4PMI: Plant Phenotyping Platform for Plant and Microorganisms Interactions Phenotyping innovations, opportunities and challenges

Christophe Salon, Céline Bernard, Mickaël Lamboeuf, Christian Jeudy

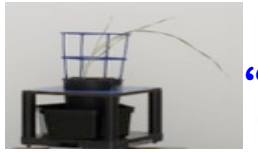
4PMI: Plant Phenotyping Platform for Plant and Microorganisms Interactions

Phenotyping innovations, opportunities and challenges

(Christophe Salon, Céline Bernard, Mickael Lamboeuf, Christian Jeudy, UMR Agroécologie, INRA, Dijon, France)

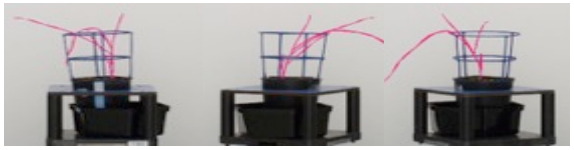
Shoot phenotyping: basics

"Manual" image



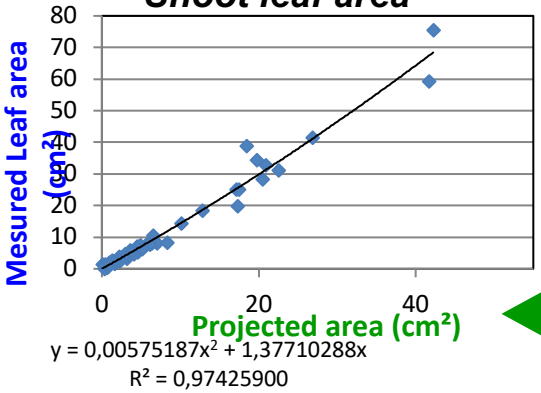
"Manual" weight

4PMI image

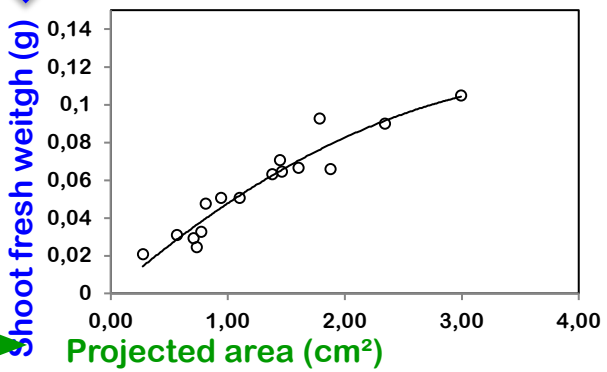


Mean of 3 lateral views

Shoot leaf area



Shoot Fresh weight



Choice of best image acquisition model !

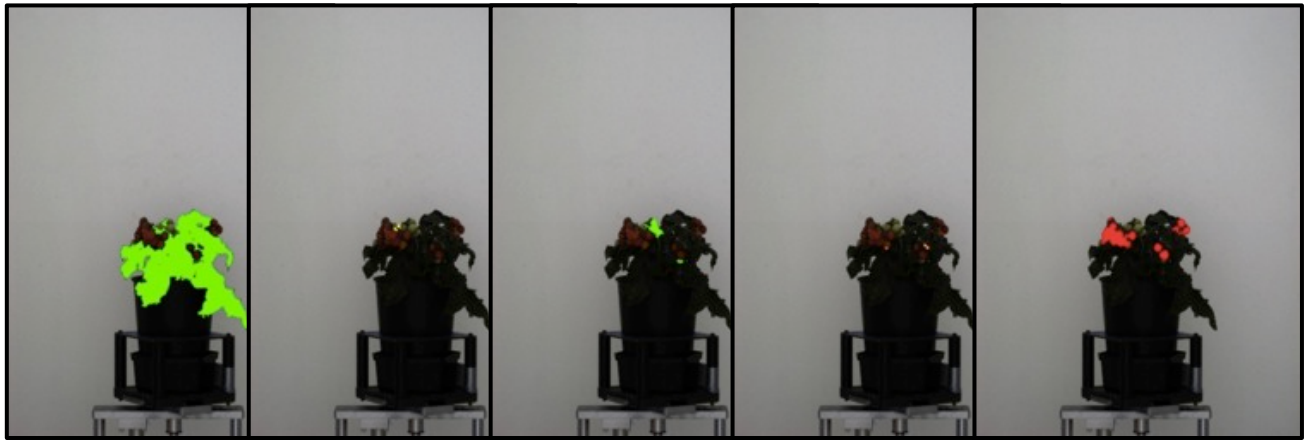
Shoot phenotyping: 1st example

Micro tom phenotyping, coll. C Rothan (BFP Bordeaux, France)

Tomato in pots

Original image

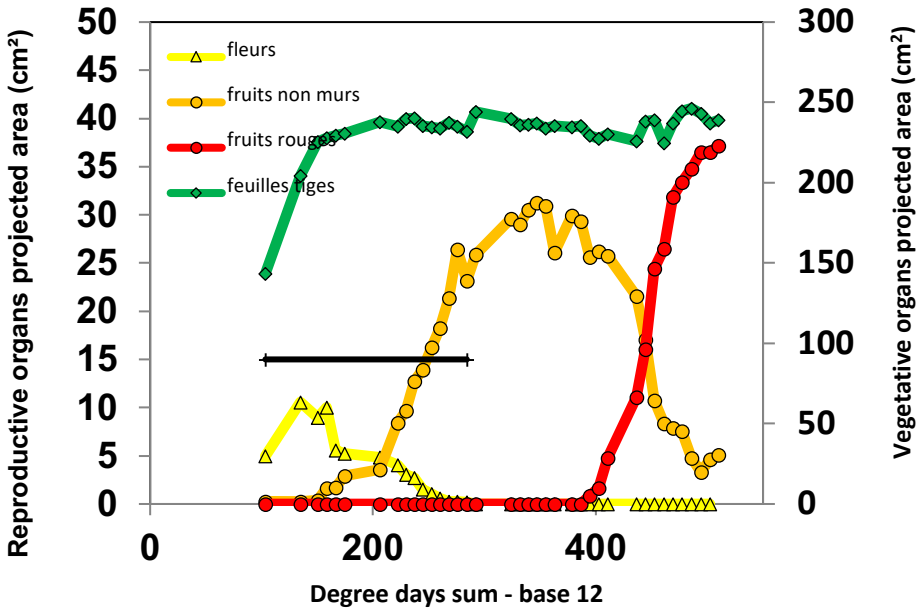
Segmentation

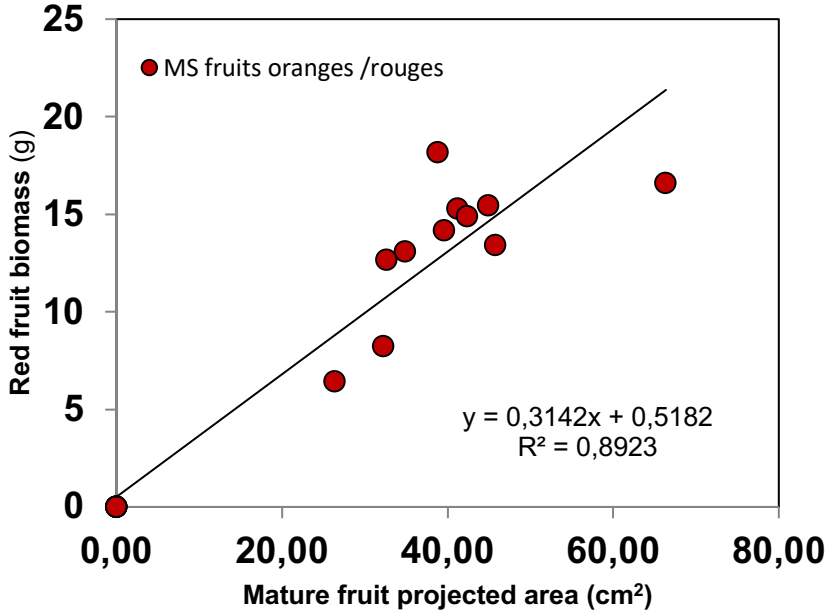


Leaf **Flowers** **Green fruit** **Orange fruits** **Red fruits**

Shoot phenotyping: 2nd example

Micro tom phenotyping, coll. C Rothan (BFP Bordeaux, France)





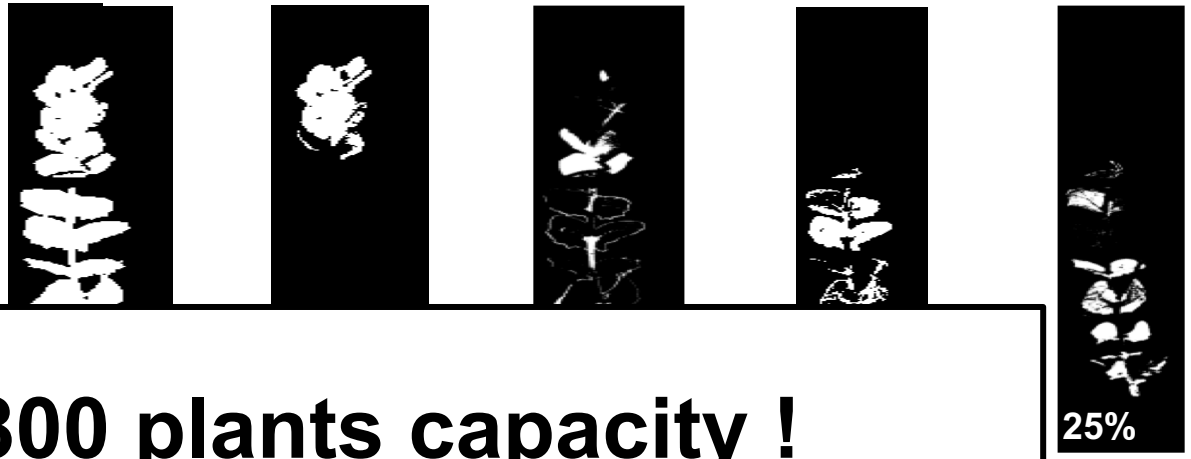
- **Phenology and fruit maturing followed non destructively from image analysis.**
- **Fruit detection realized = f(image analysis).**

