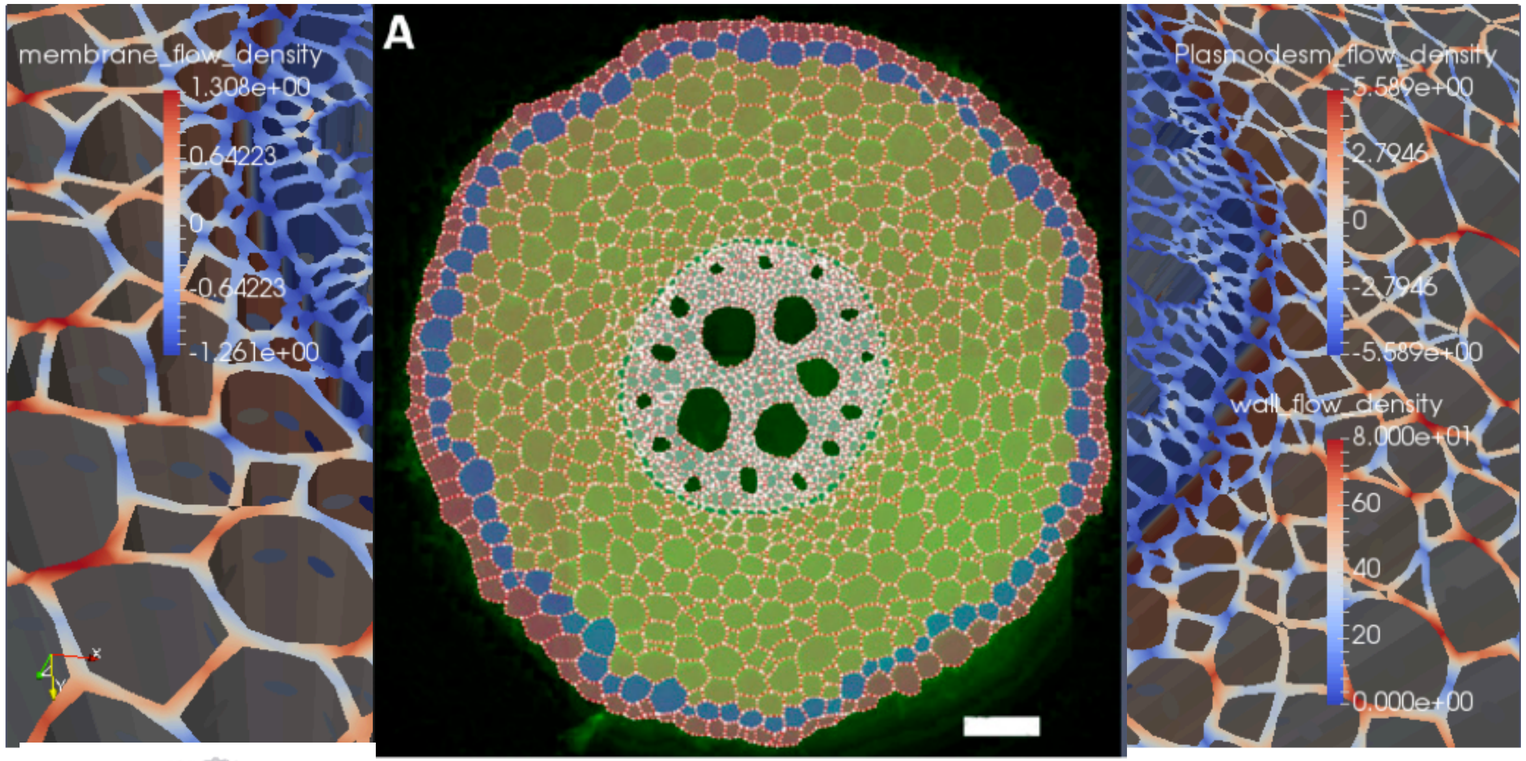


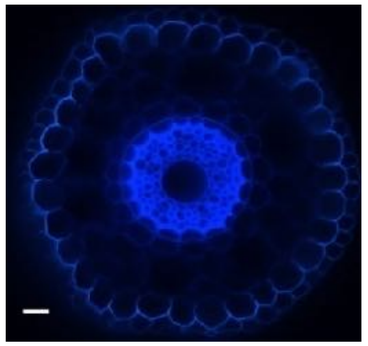
Kr : radial conductance (composite transport) ➛ AQP, anatomy
Kx : axial conductance (xylem) ➛ diameter and number of vessels

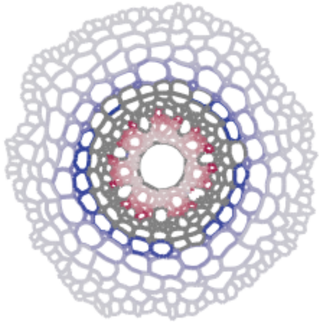
DRAYE ET AL (2010)

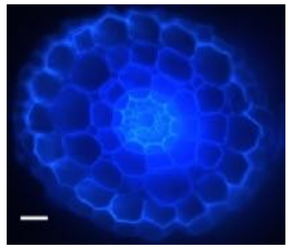
ROOT HYDRAULIC ANATOMY

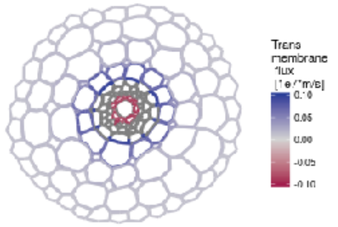
MECHA – Water fluxes across the root section







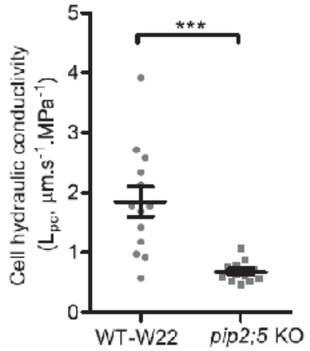


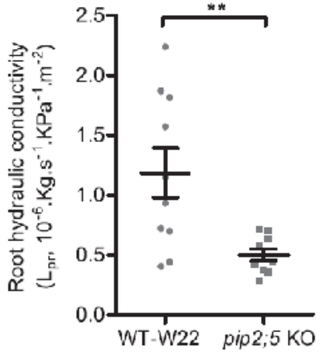


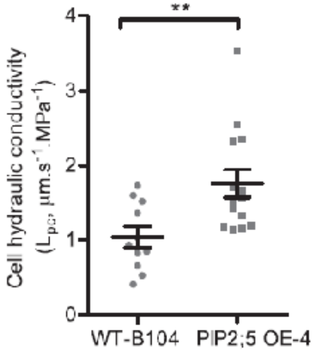
COUVREUR ET AL (2018)

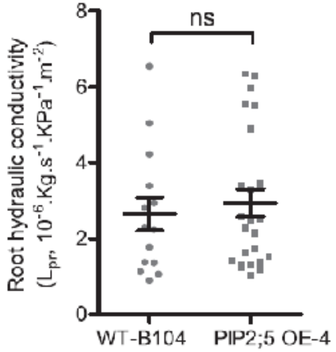
EXPLORING THE TRANS-MEMBRANE PATHWAY

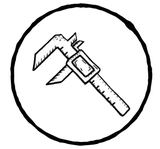
MECHA helps interpreting surprising AQP-related data

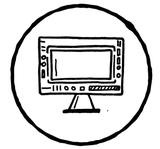






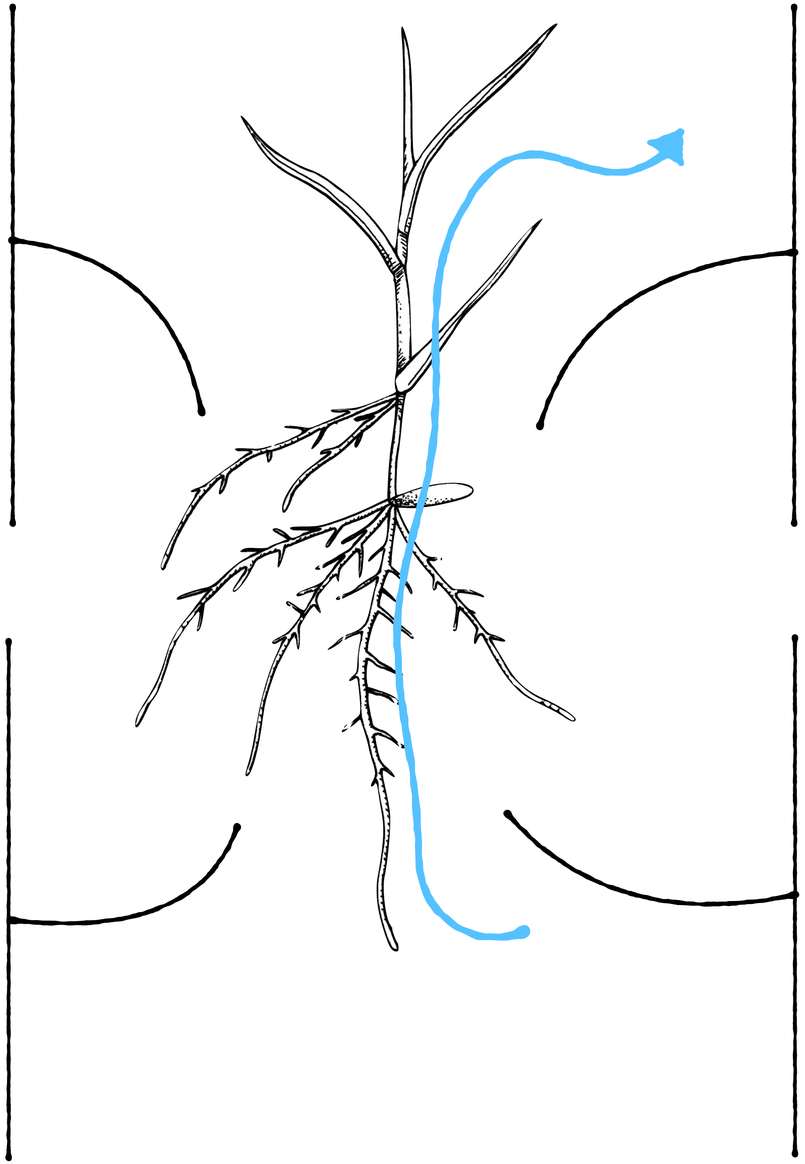


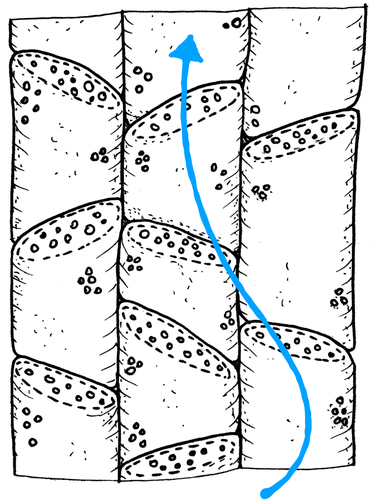




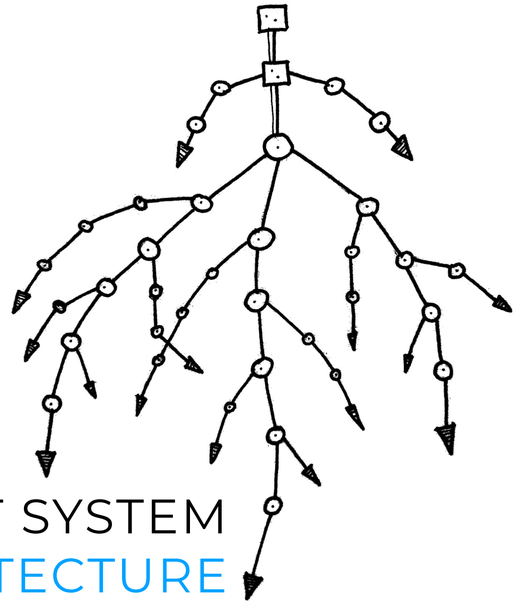
DING ET AL (2020)

SOIL
PROPERTIES

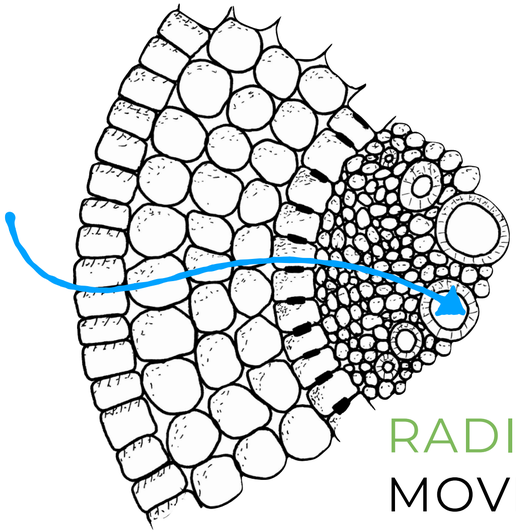




AXIAL
MOVEMENT



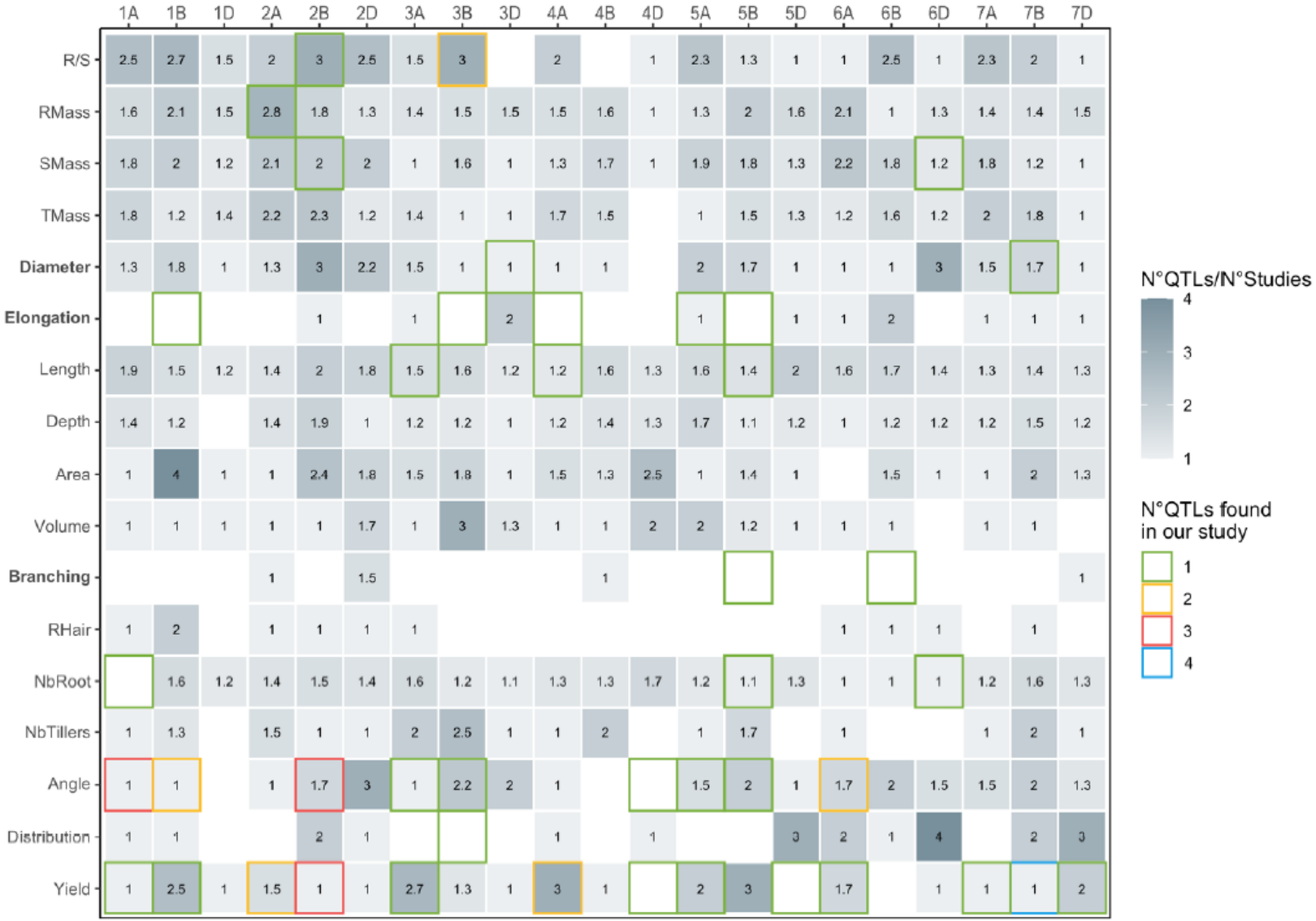
ROOT SYSTEM
ARCHITECTURE



RADIAL
MOVEMENT

ROOT ARCHITECTURE QTL META ANALYSIS (57 WHEAT STUDIES)