Shoot phenotyping: 3rd example

RAGT

PEA plants

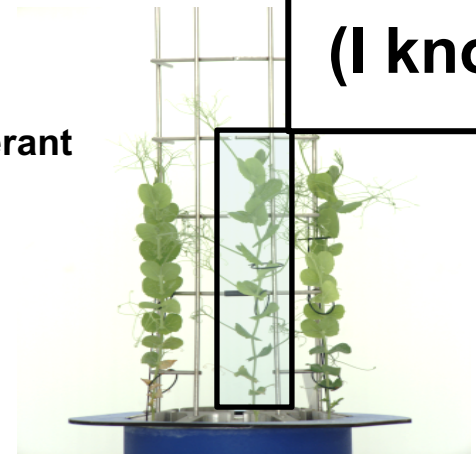
Chlorosis Sensible

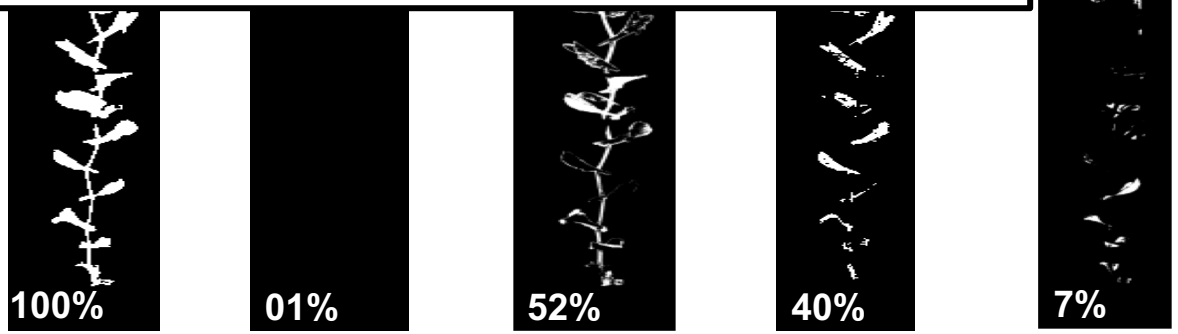


1800 plants capacity !

(I know…, that's less than Trevor's PF..)

Tolerant





Algorithms to identify symptoms on 300 genotypes

Root phenotyping: why go into trouble ?

- **Crop breeding programmes**: root traits rarely used as selection criteria, a focus on adaptation to high-input systems,

Improve crop resource-use efficiency through:
(i) physiological utilization of acquired resources,
(ii) resource acquisition

- **Technical difficulties:**
  - Access to roots ,
  - Root diversity,
  - Plasticity of RSA (abiotic and biotic factors including plant and microorganisms interactions) in order to enhance its efficiency.

Christmas wishes

We wish:

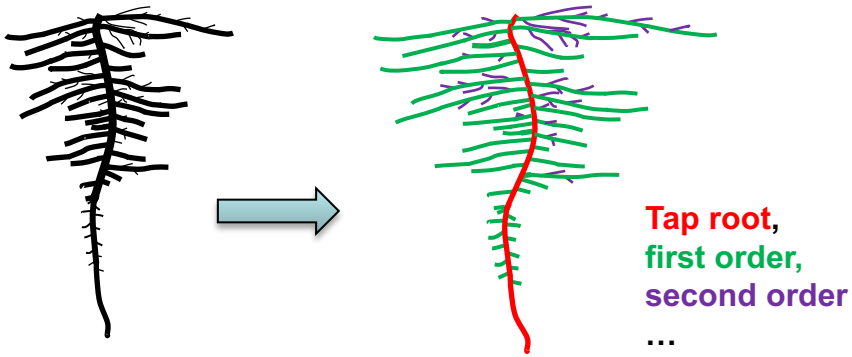
- To visualize (harvest) roots, at high resolution, dynamically and non destructively, for a large number of biological units, various species.
- To estimate structural (and functional?) traits, avoid shading roots, oxygen shortage and pH, nutrient unregulated conditions
- To study plant-plant and plant-microorganism interactions

…and access various descriptors of RSA:

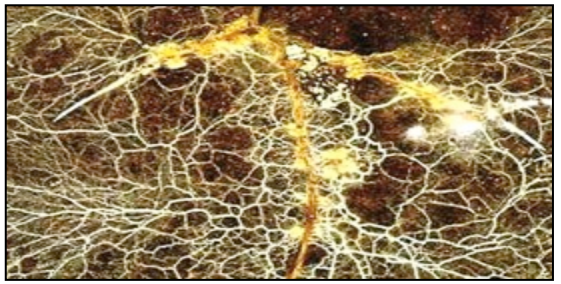
First priority
Root projected area
Nodule projected area
Nodule number
Total root length
Root depth, prospection

then
Main and lateral root length
Number of lateral roots, of secondary roots on lateral roots
Number and position of nodules on each root
Apical diameter of roots

Notes:
Number: total, by segment-segment length
Projected area: individual, by class
Position: individual, by class
Nodule efficiency: individual, by class
Estimated biovolume: a root ≠ cylinder
Biomass estimation: calibration



Also structures arising from plants and microorganisms : nodules, mycorrhiza



Slide 8 over … a lot

Many opportunities

Soil

Growth pouches

Agar plates, petri disches

Hydroponic

Tube

X Ray tomography

Mooney et al. 2012. Plant Soil, 352:1–22

Moradi et al. Plant Soil (2009) 318:3

MRI

LEGATO

C. Windt R. Metzner

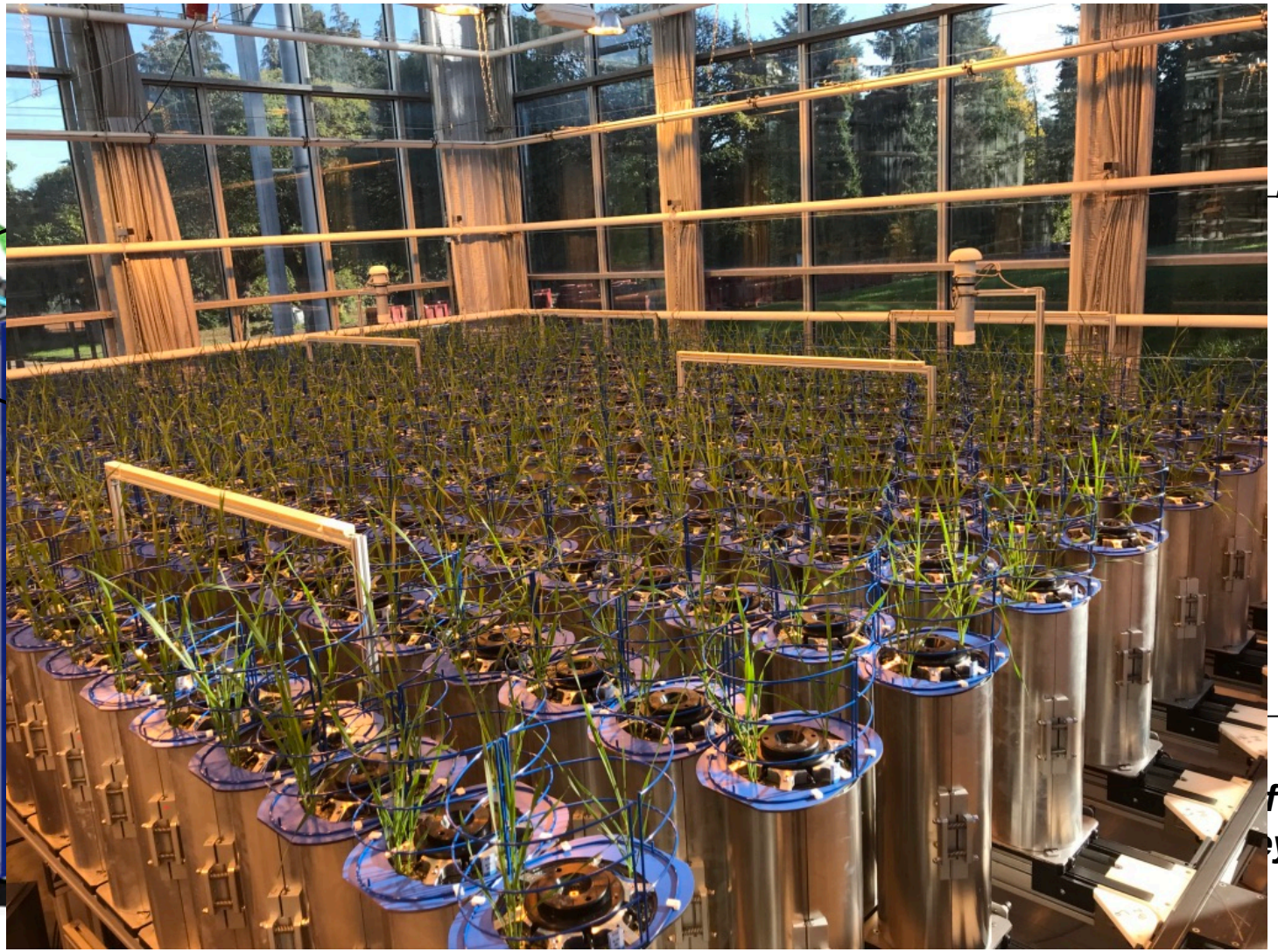
Clark et al. 2011.