Root morphology controlled by a large number of loci

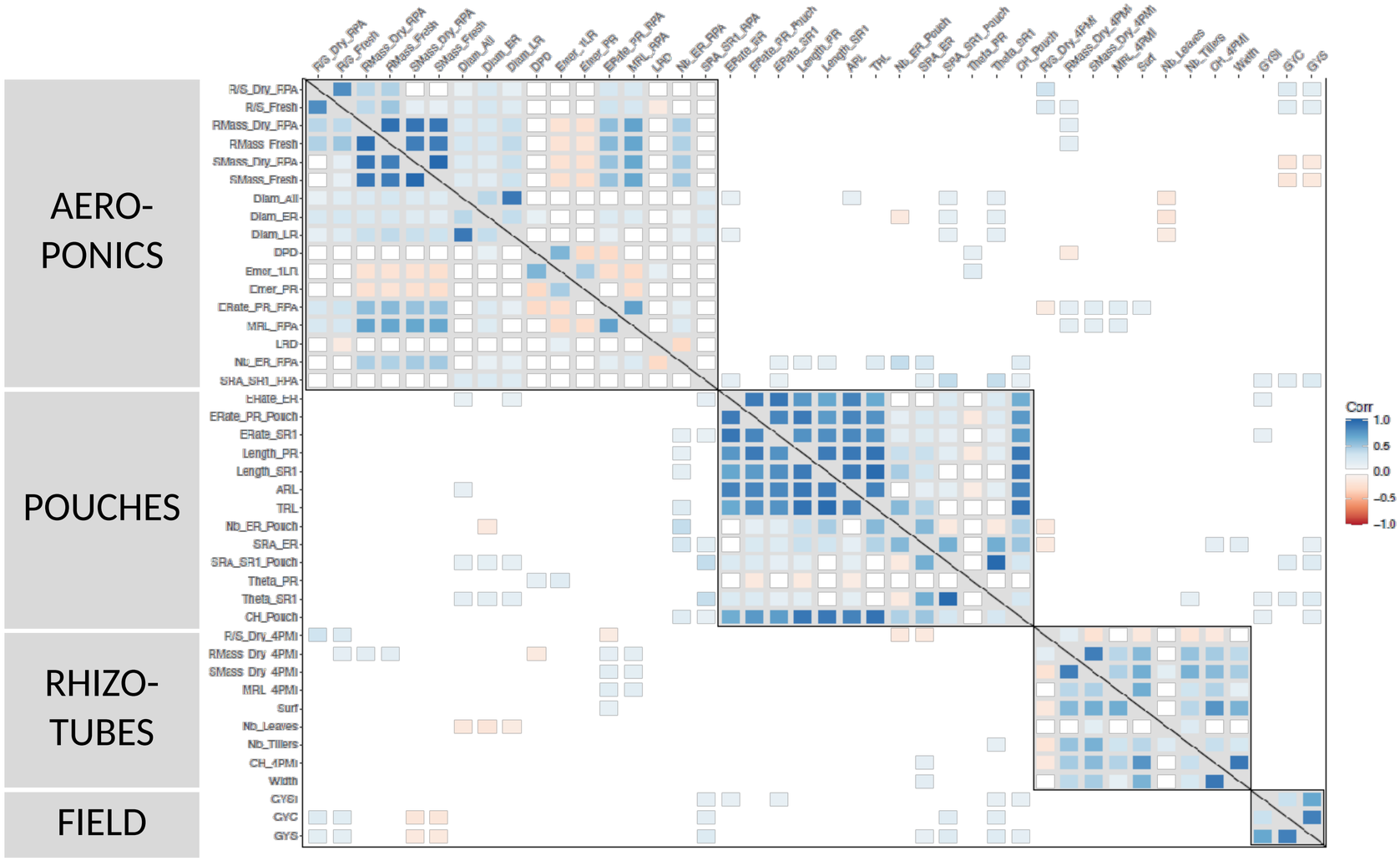


SolACE

COLLET (2022) PHD THESIS

ROOT ARCHITECTURE ACROSS PHENOTYPING PLATFORMS

Controlled conditions experiments indicate large GxE effects



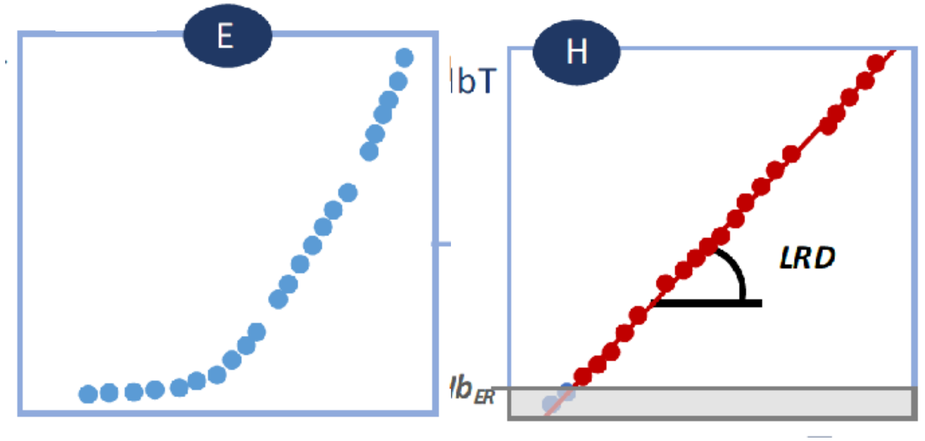
SolACE

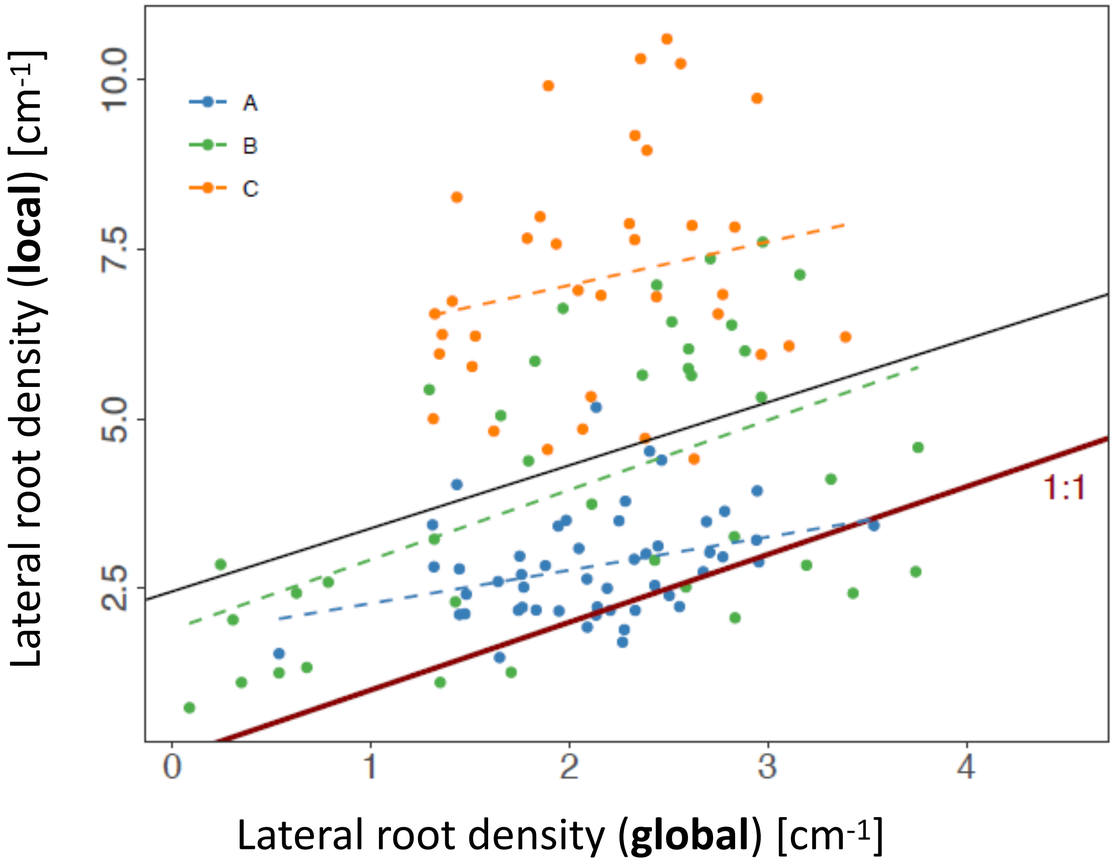
COLLET (2022) PHD THESIS

LATERAL ROOT PLASTICITY (1)
LR FORMATION

Structured
and random

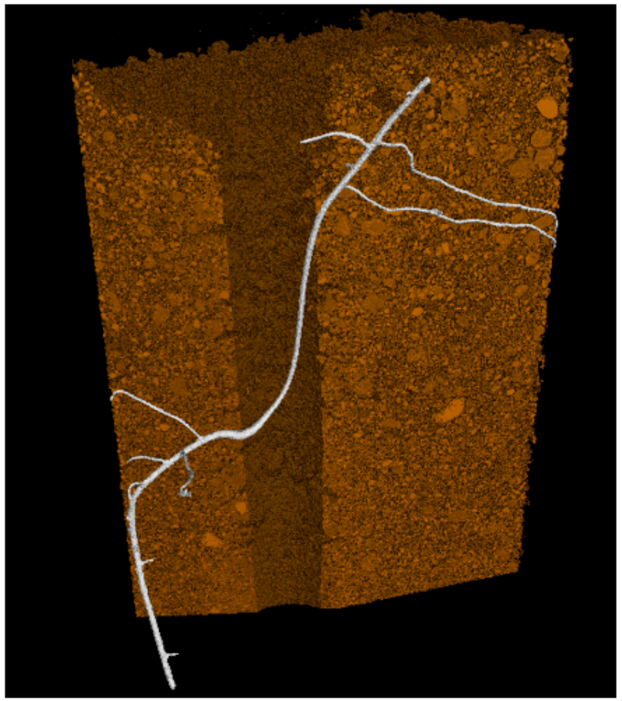
A global metrics of LR formation



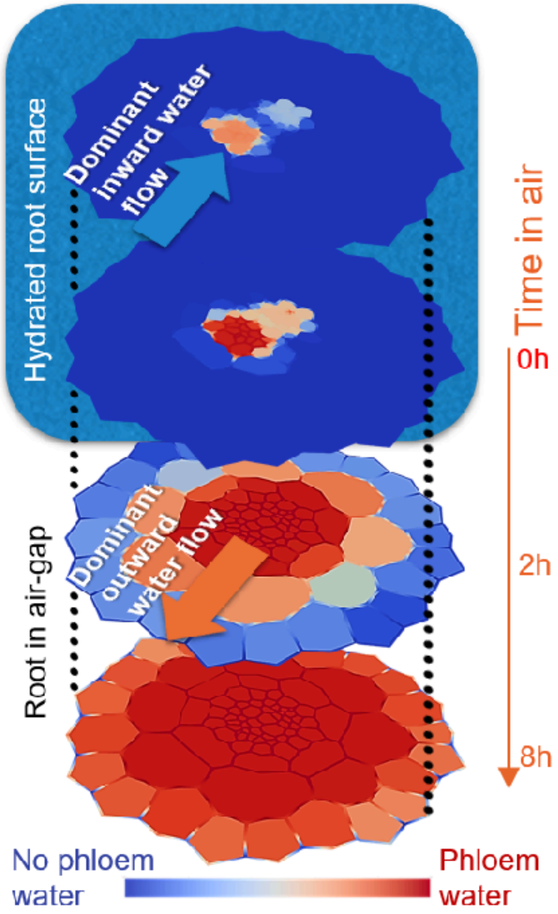


COLLET (2022) PHD THESIS
NGUYEN (2023) PHD THESIS

LATERAL ROOT PLASTICITY (1)
LR FORMATION

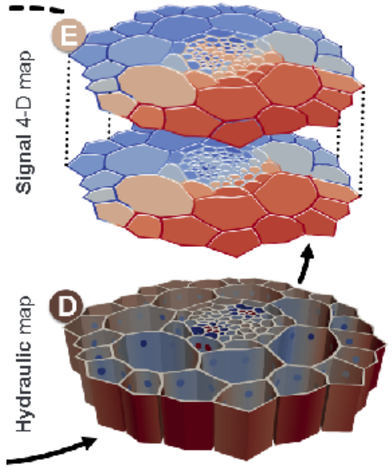


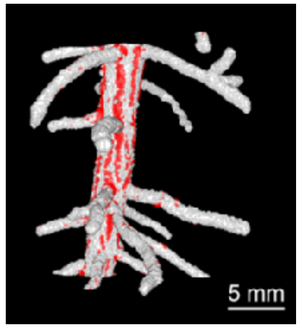
E Morris, C Sturrock & MJ Bennett, UoN



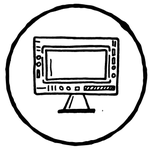
MEHRA (2022) SCIENCE

Water availability (soil root contact) influences LR formation





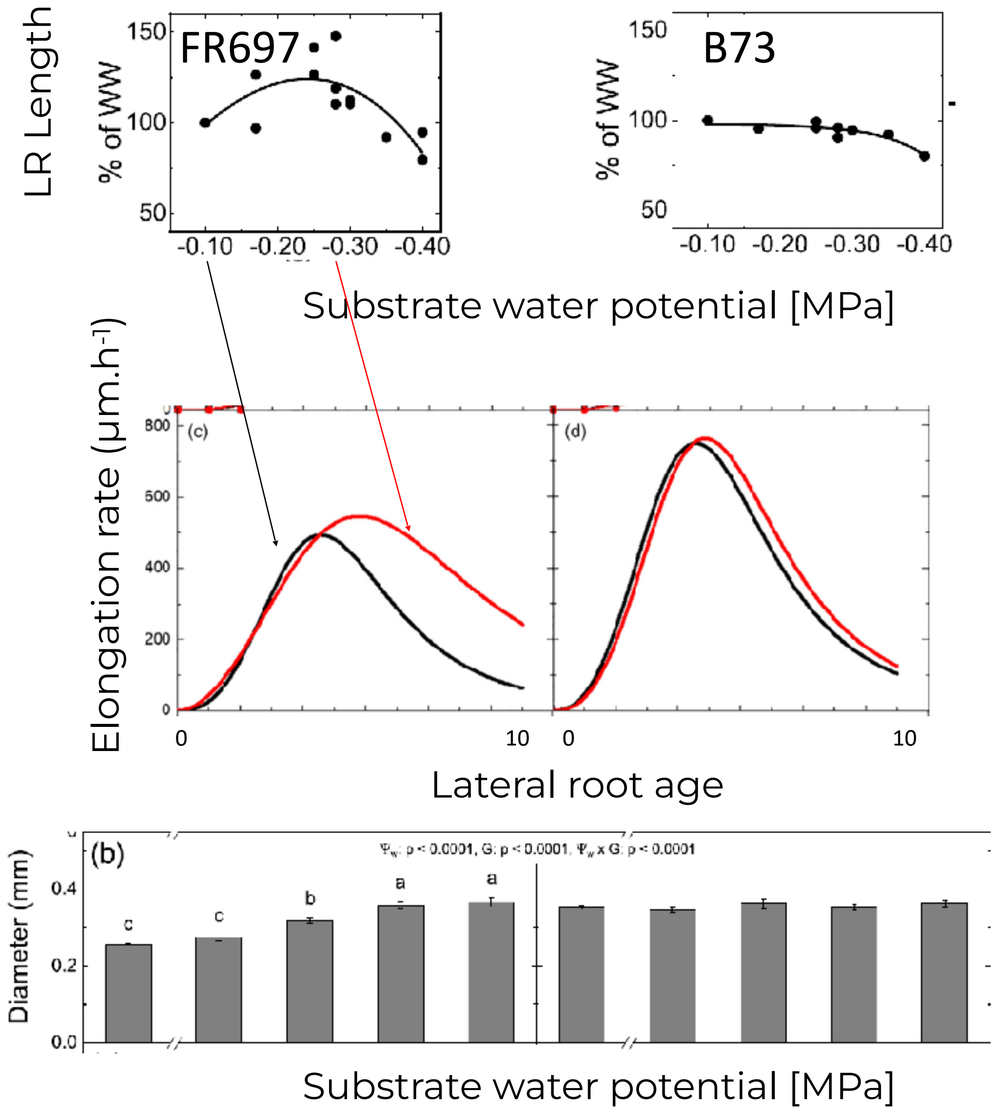
PLANT SOIL 431:417



Phenotyping LR distribution in field < ?? > mapping soil porosity

LATERAL ROOT PLASTICITY (1)
LR ELONGATION

Response curves indicate structured plasticity is at play



Response curves

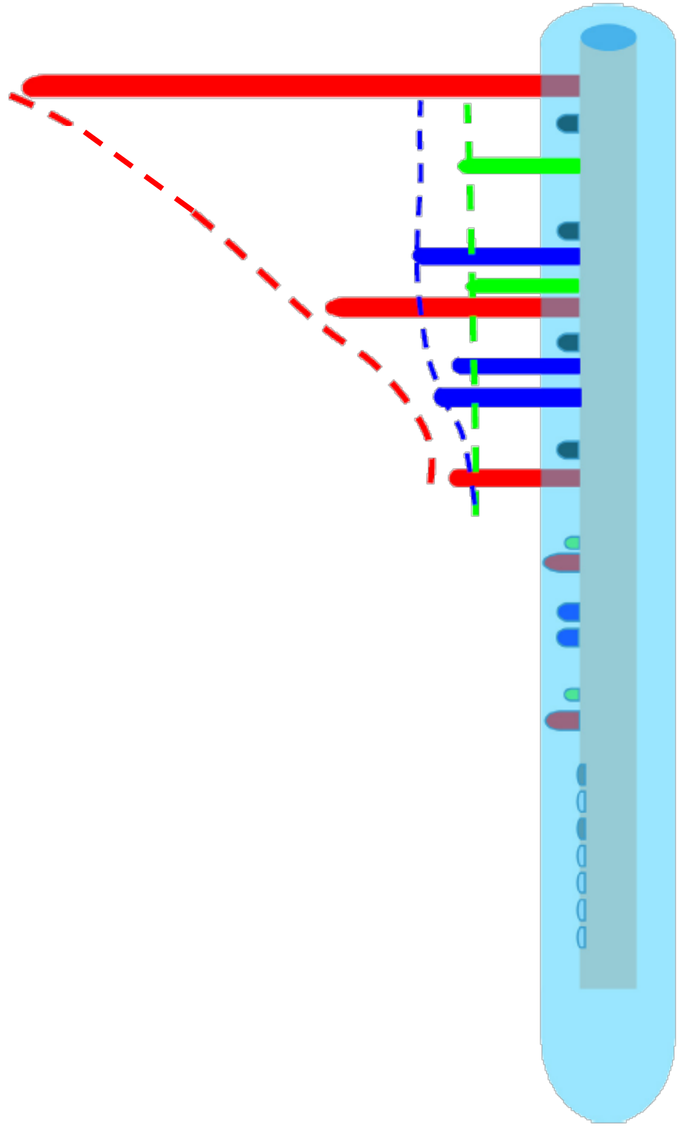
DOWD ET AL (2019)