Artificial

Downie et al. 2012
DOI: 10.1371/journal.pone.0044276

I give up counting slides…

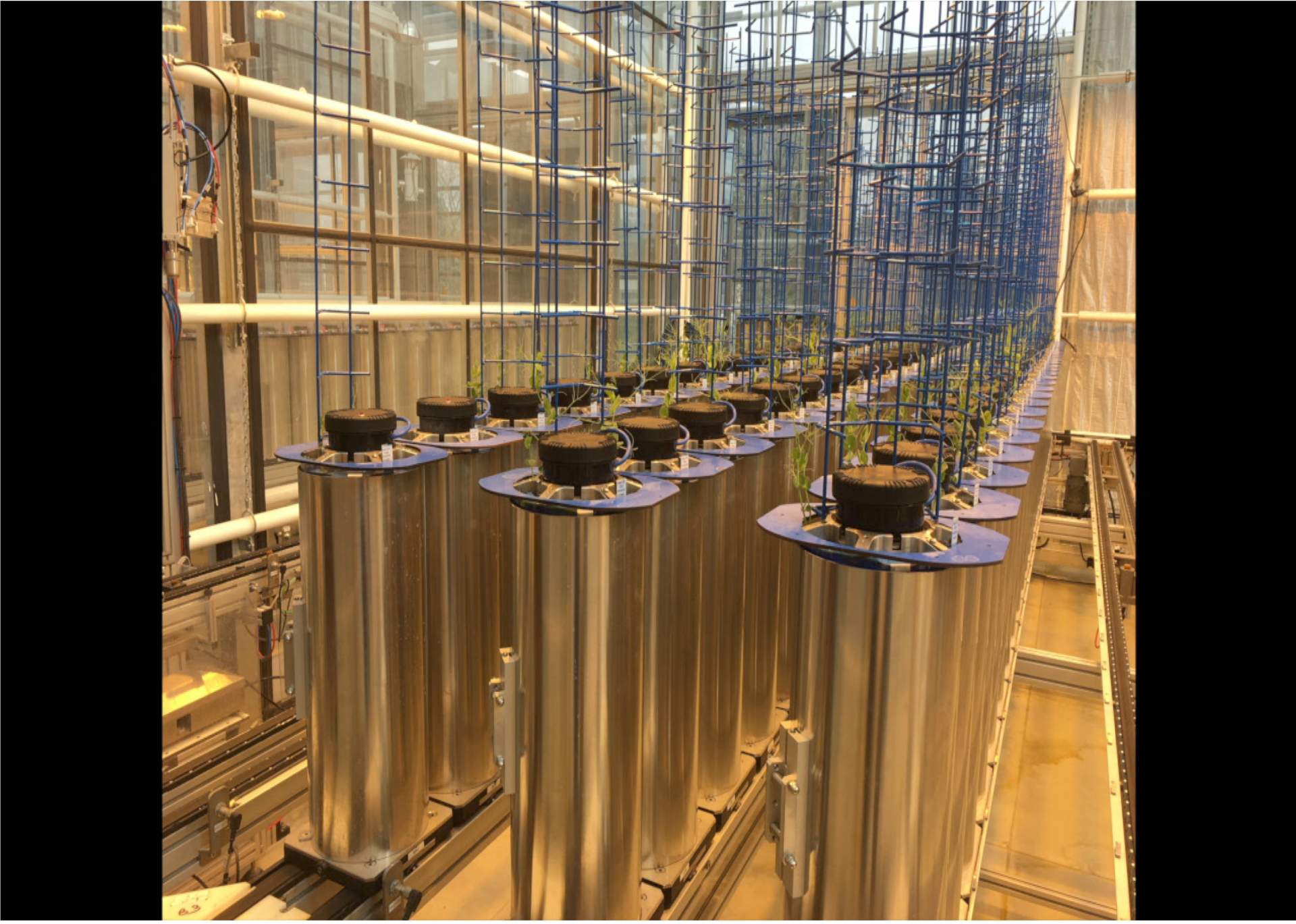
RhizoTube: the concept



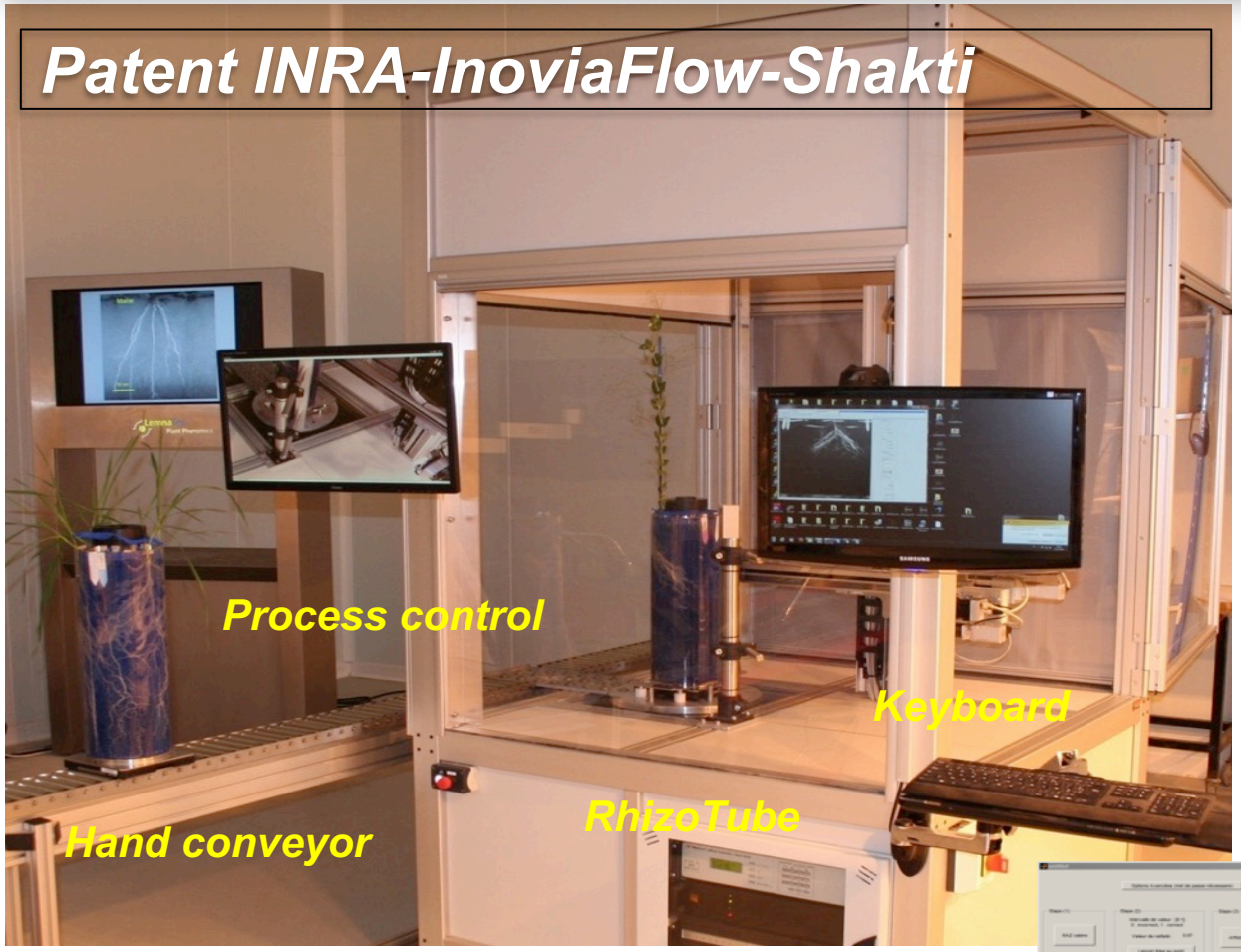
s

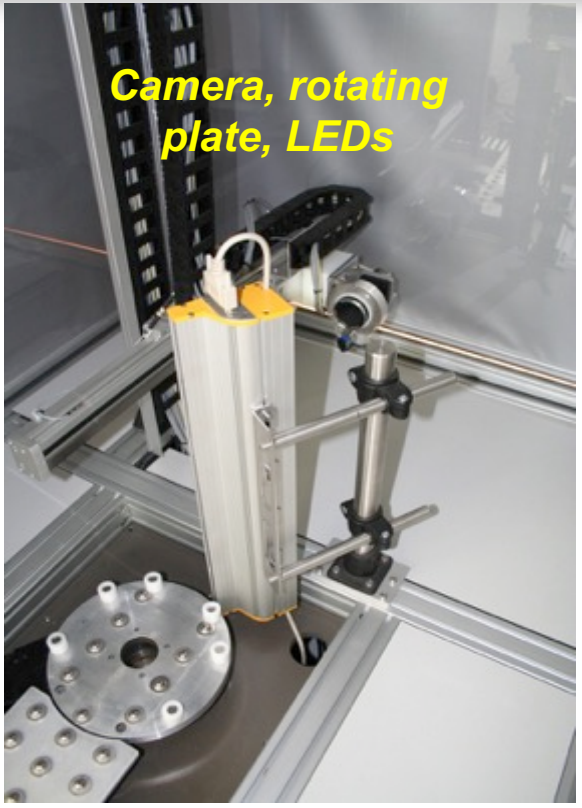
for

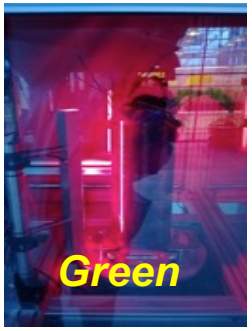