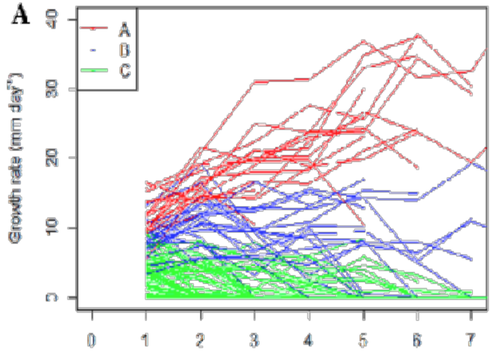
↗ Cell flux (division)
↗ Cell expansion

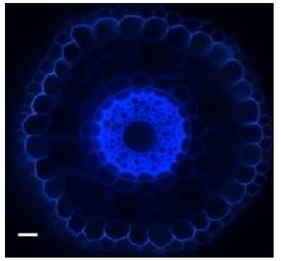
DOWD ET AL (2020)

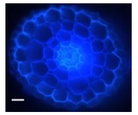
A COMMON FRAMEWORK FOR LR INITIATION AND ELONGATION

Using state transition probabilities to account for plasticity





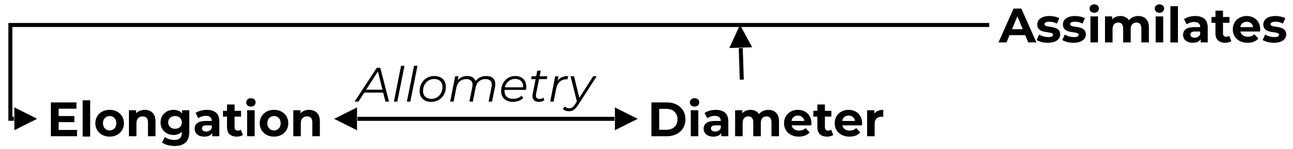


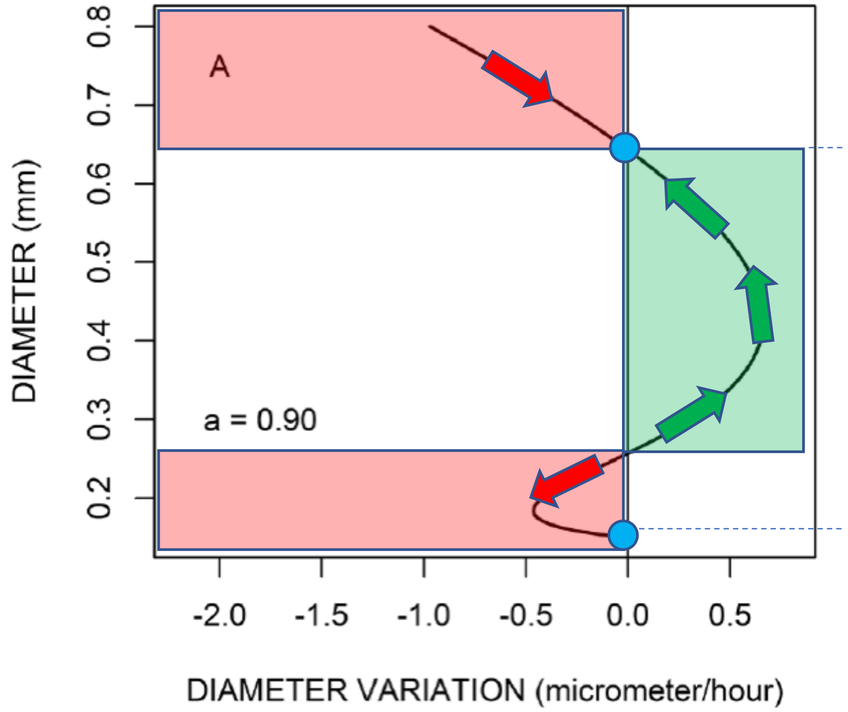


MULLER ET AL (2019)

ROOT ARCHITECTURE – A KEY ROLE FOR ROOT DIAMETER

Simple allometric rules may underly different root types



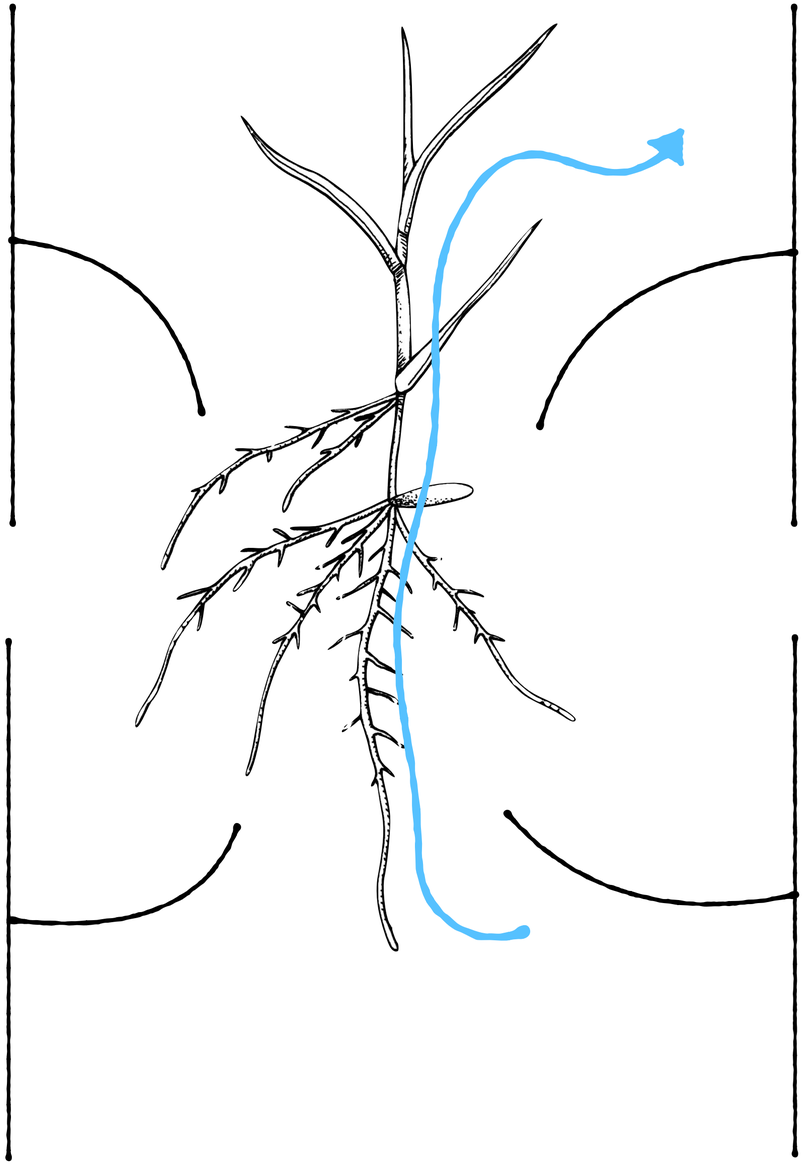


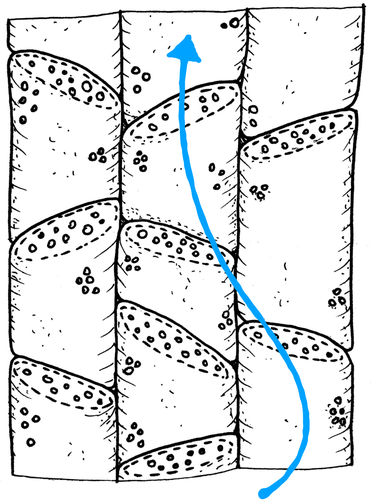
PAGÈS ET AL (2020)

PART 2
FROM **FIELD** TO **MODELS**

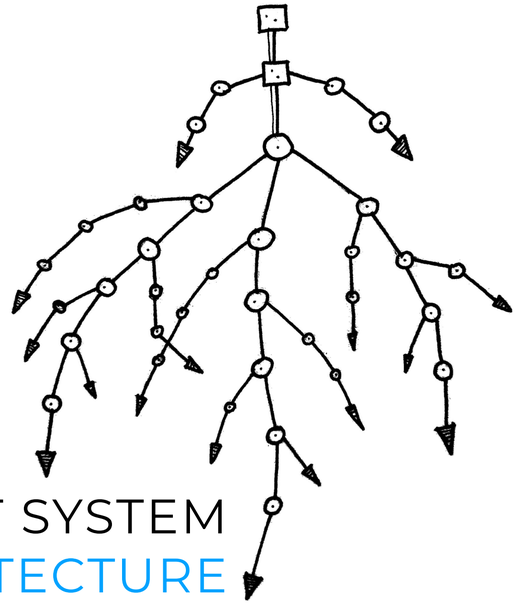


SOIL
PROPERTIES

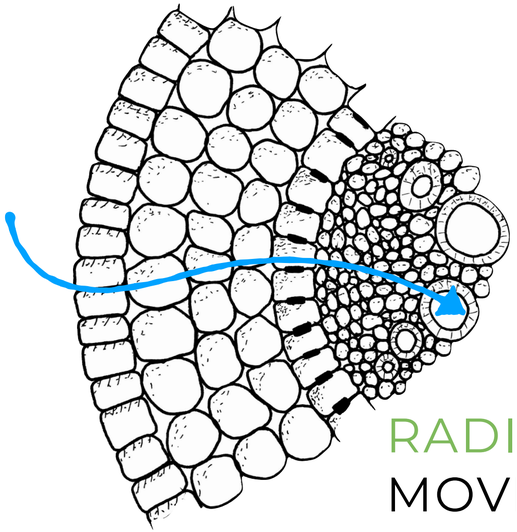




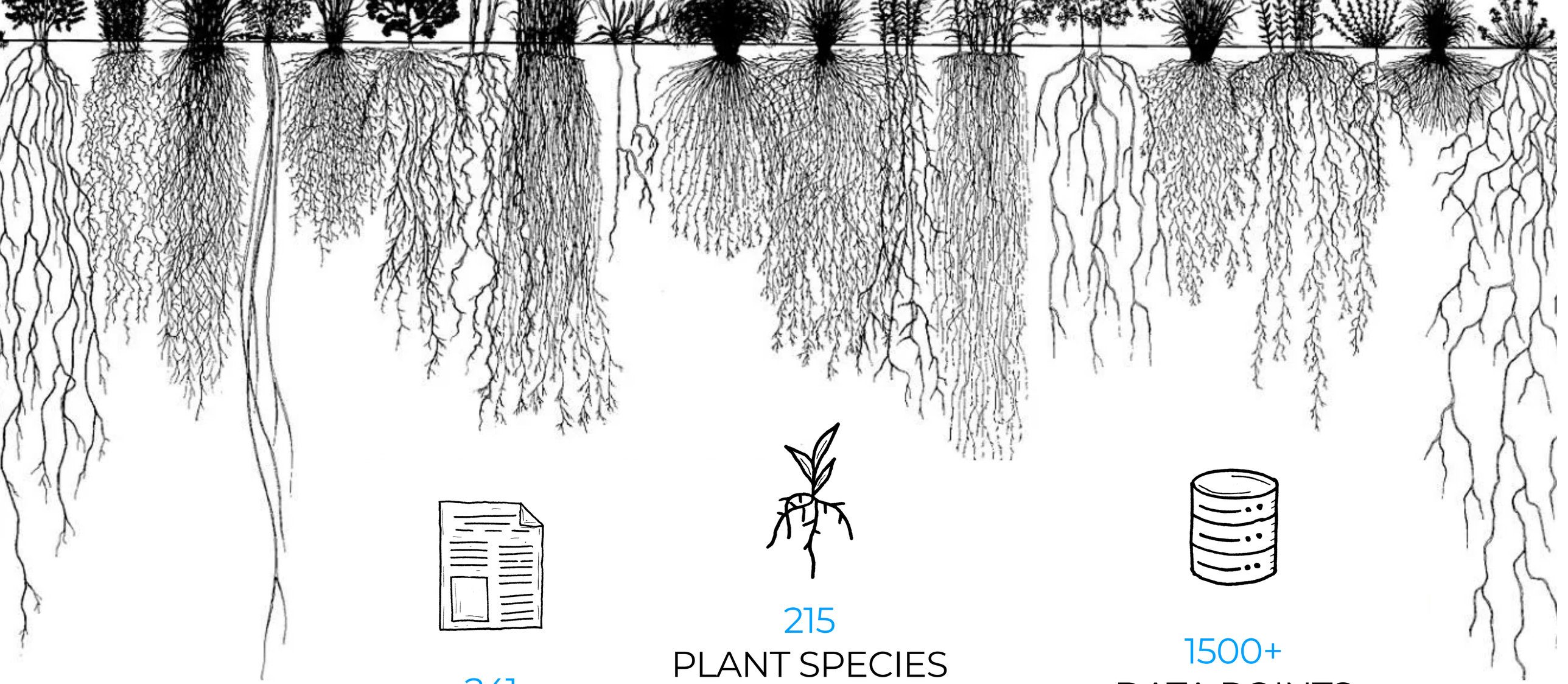
AXIAL
MOVEMENT



ROOT SYSTEM
ARCHITECTURE



RADIAL
MOVEMENT



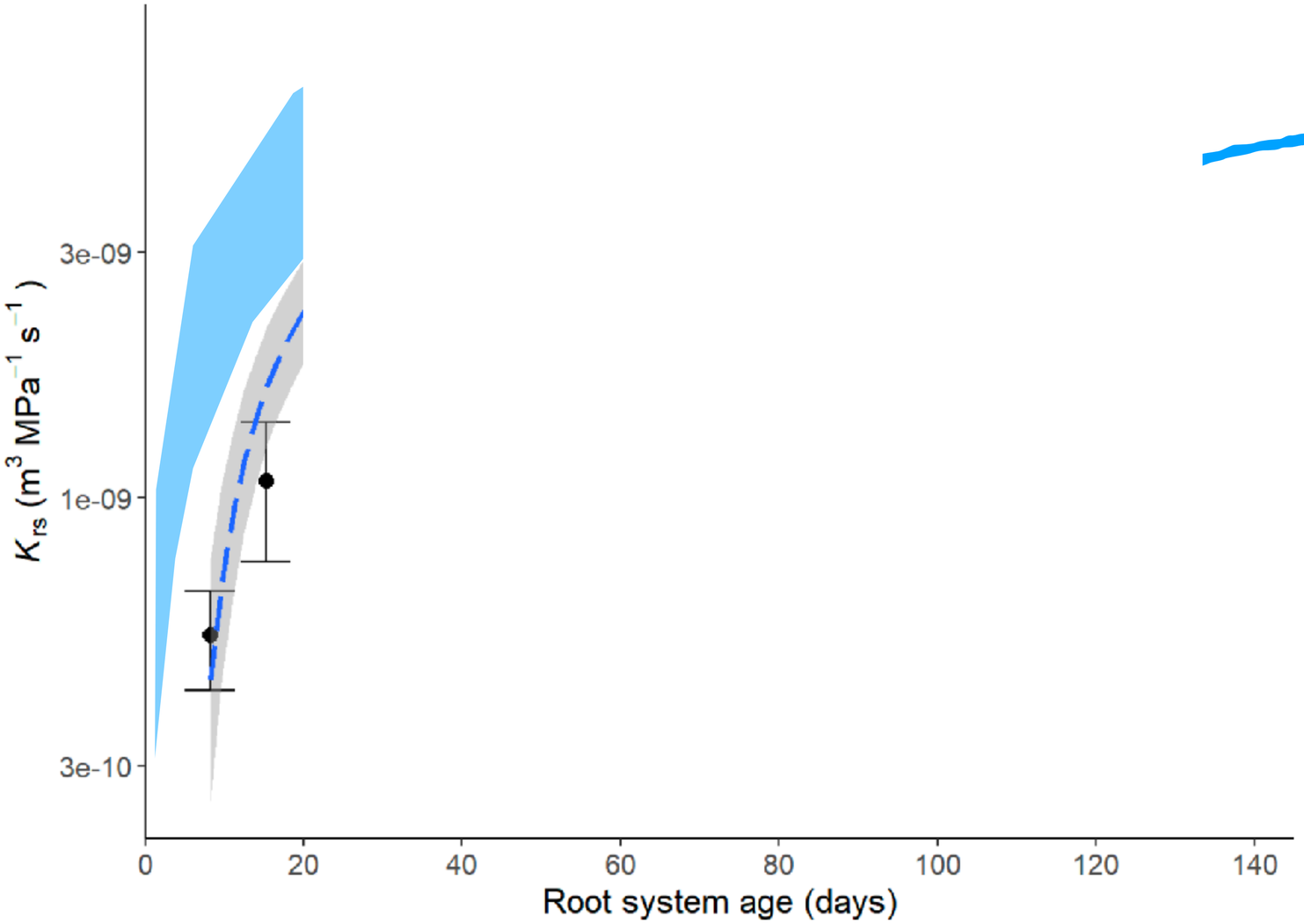
241
EXPRIMENTAL PAPERS

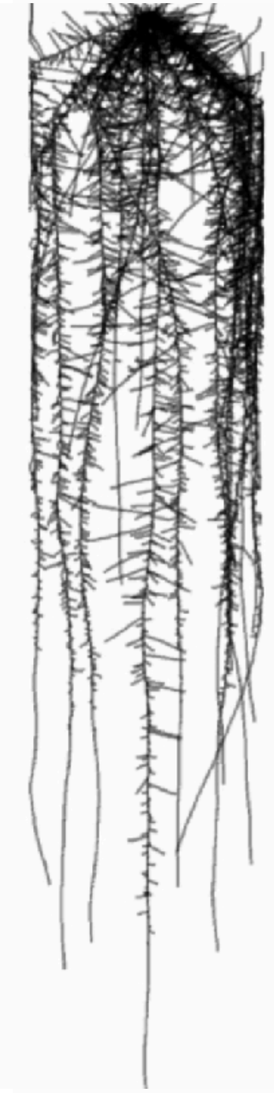
215
PLANT SPECIES
9
PLANT FUNCTIONAL TYPES

1500+
DATA POINTS

BACA CABRERA ET AL 2024

ROOT SYSTEM CONDUCTANCE OF CROPS STABILISES WITH AGE

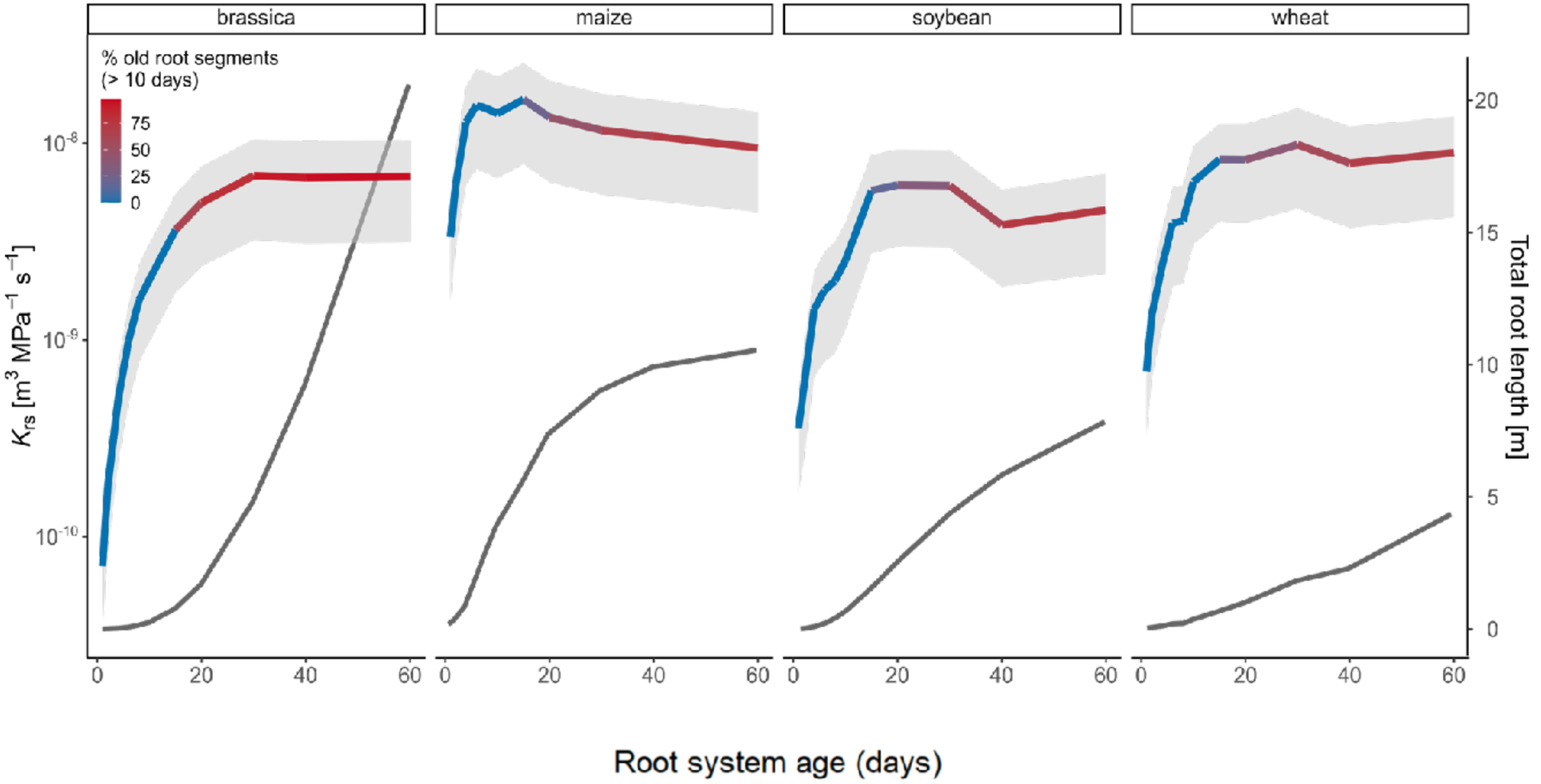




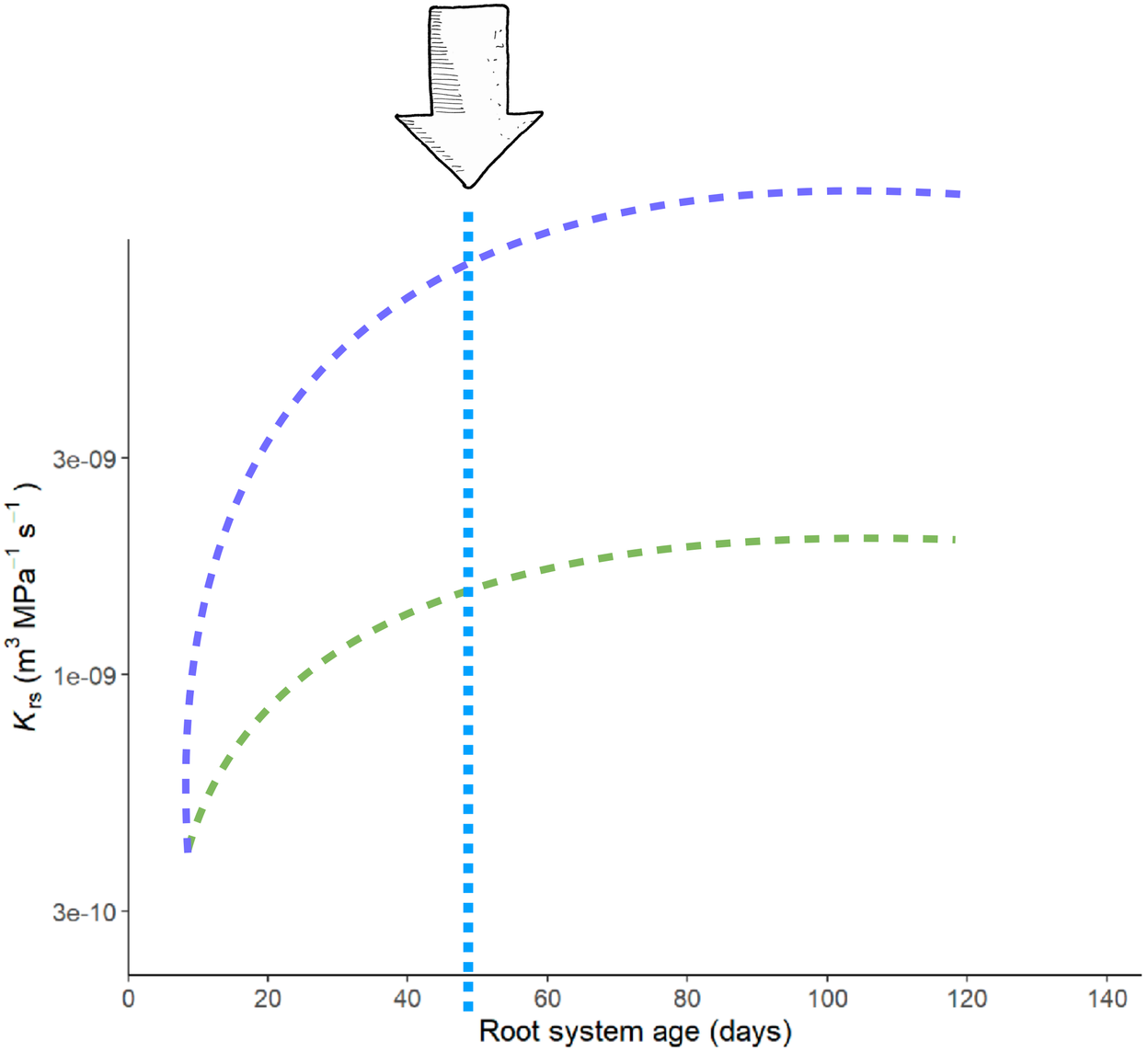
SCHNEPF ET AL 2018
MEUNIER ET AL 2019

BACA CABRERA ET AL 2024

INFLUENCE OF THE PROPORTION OF OLD SEGMENTS



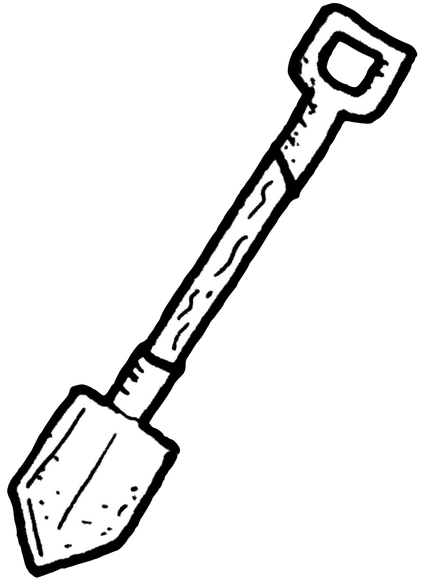
DECOUPLING WITH ROOT SYSTEM LENGTH



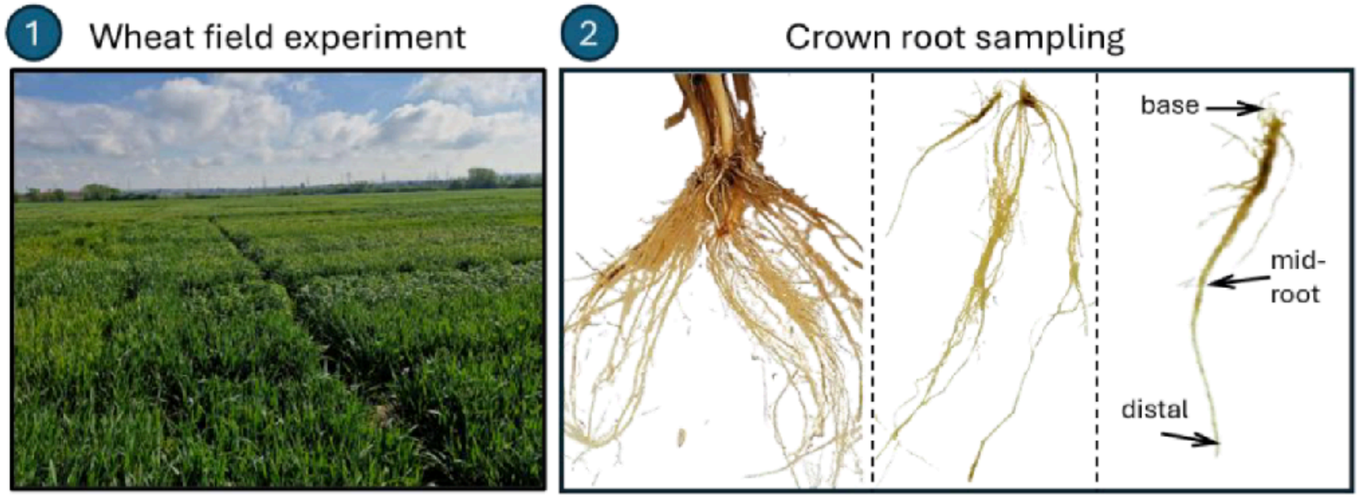
WHAT DOES IT MEAN ?

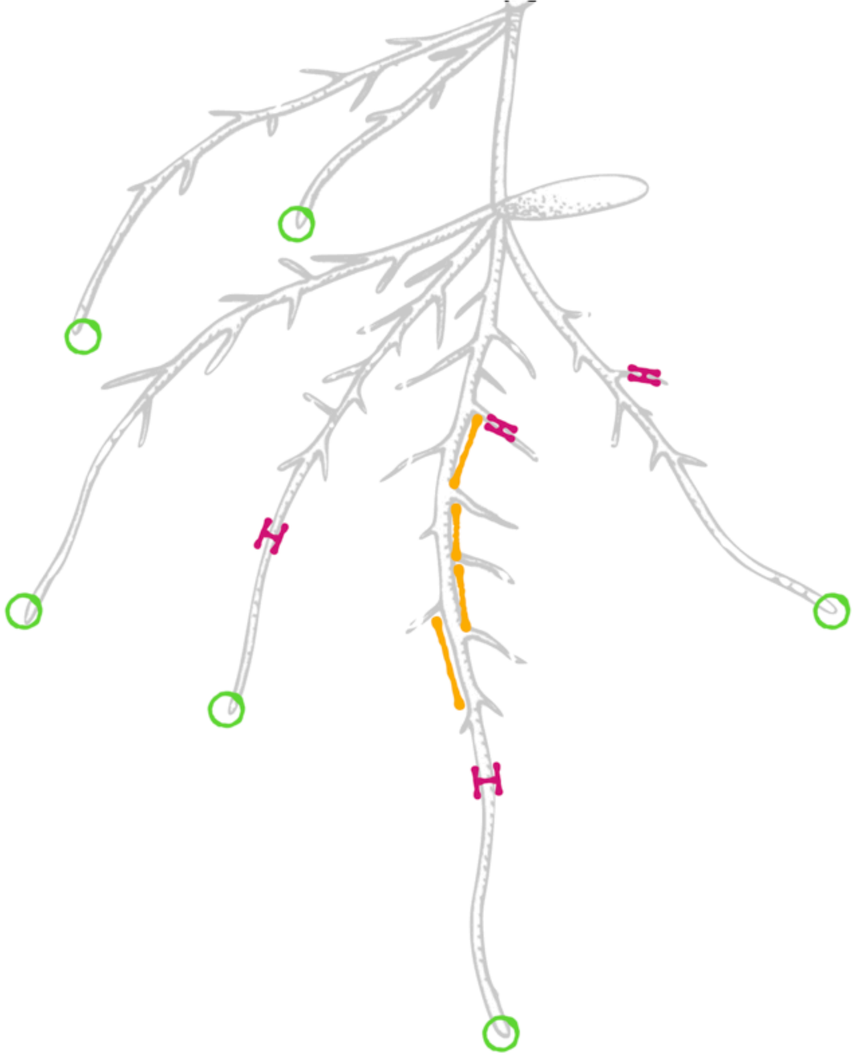
- NOT ALL ROOTS ARE ACTIVE
- ADAPT SAMPLING STRATEGIES ?