eyors

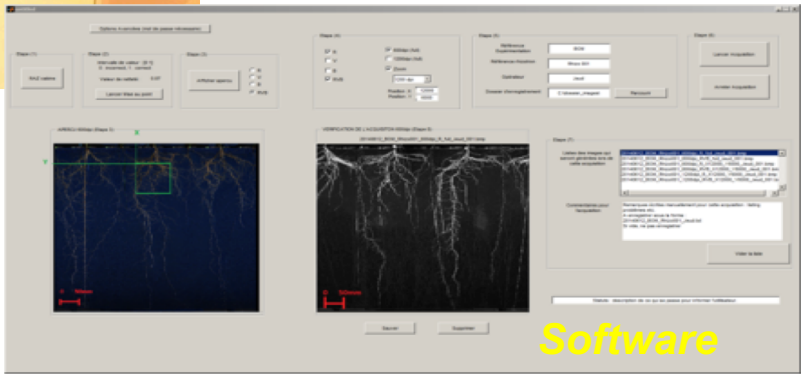


Imaging : RhizoCabs

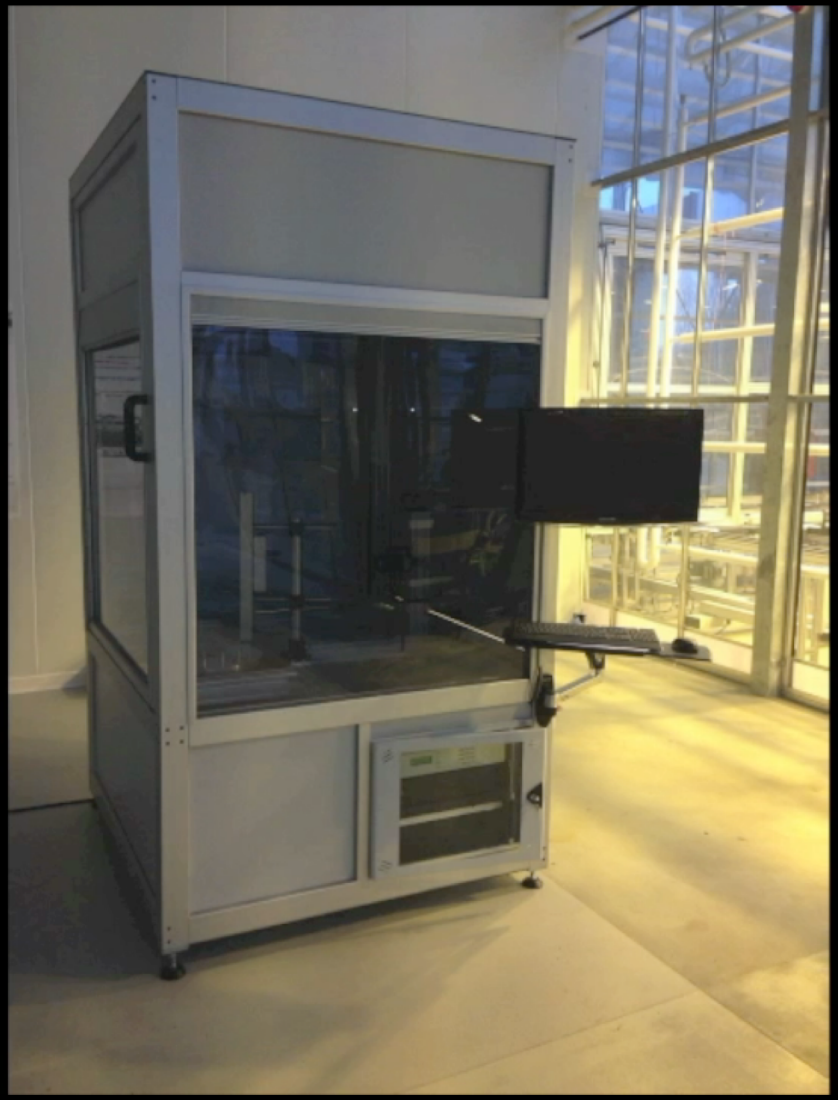






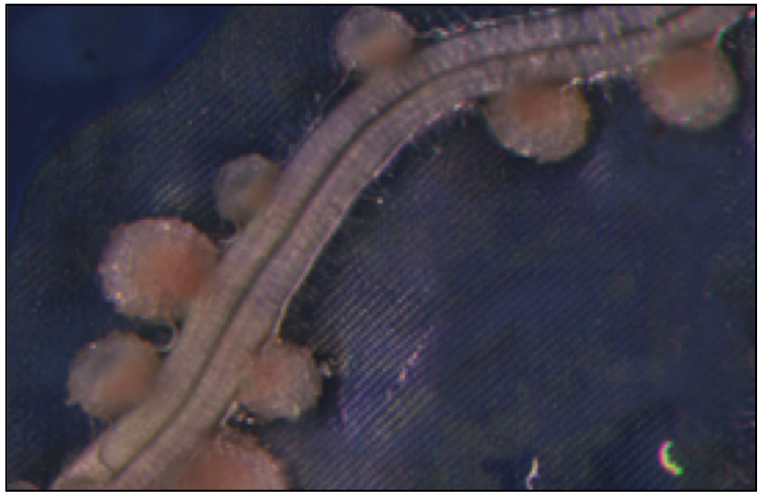


High Resolution RhizoCab



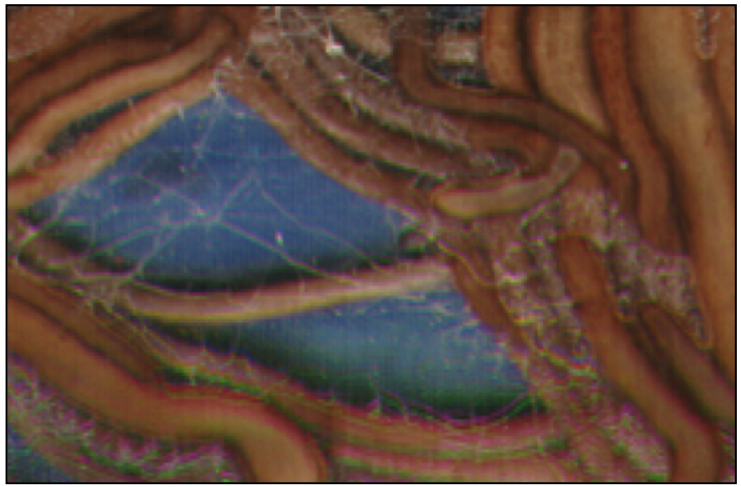
High Resolution RhizoCab

Maize



Nodules

10 cm

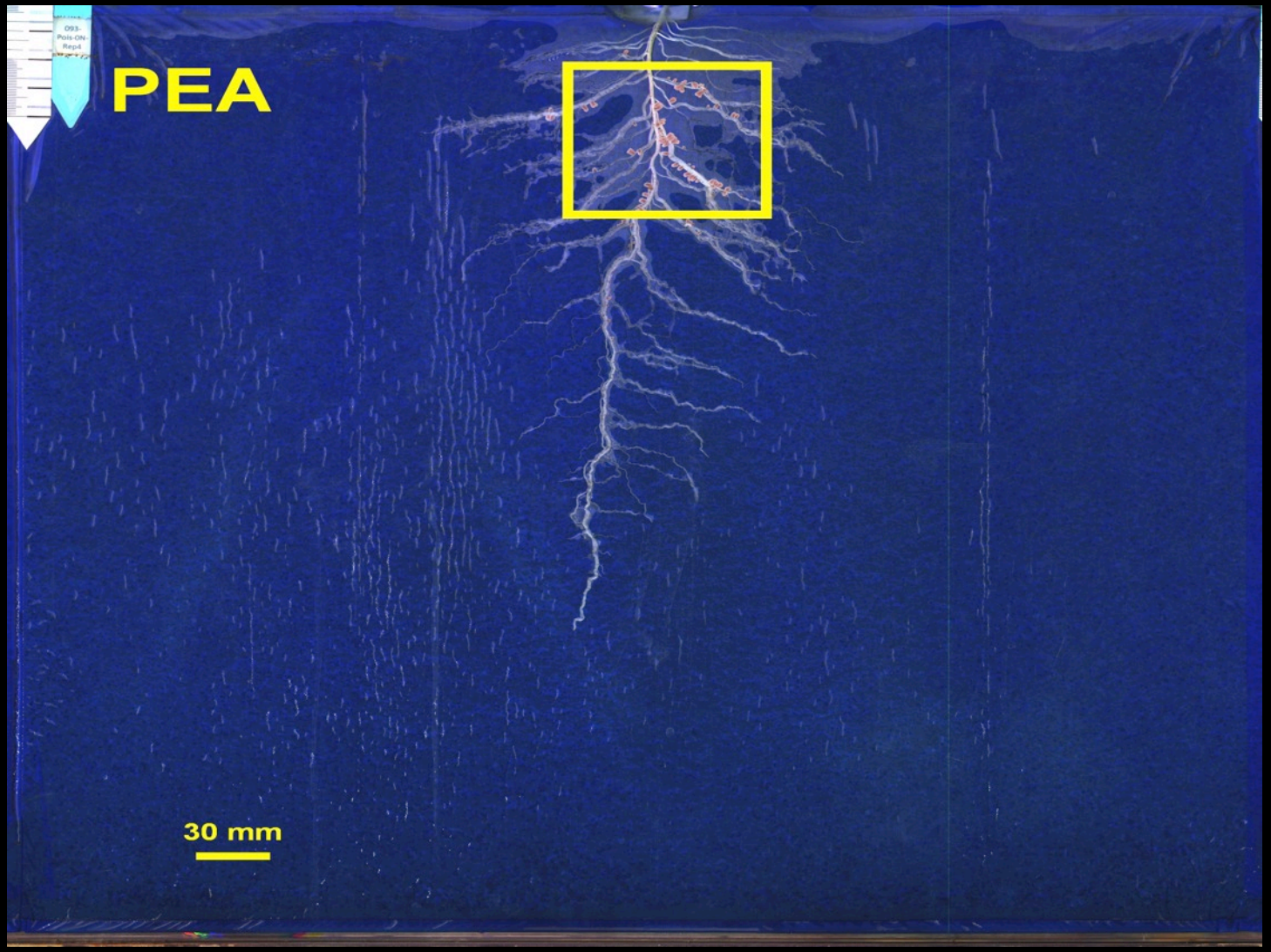


Hyphaes

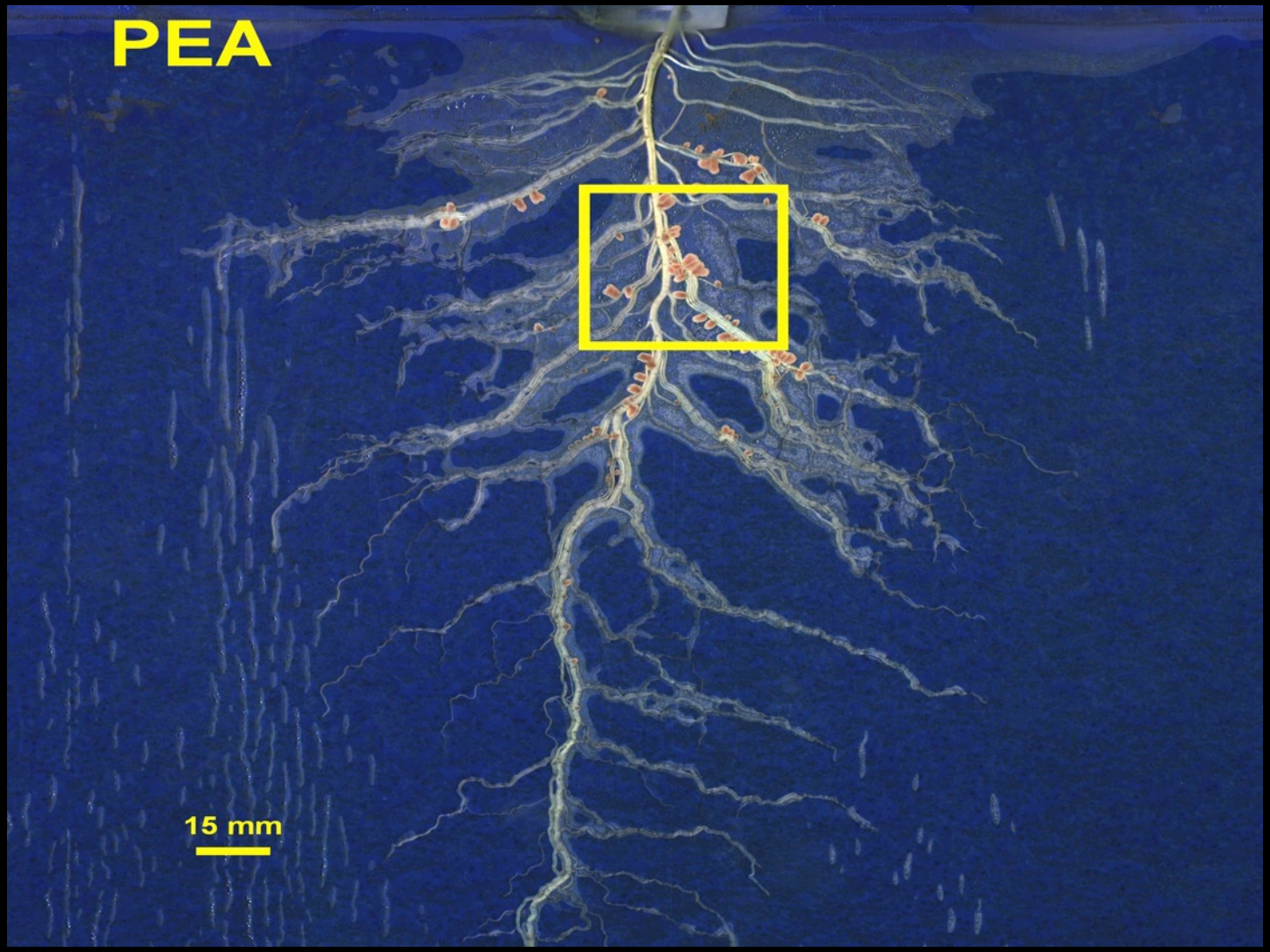
100 µm

10 µm

High Resolution RhizoCab



High Resolution RhizoCab



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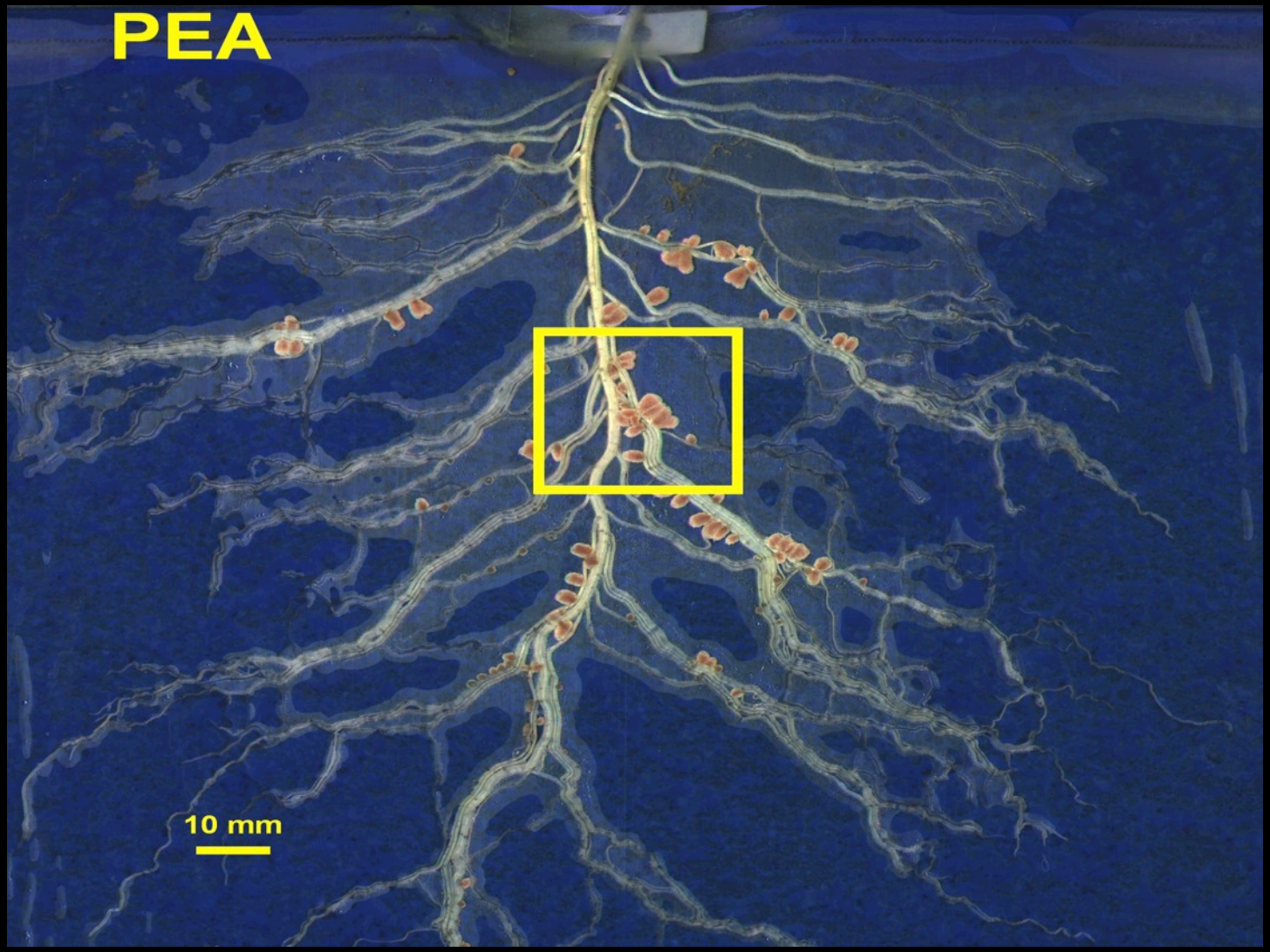