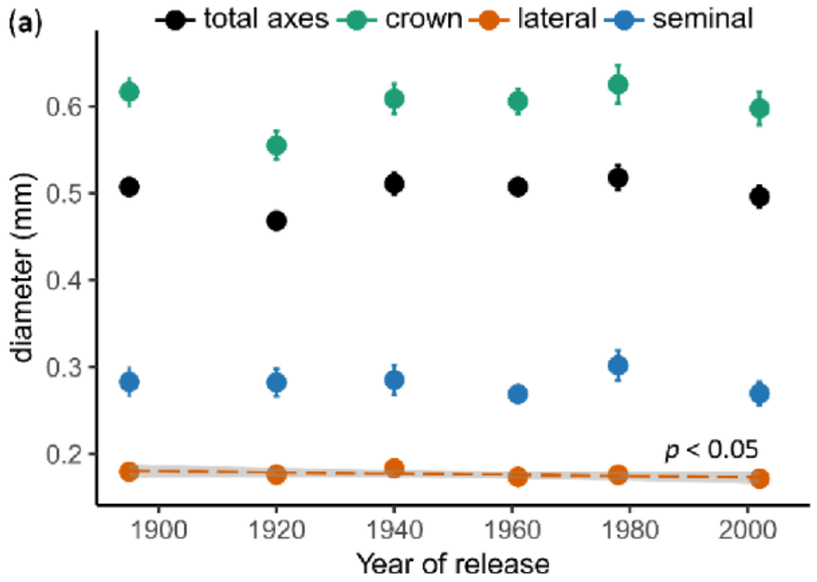
FIELD TRIALS - WHEAT - 6 HISTORICAL GENOTYPES

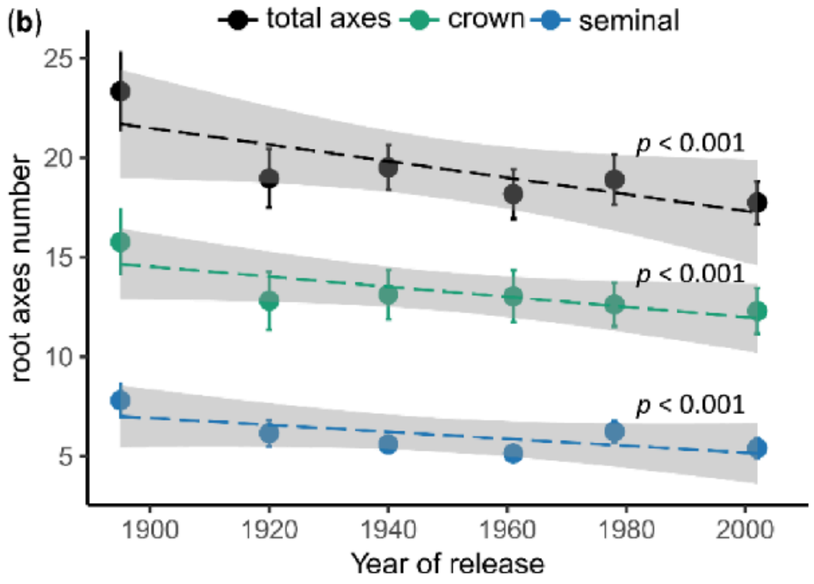


FIELD SAMPLING - THE “SHOVELOMICS” WAY





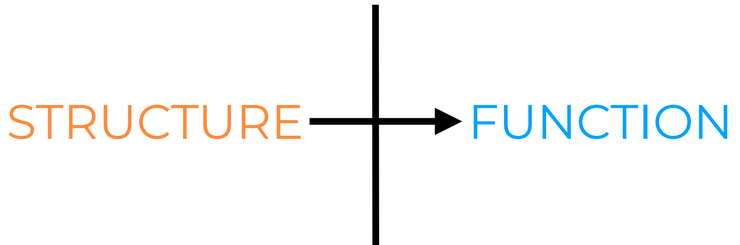




ROOT AXIS COUNT
ROOT BRANCHING
ROOT DIAMETERS

CONNECTING DATA AND MODELS

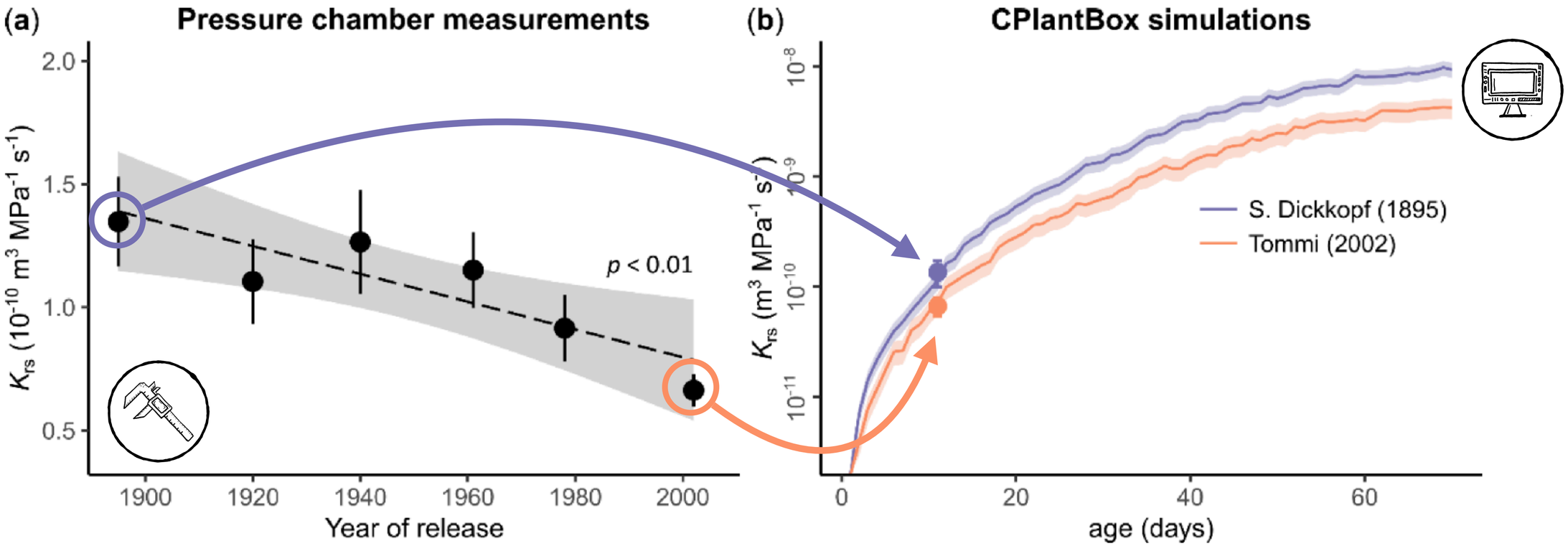
PLANT



MODELLING ROOT ARCHITECTURE WITH CROOTBOX

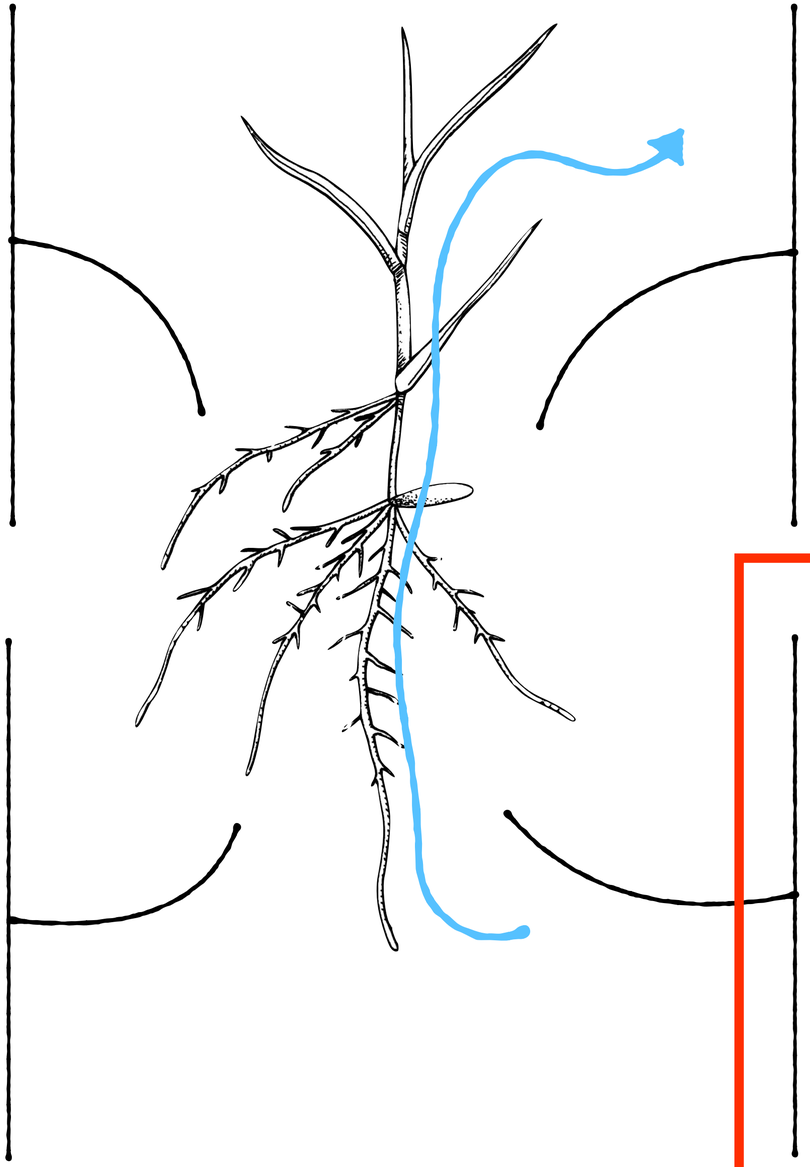
ROOT HYDRAULIC ARCHITECTURE WITH MARSHAL