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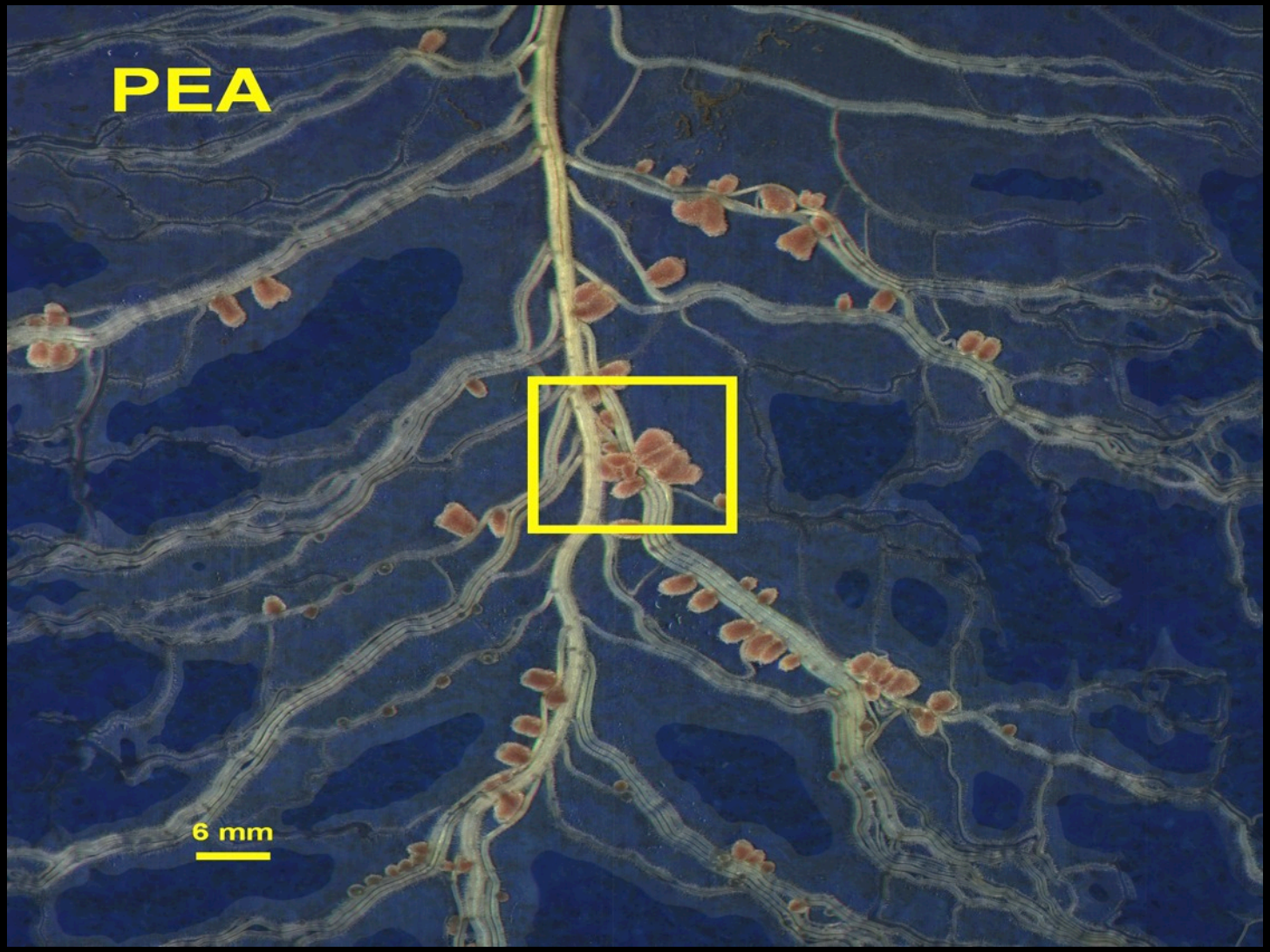

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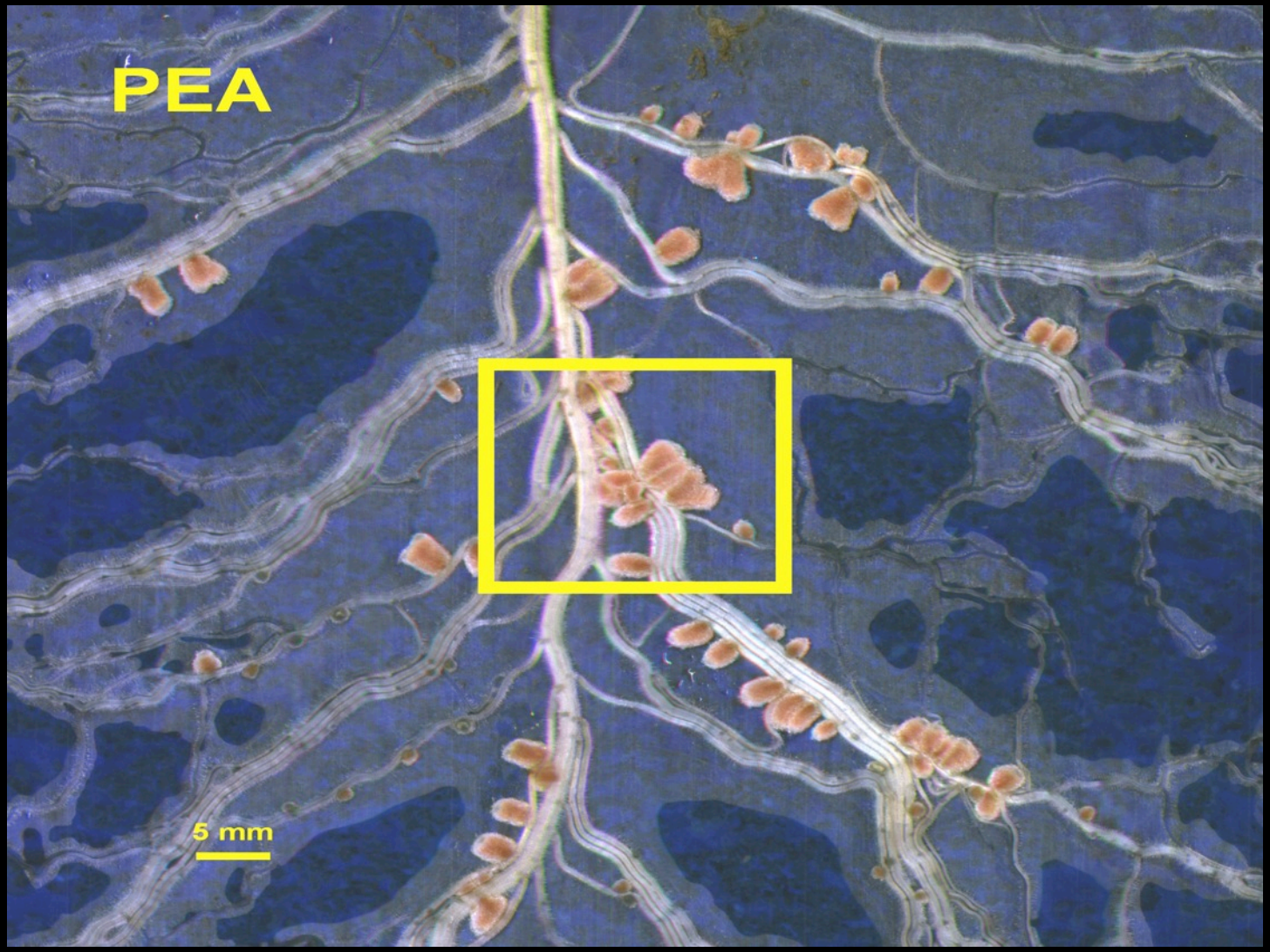