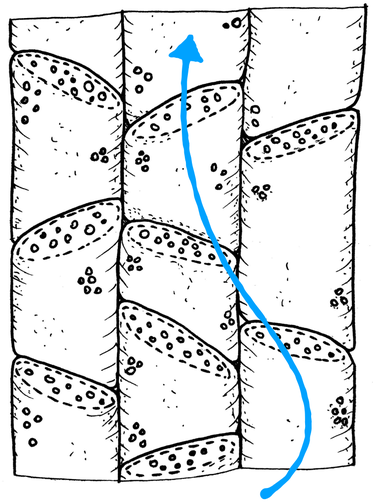
MODELS TO EXTEND EXPERIMENTAL DATA



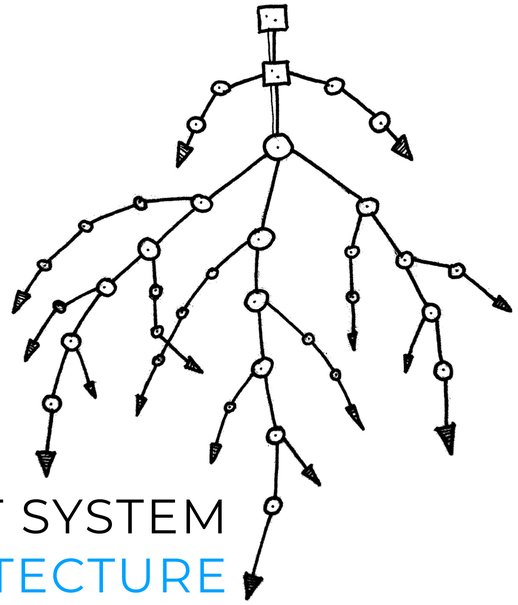
> BACA CABRERA ET AL 2024 - B

SOIL
PROPERTIES

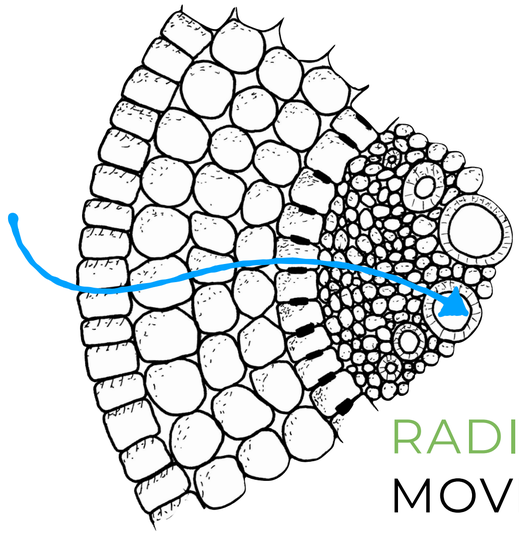




AXIAL
MOVEMENT

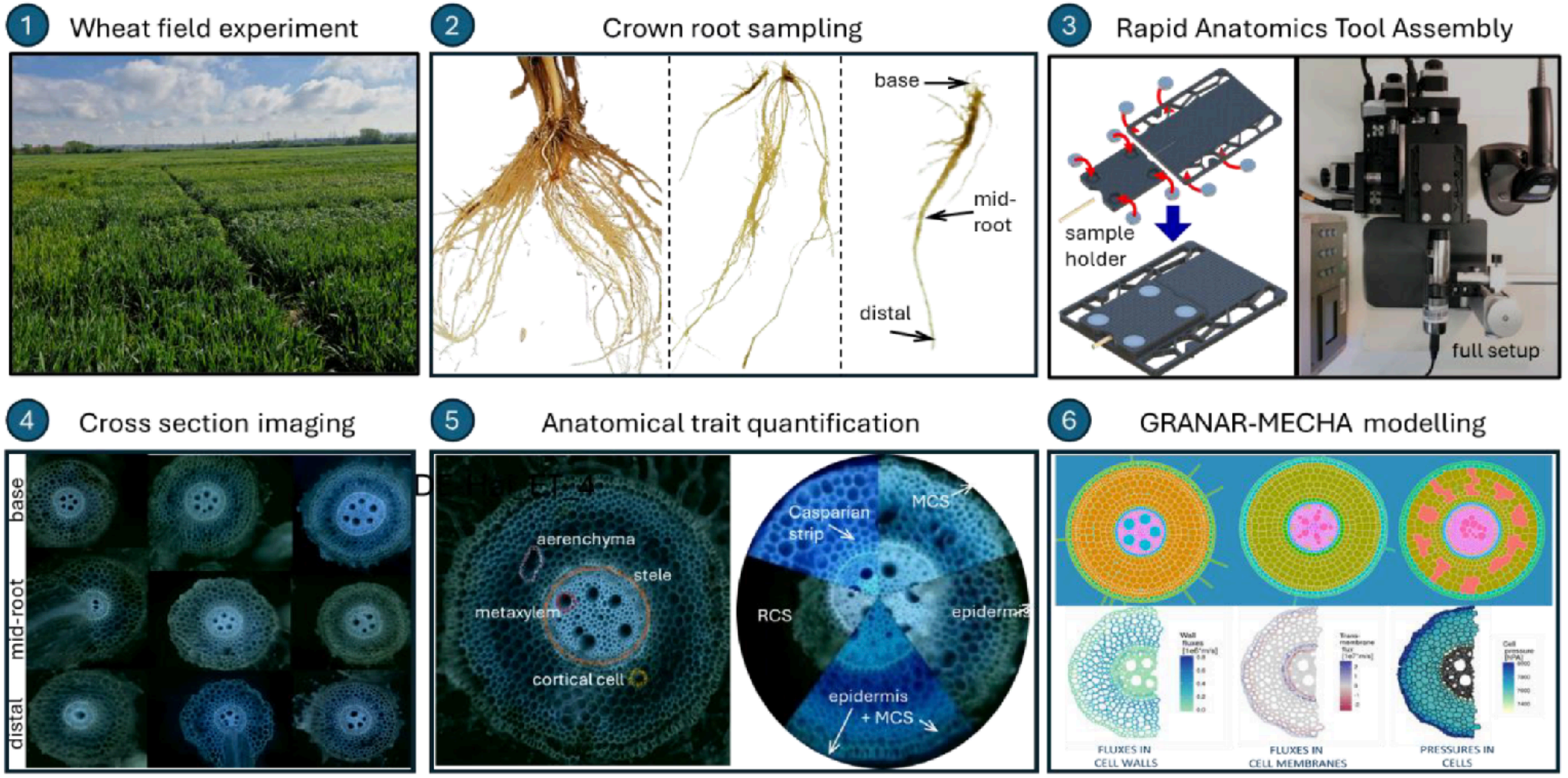


ROOT SYSTEM
ARCHITECTURE



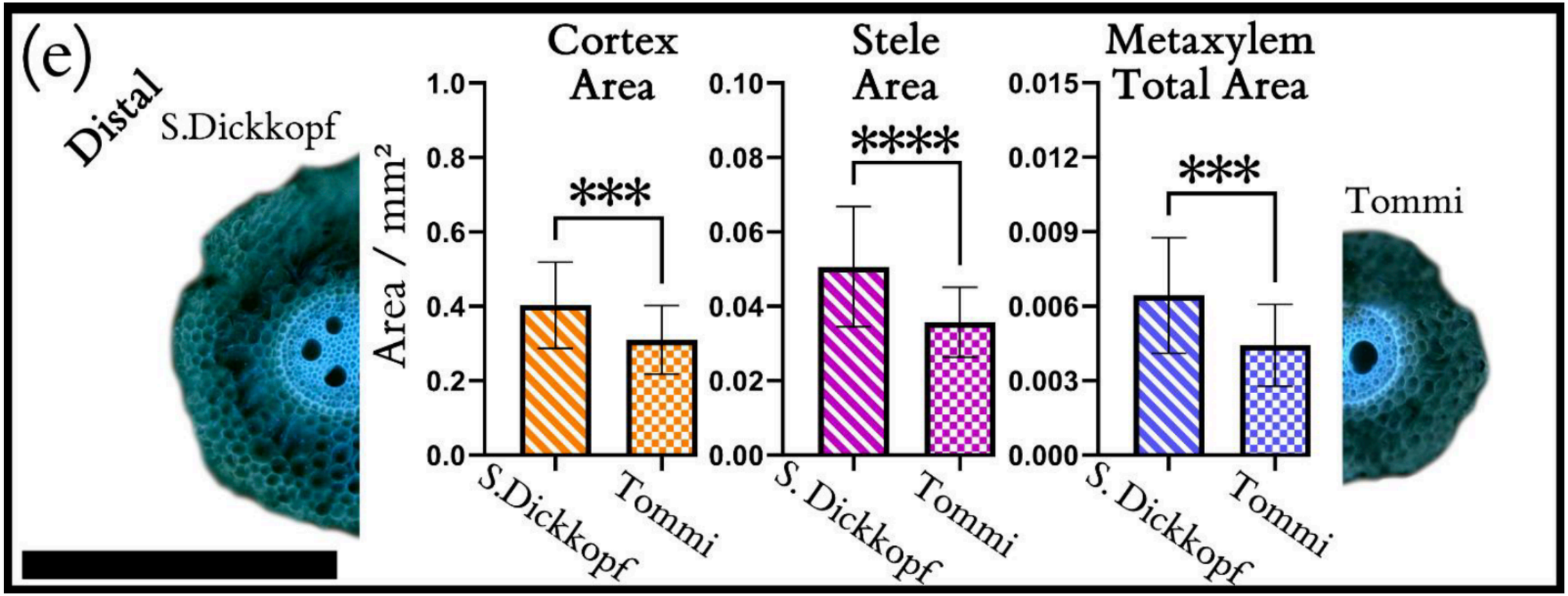
RADIAL
MOVEMENT

FIELD ANATOMICS



> BACA CABRERA ET AL 2025

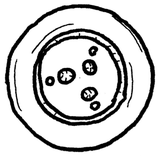
ANATOMICAL VARIATION BETWEEN HISTORICAL LINES

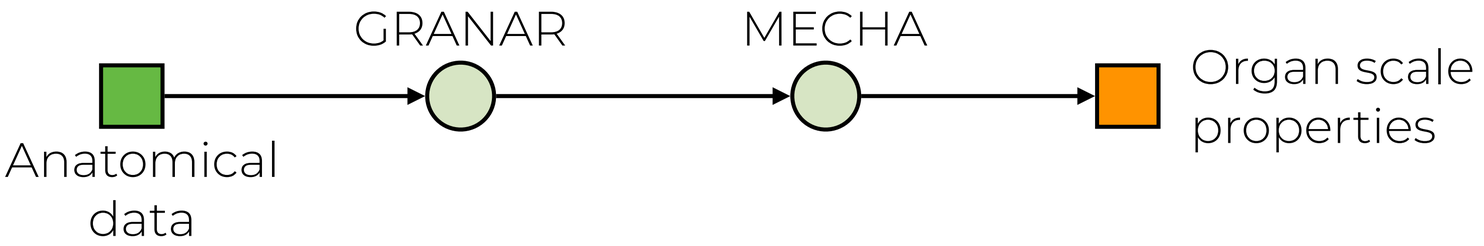


> BACA CABRERA ET AL 2025

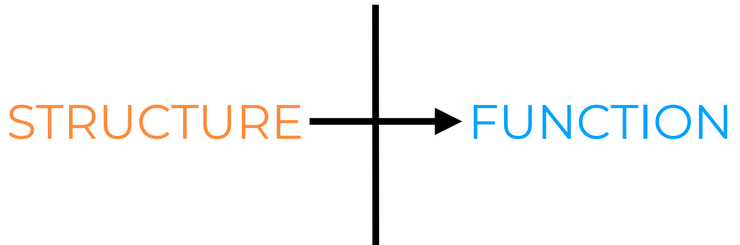
CONNECTING DATA AND MODELS

ORGAN



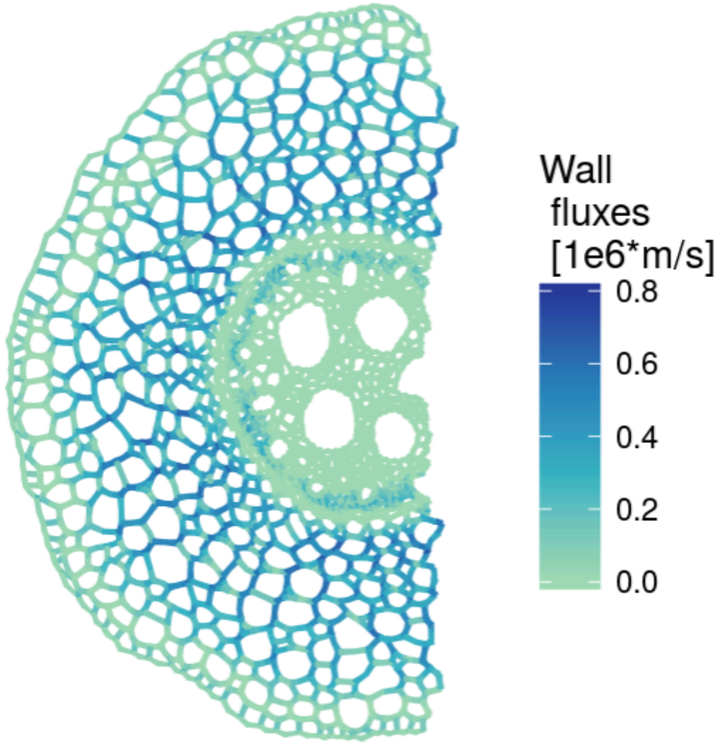


PLANT

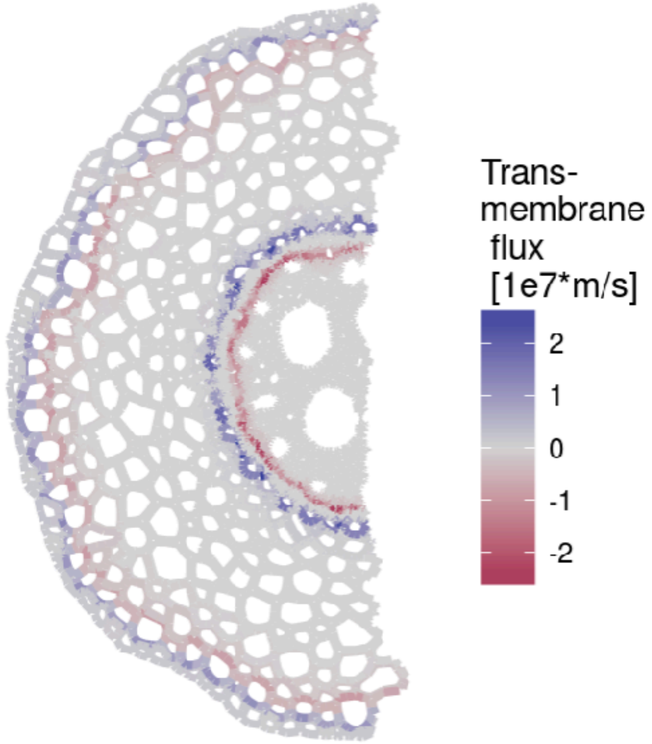


MODELLING **WATER** FLOW AT THE **ORGAN** SCALE

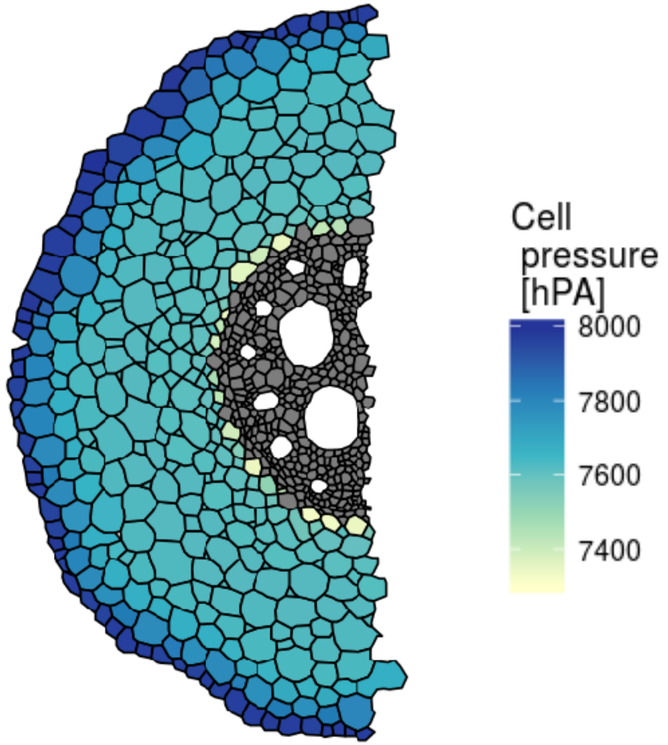
- MECHA -



FLUXES IN
CELL WALLS



FLUXES IN
CELL MEMBRANES

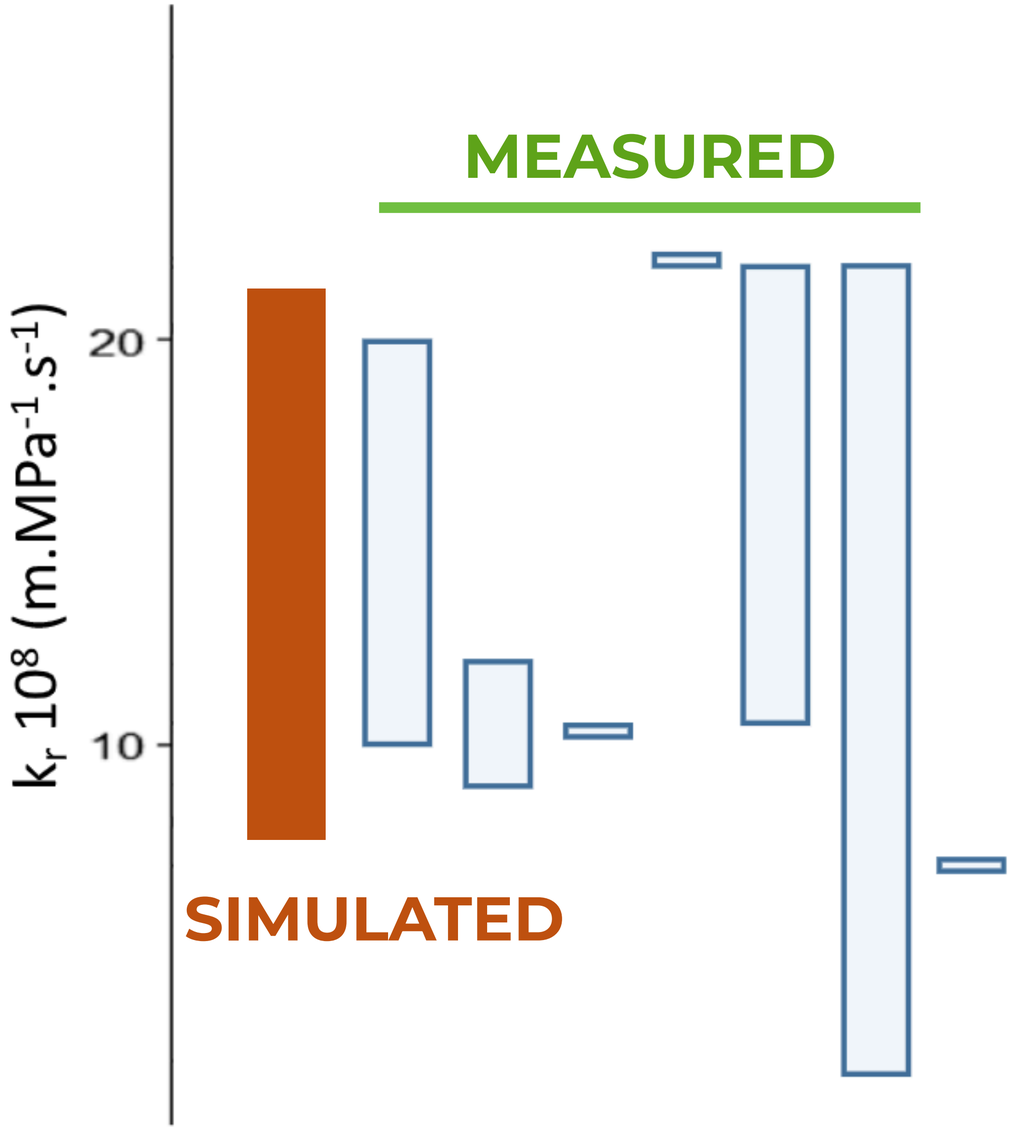