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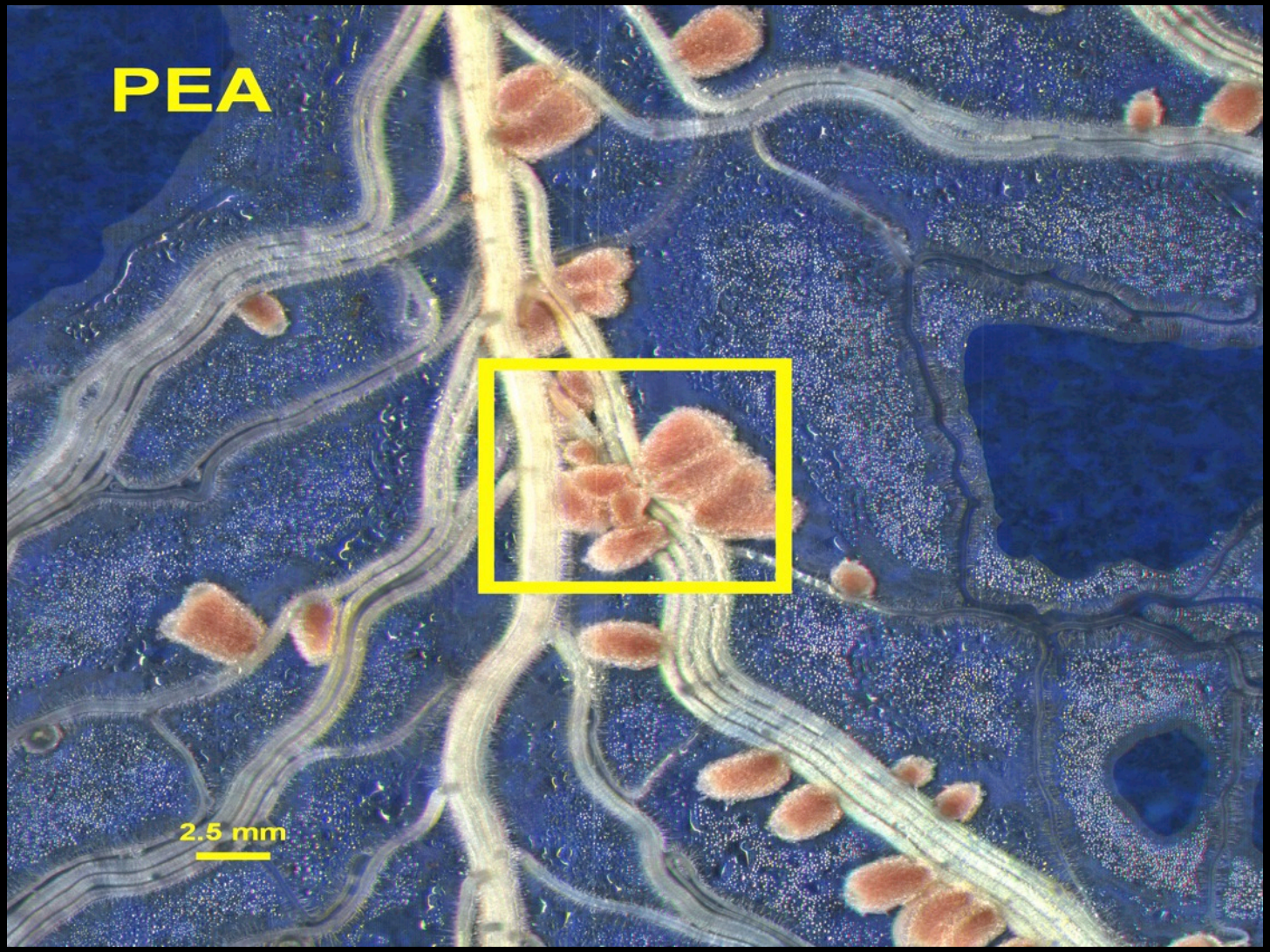

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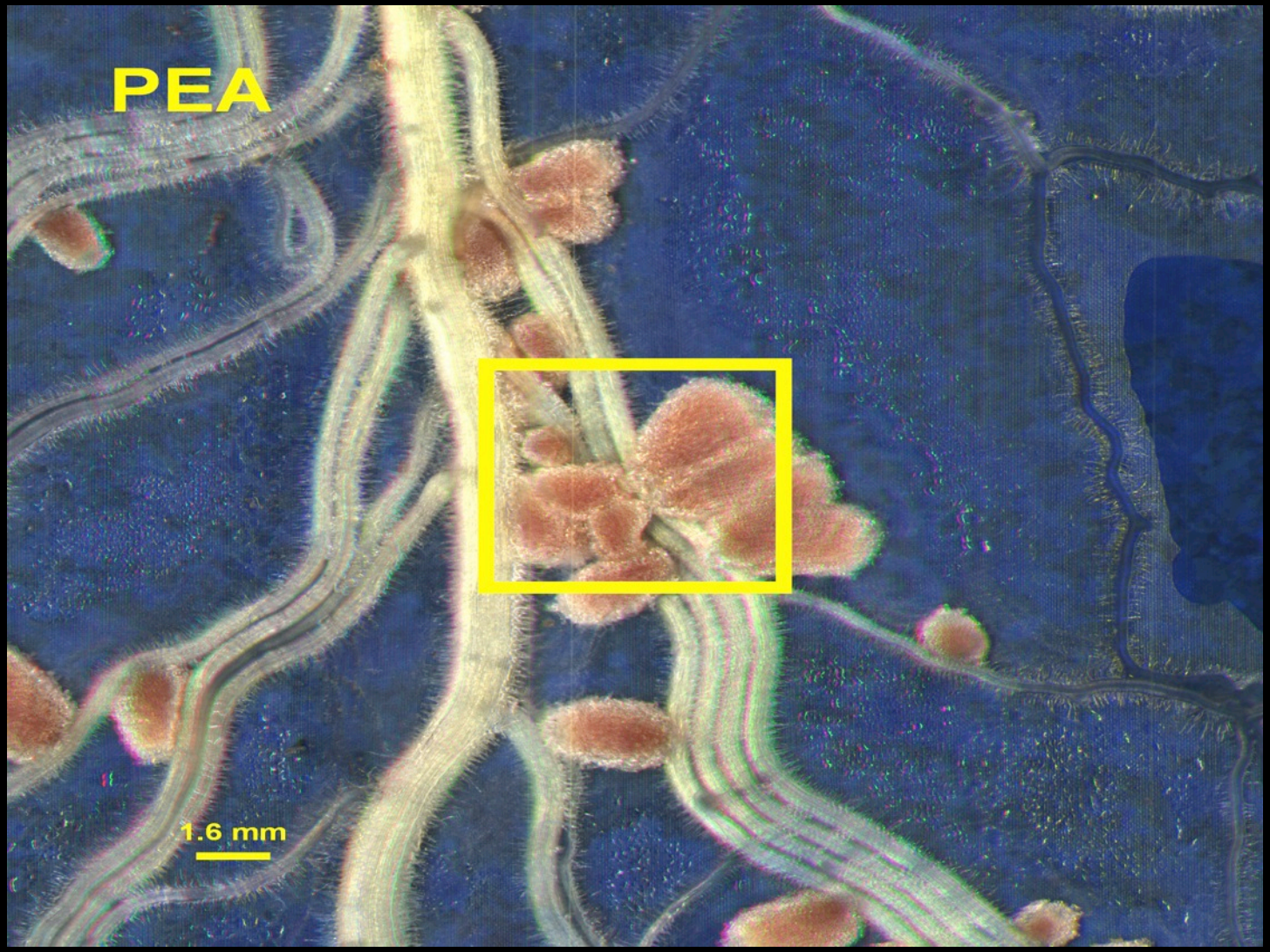
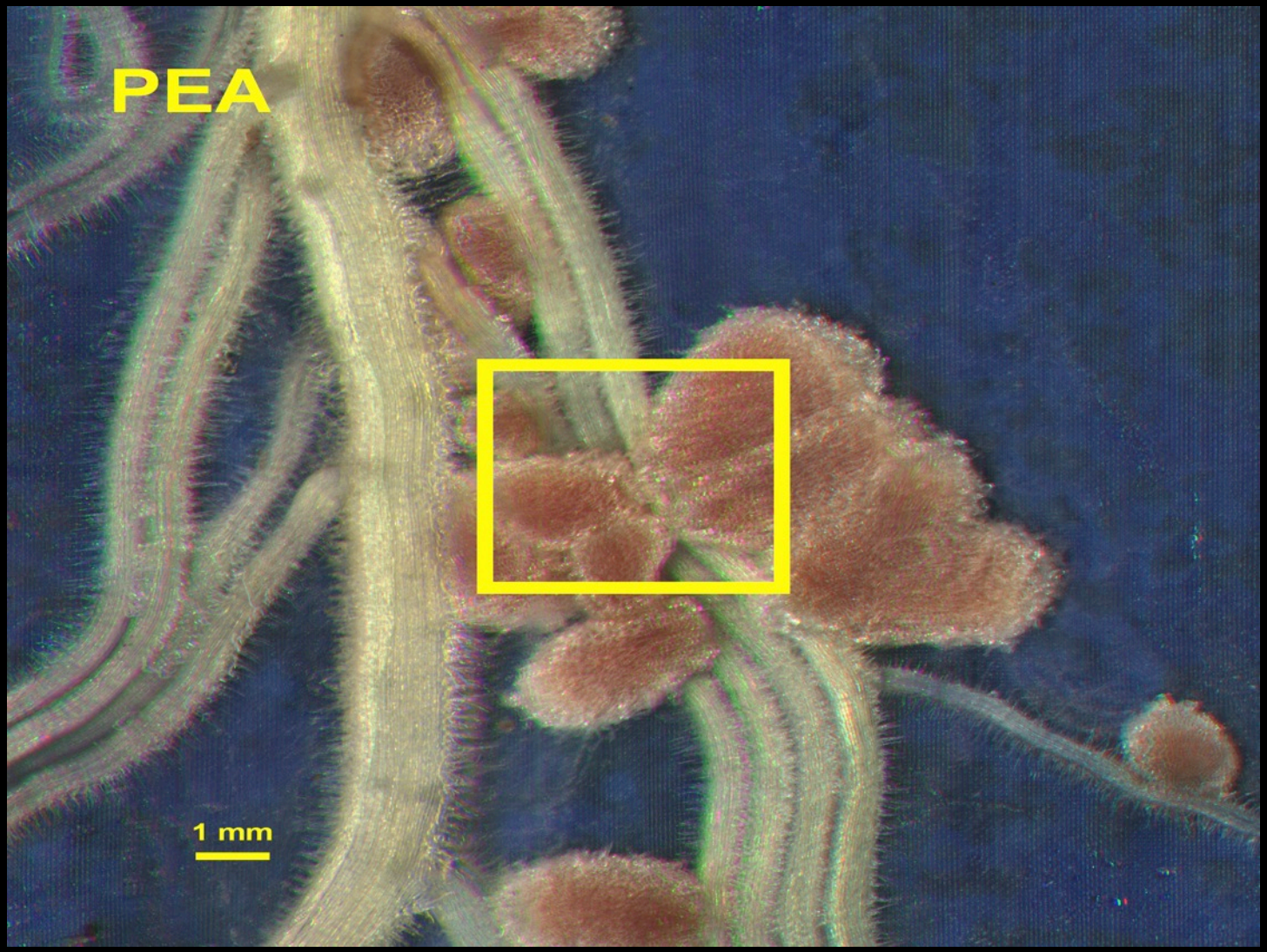
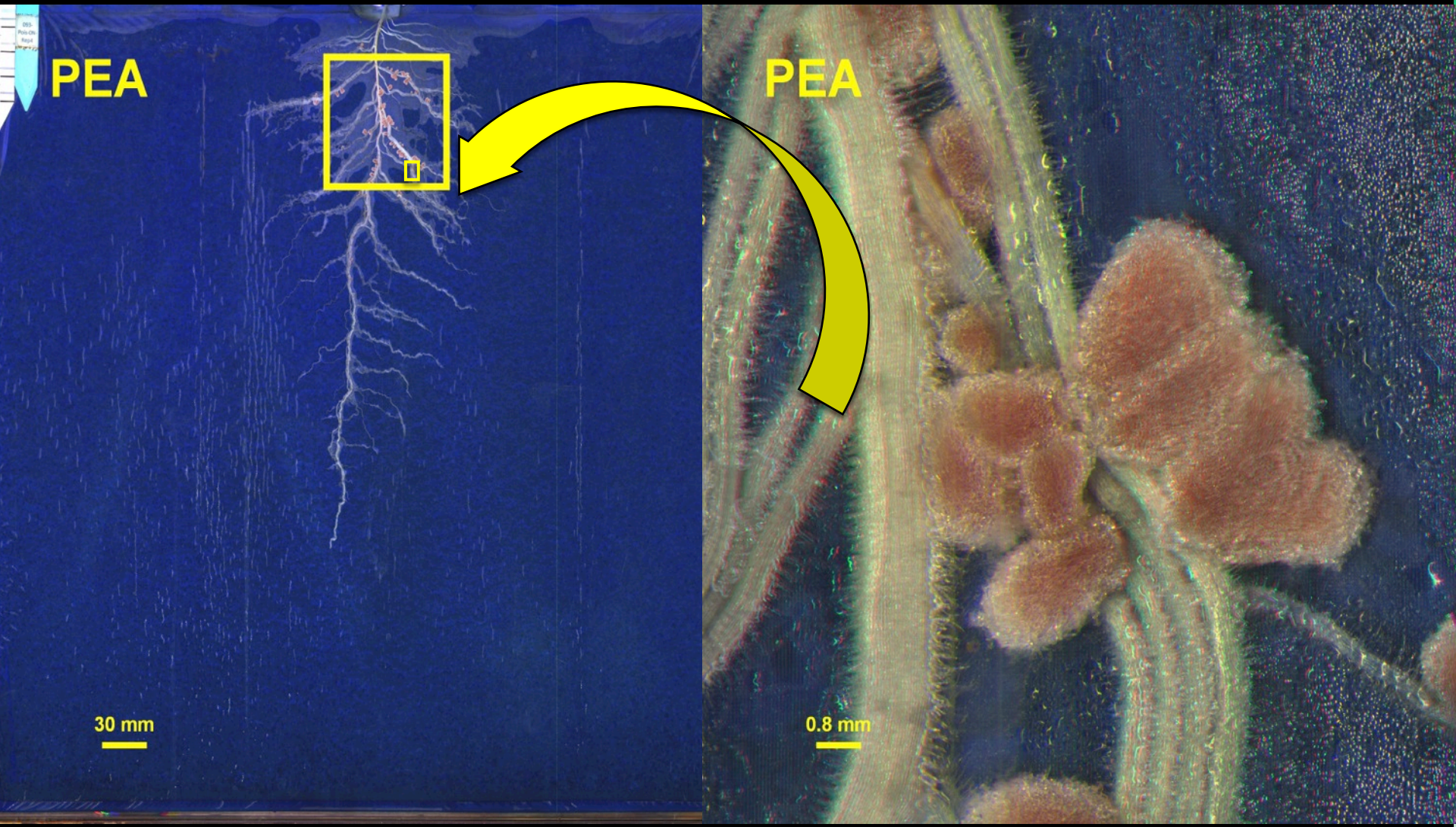