PRESSURES IN
CELLS

RADIAL CONDUCTIVITY

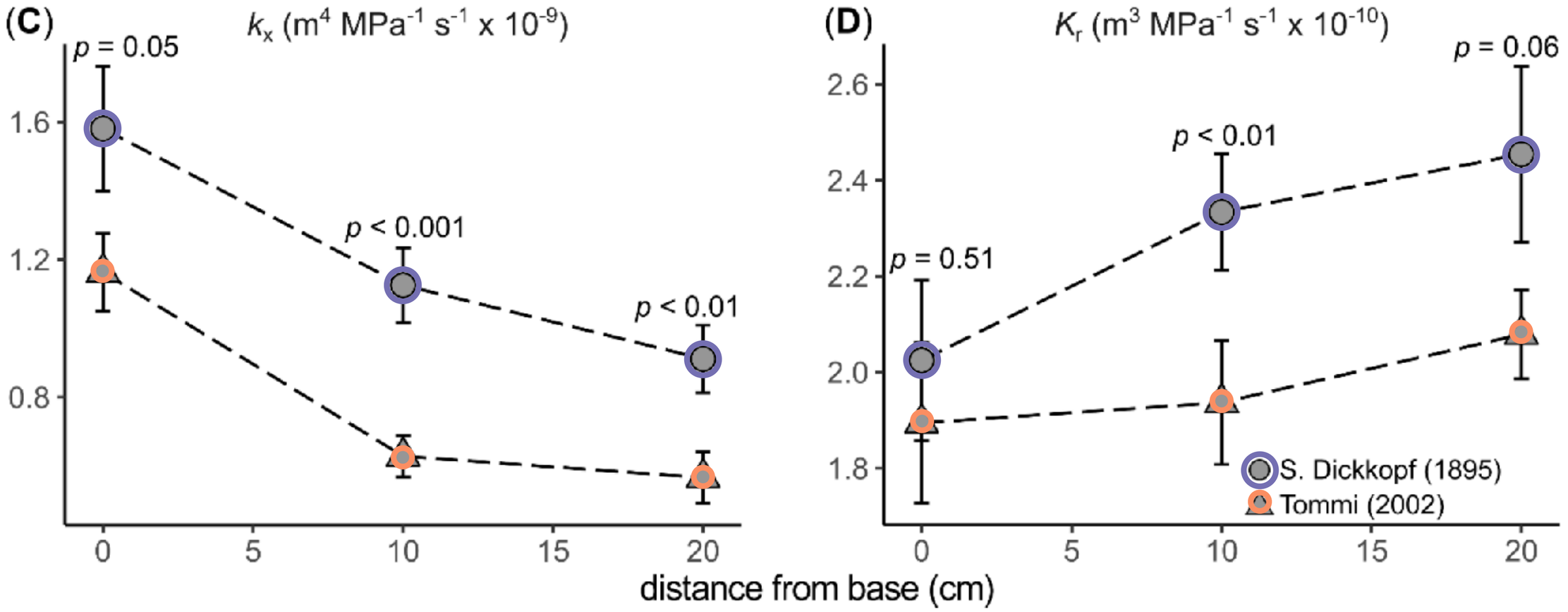
AXIAL CONDUCTIVITY

SIMULATED
RADIAL
CONDUCTIVITIES
VS
MEASURED
RADIAL
CONDUCTIVITIES



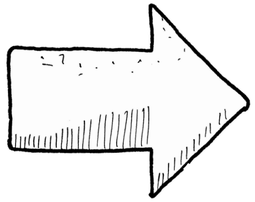
JÜLICH
Forschungszentrum

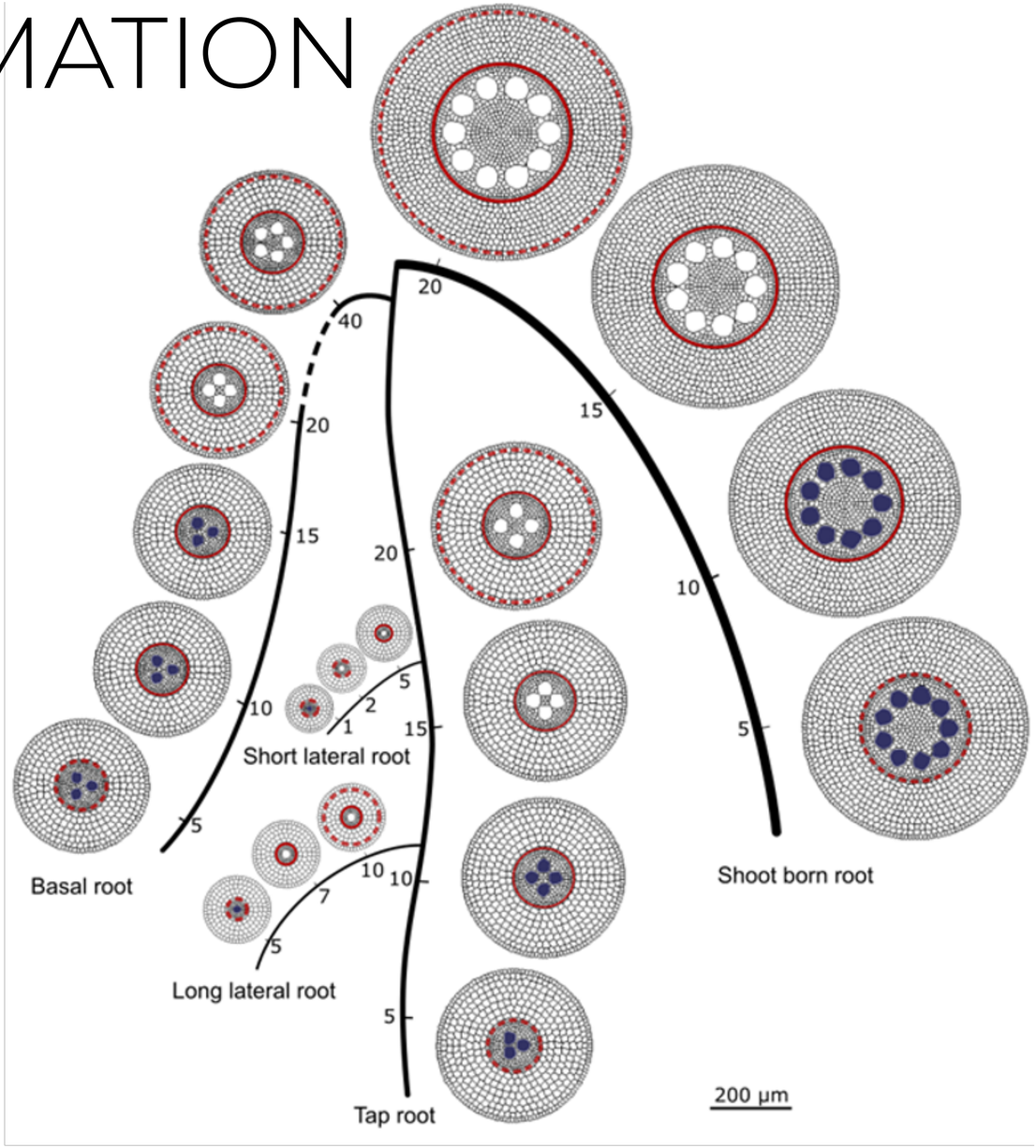
ANATOMICAL VARIATION BETWEEN HISTORICAL LINES



> BACA CABRERA ET AL 2025

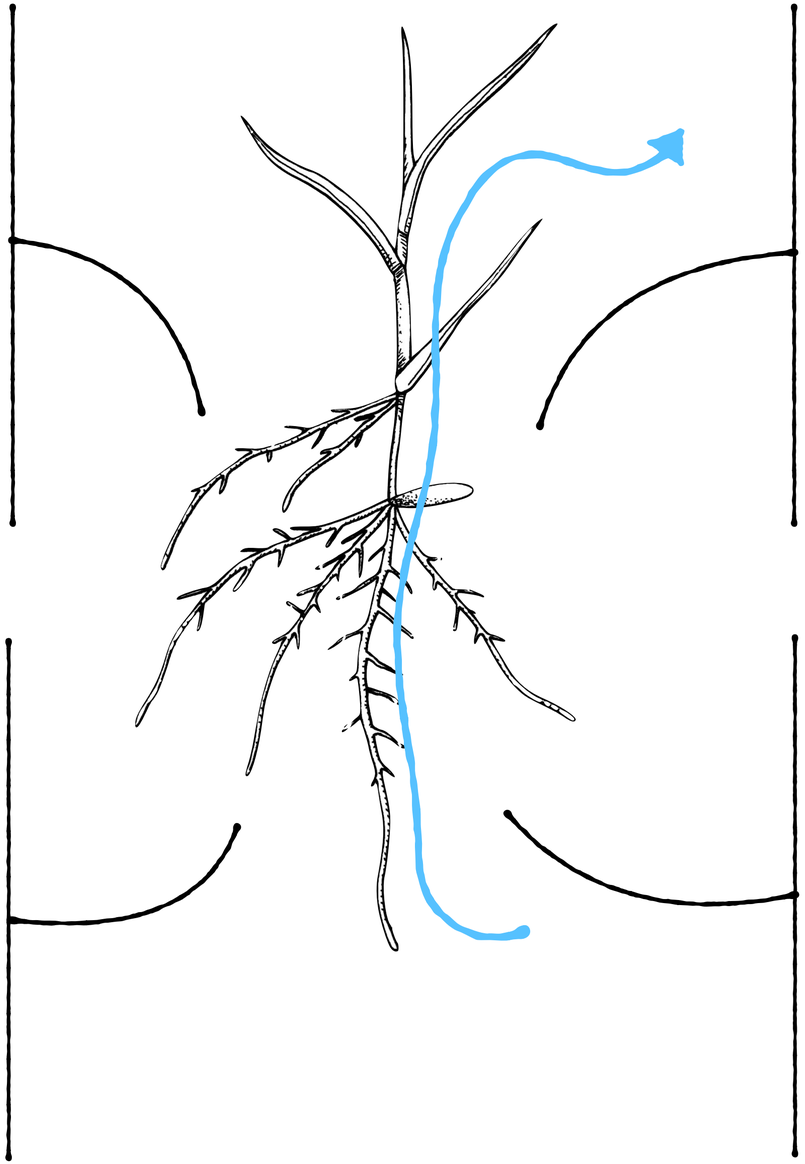
MODELS TO INTEGRATE INFORMATION

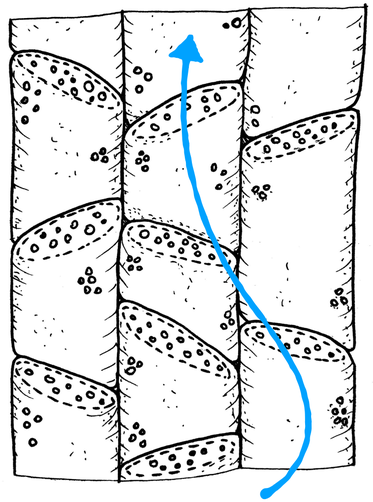




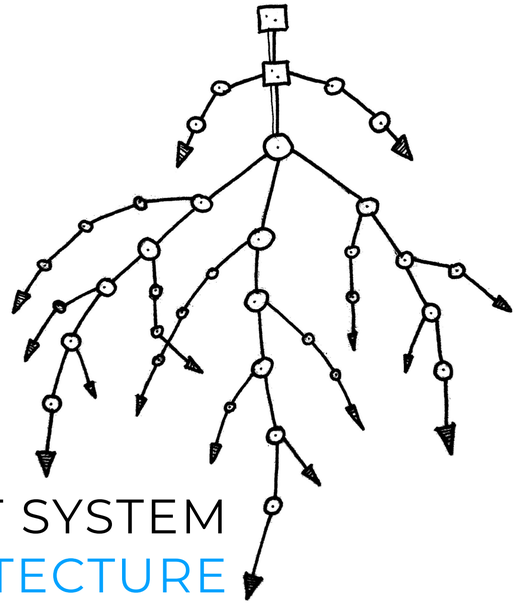
> HEYMANS ET AL 2023

SOIL
PROPERTIES

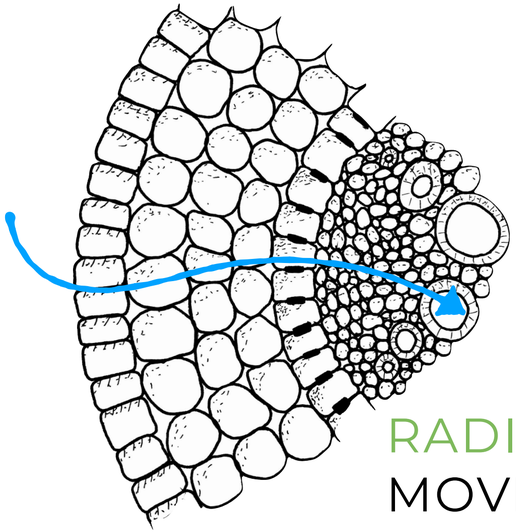




AXIAL
MOVEMENT



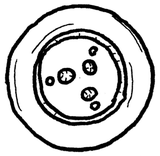
ROOT SYSTEM
ARCHITECTURE



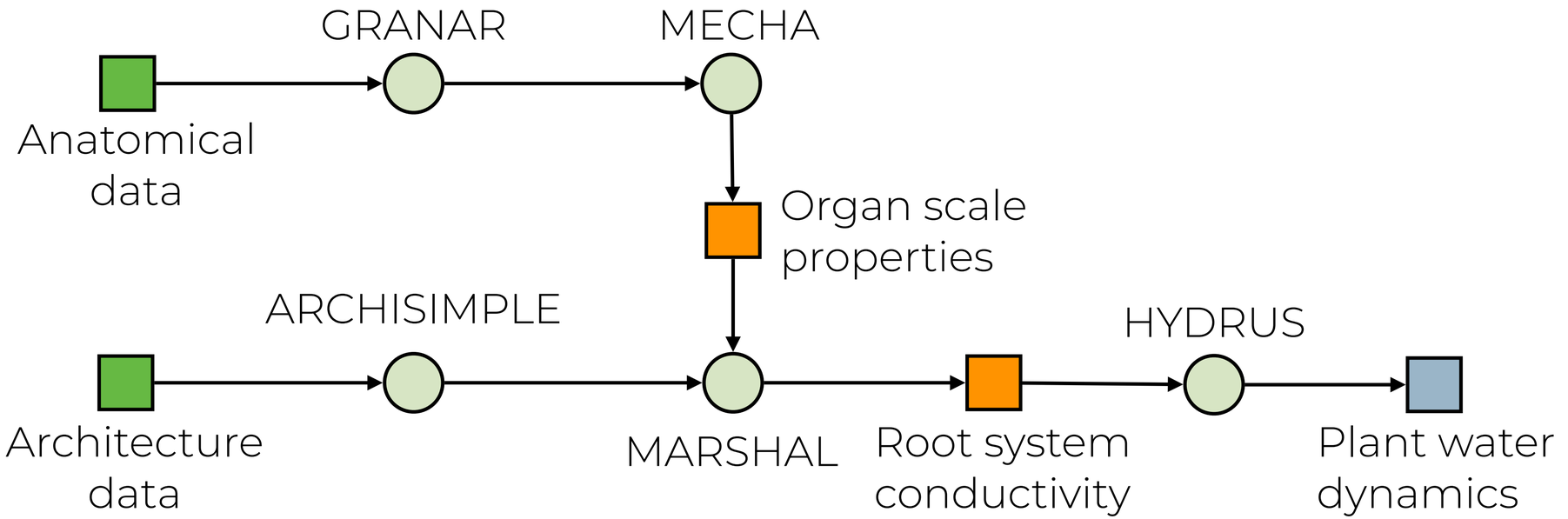
RADIAL
MOVEMENT

CONNECTING DATA AND MODELS

ORGAN

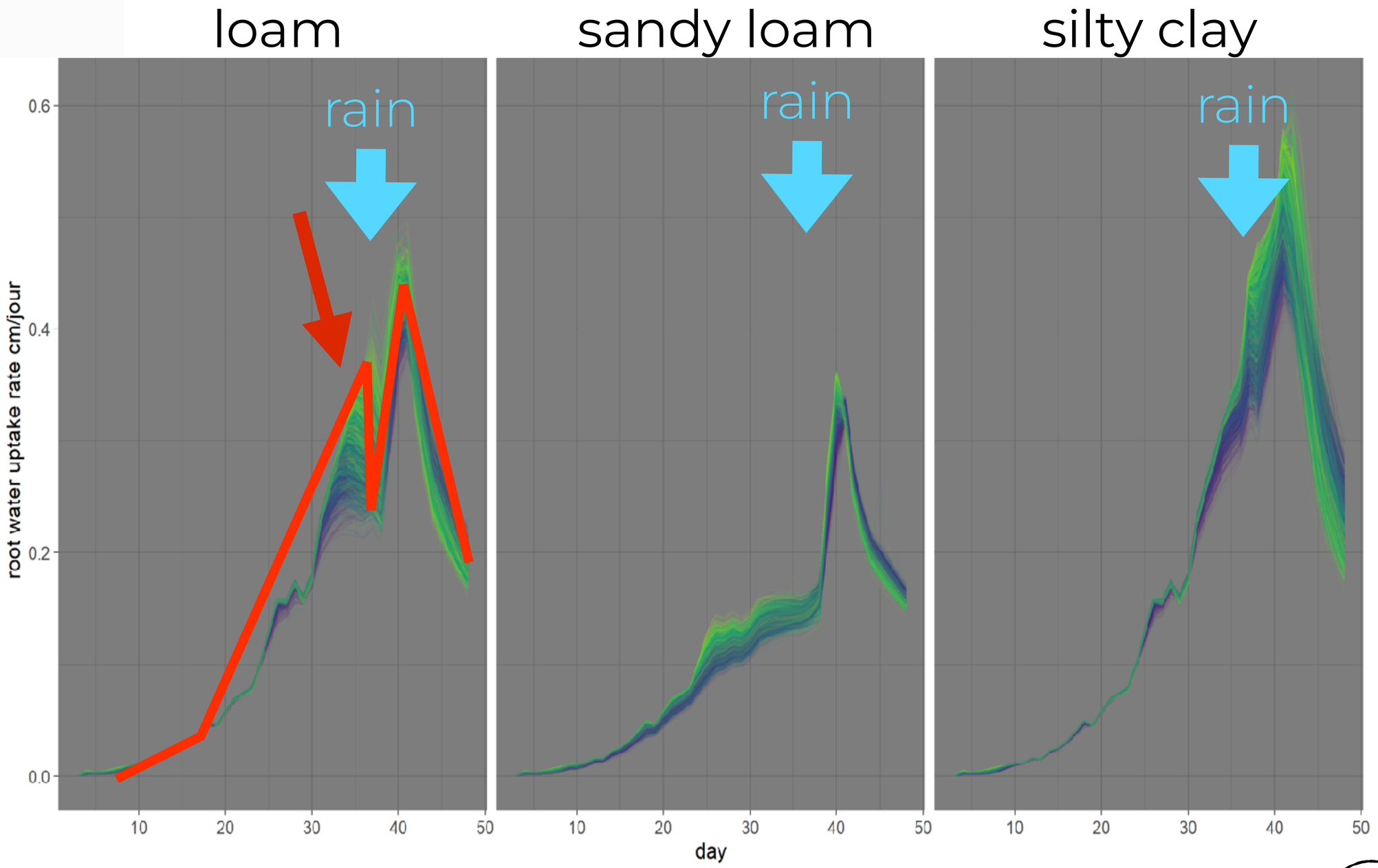


PLANT



STRUCTURE → FUNCTION

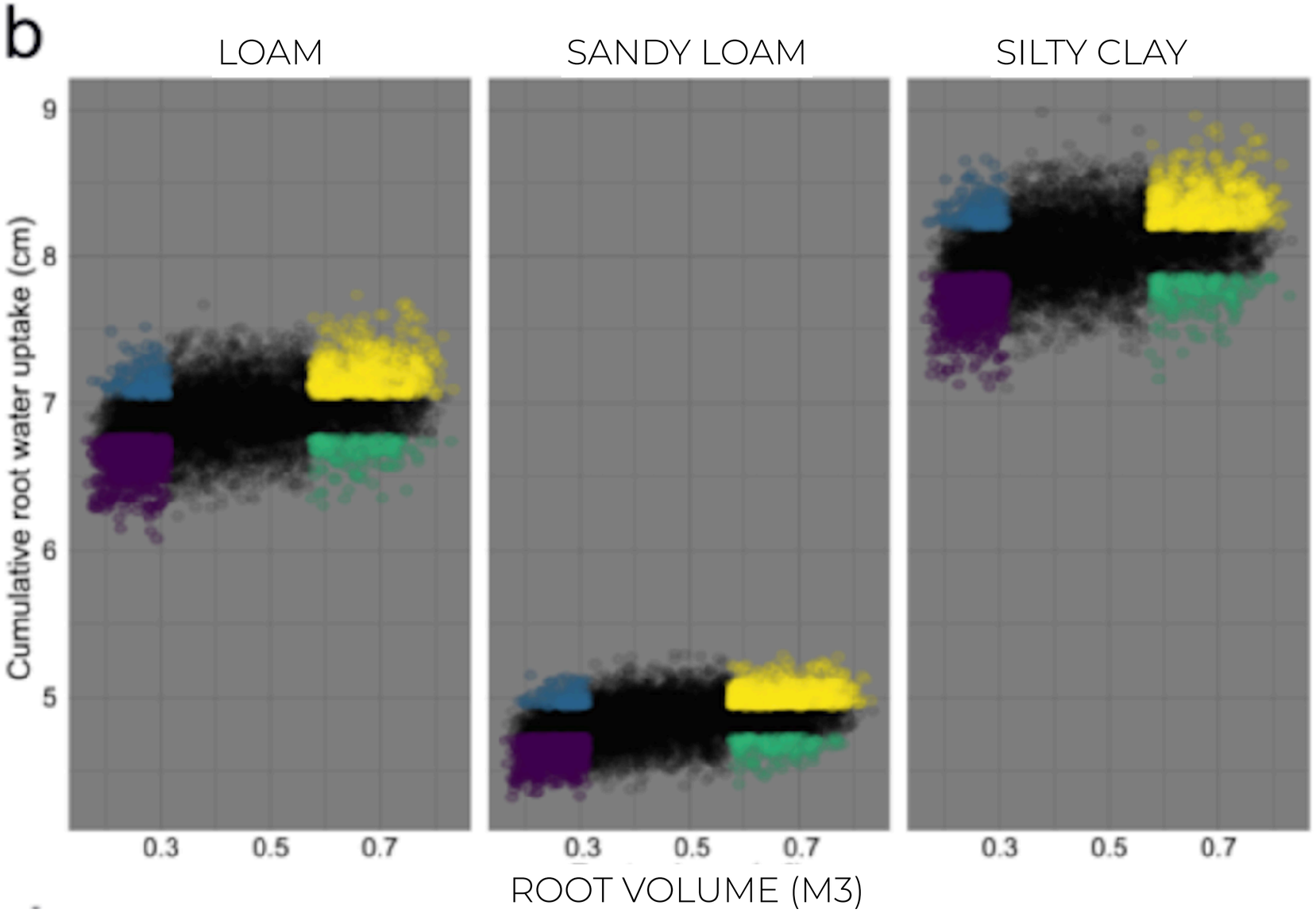
1



HEYMANS ET AL (2022)

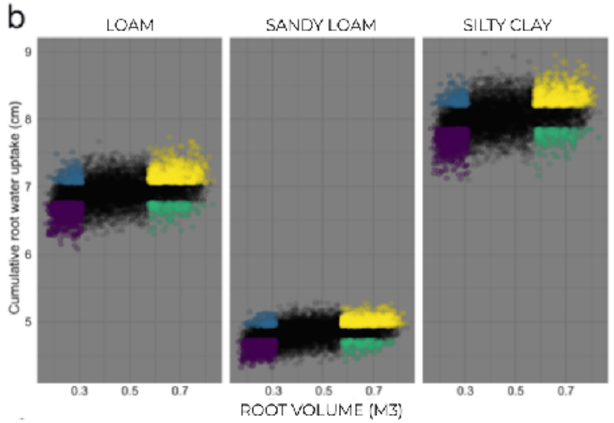
SOIL SPECIFIC DYNAMICS

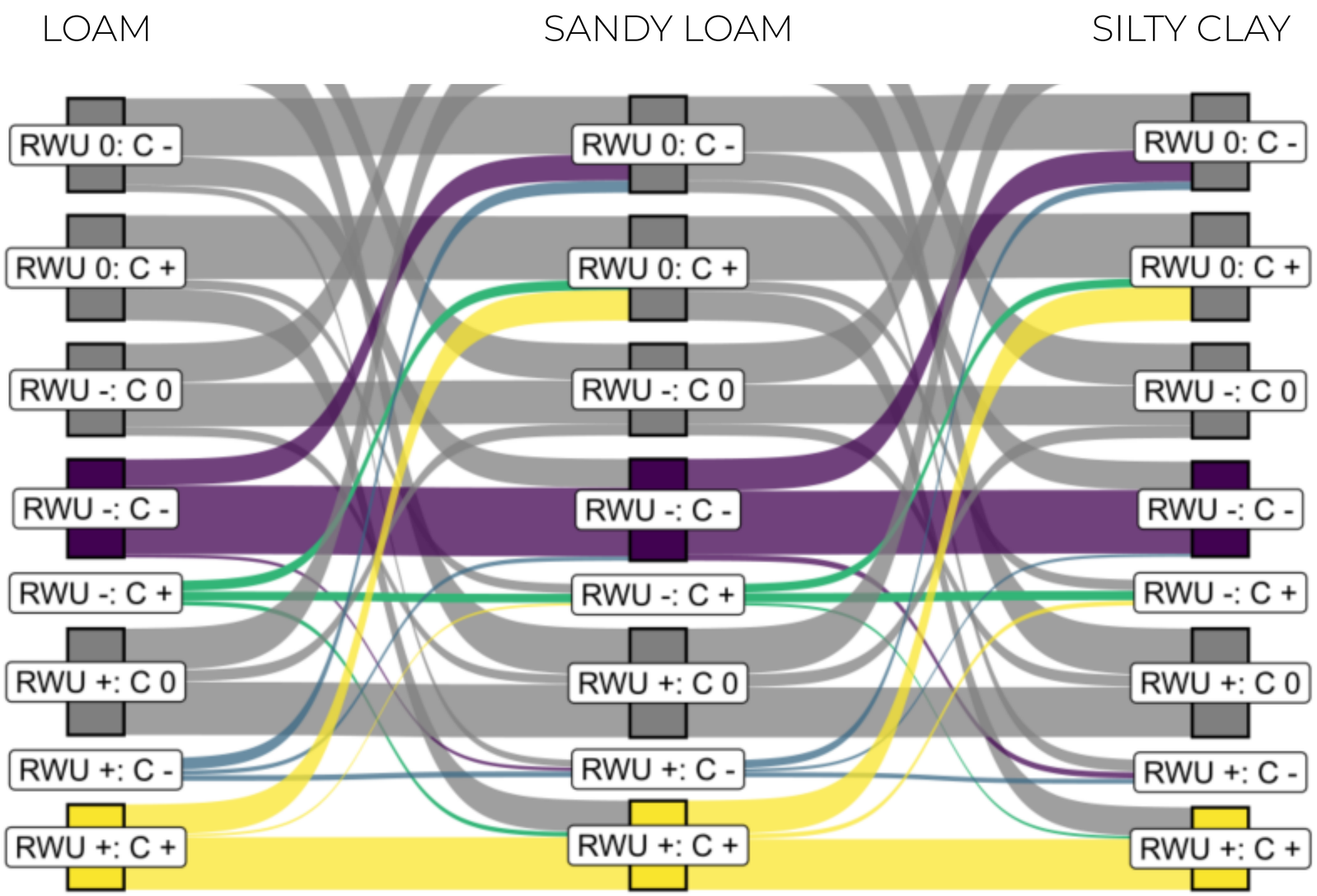
MODELS TO IDENTIFY ECO-IDEOTYPES



> HEYMANS ET AL 2024

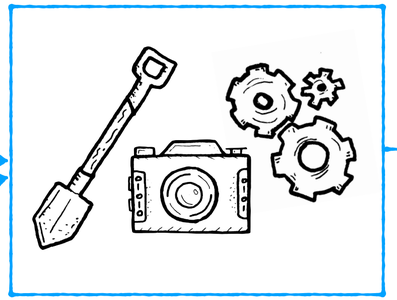
MODELS TO IDENTIFY ECO-IDEOTYPES





> HEYMANS ET AL 2024

LINK FIELD DATA WITH FUNCTIONAL TRAITS



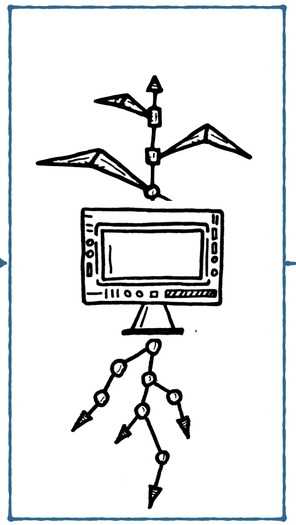
Lightweight phenotyping pipeline

Diameter distribution

Distance between laterals

# of roots

Structural traits



Multiscale modelling platform

Organ scale properties

Root system conductivity

Plant water dynamics

Field water dynamics

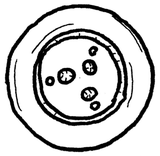
Yield

Functional traits

DROOGHT

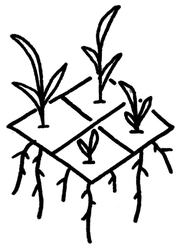
DEVELOPMENT OF A LIGHTWEIGHT MULTISCALE MODELING FRAMEWORK

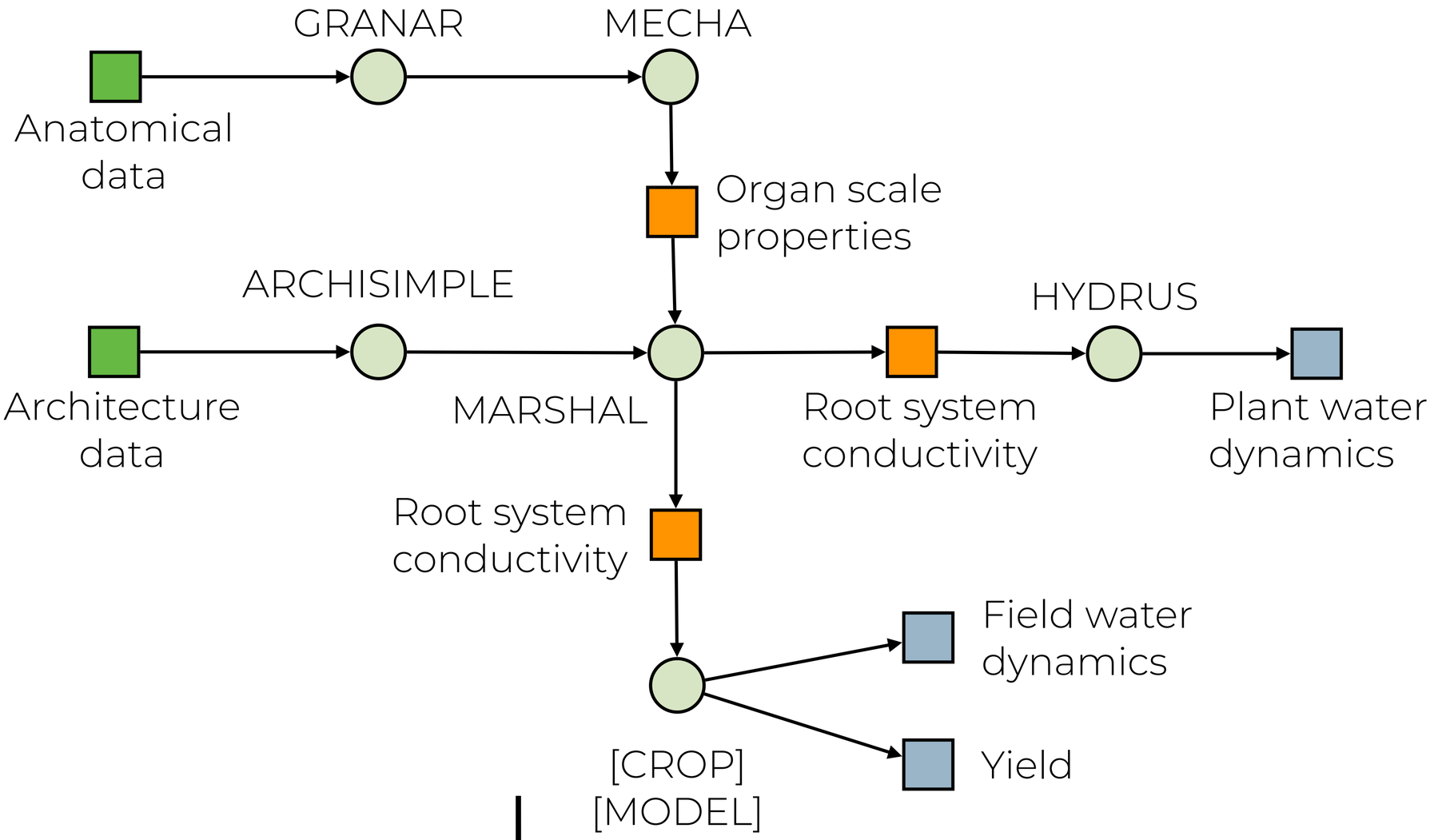
ORGAN



PLANT

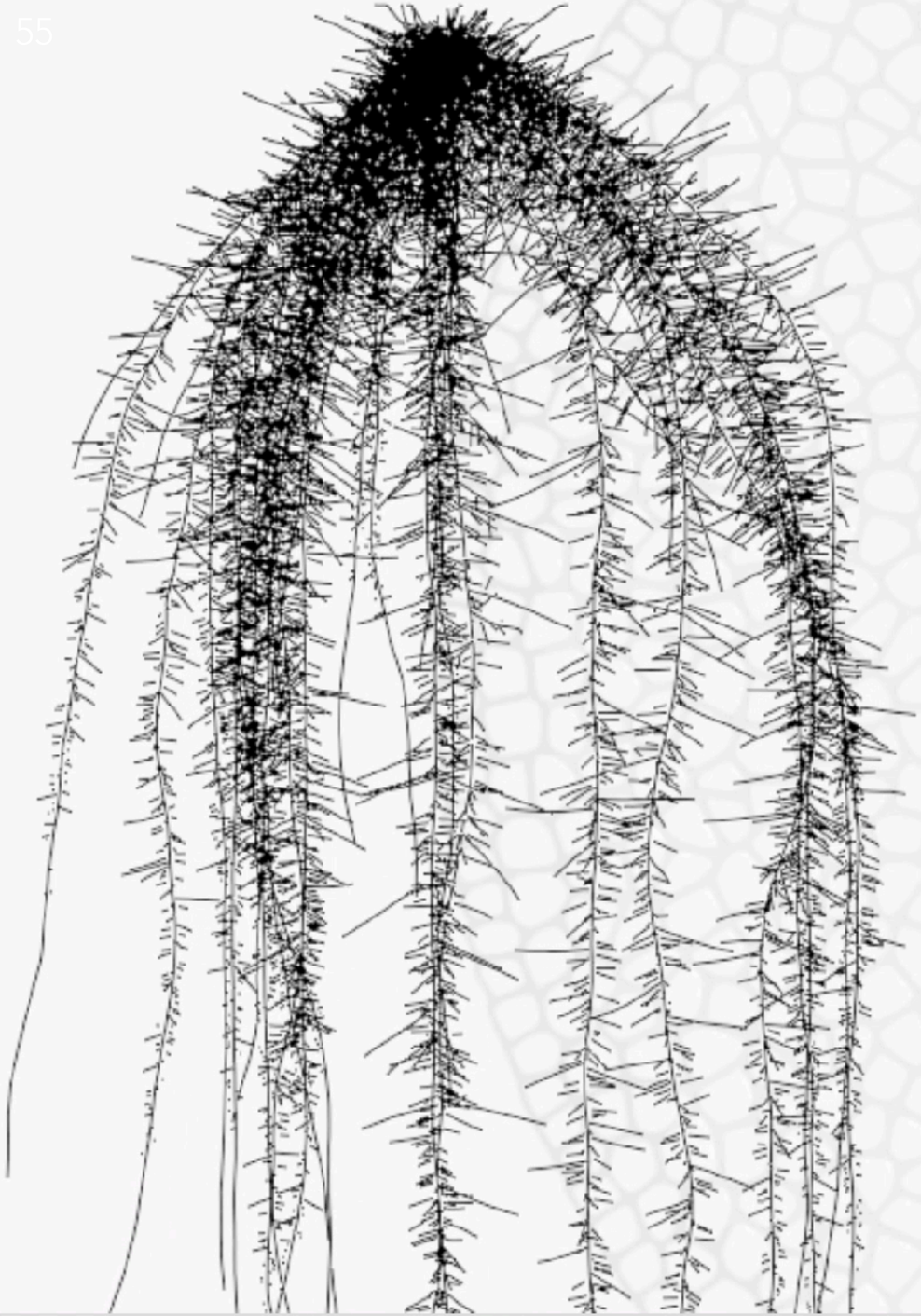
FIELD





STRUCTURE → FUNCTION


WRAPPING UP



FUNCTIONAL-STRUCTURAL PLANTS MODELS CAN HELP INTEGRATE INFORMATION ACROSS THE WHOLE SYSTEM

CONCLUSIONS

Deep water acquisition

- Constitutive phenes known and proven (G)
- Crop management opportunities (M)
- Already in most crop models
- Phenotyping bottleneck

Scope for new routes based on hydraulics

- More complex (GxE)
- Multi-scale, spatially structured and dynamic hydraulic circuits
- Value for representing drought responses
- Eco-ideotyping in future environments

UCLouvain

Félicien Meunier
Mathieu Javaux
Valentin Couvreur
Adrien Heymans
François Chaumont

JÜLICH Forschungszentrum

Andrea Schnepf
Daniel Leitner
Juan Baca Cabrera

INRAE

François Tardieu
Claude Welcker
Bertrand Muller
Pierre Martre
Philippe Hinsinger
Loïc Pagès

ETH zürich

Achim Walter,
Andreas Hund
Andrea Carminati

IRD Institut de Recherche pour le Développement FRANCE

Laurent Laplaze
Alexandre Grondin
Vincent Vadez

UNIVERSITÀ DI BOLOGNA

Roberto Tuberosa
Silvio Salvi

The University of Nottingham

Malcolm Bennet

IPK GATERSLEBEN

Hannah Schneider
Dylan Jones

The James Hutton Institute

Brian Foster

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

Graemme Hammer

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Tom Beeckman

UNIVERSITY OF COPENHAGEN

K Thorup Kristiensen

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