High Resolution RhizoCab



High Resolution RhizoCab

High Resolution RhizoCab



High Throughput RhizoCab

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InoviaFlow

INRA
SCIENCE & IMPACT

SHAKTI

World wide distribution

Phenoware

Qubit SYSTEMS

PhenoTrait

Trademark

Rhizo

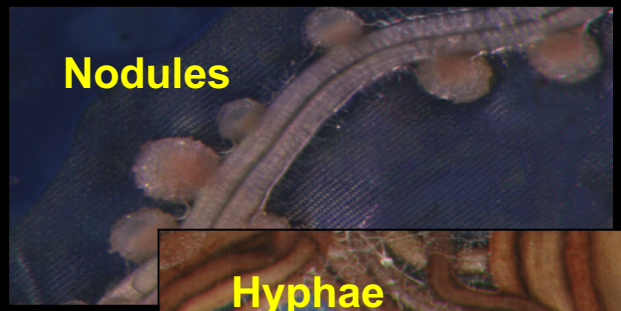
Rhizo tubes

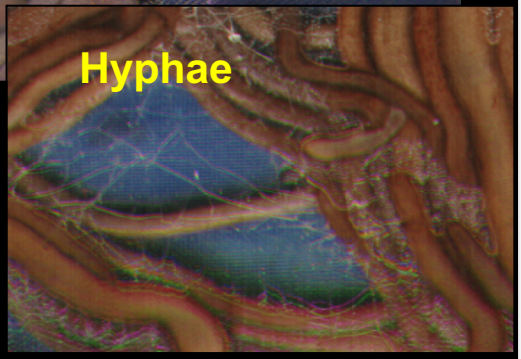
Rhizo cab

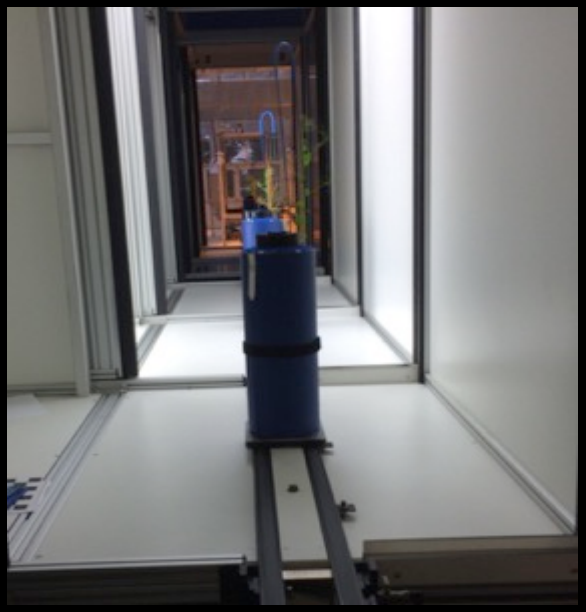
RhizoCabs : summary

RhizoCab HR

Medium throughput:
100 RT/Day, 5-60s/day/WL
Very high resolution (7 µm)

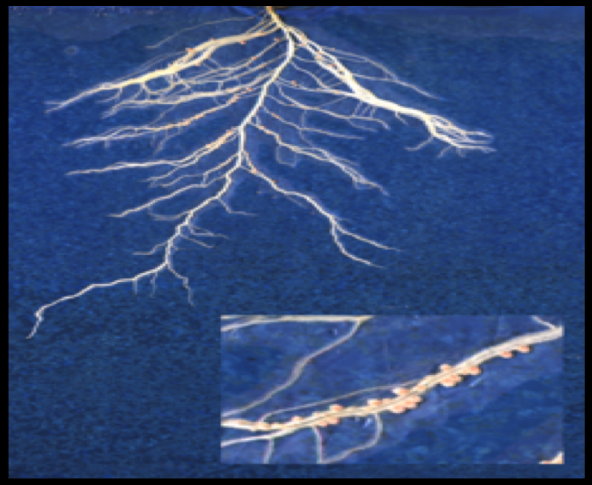




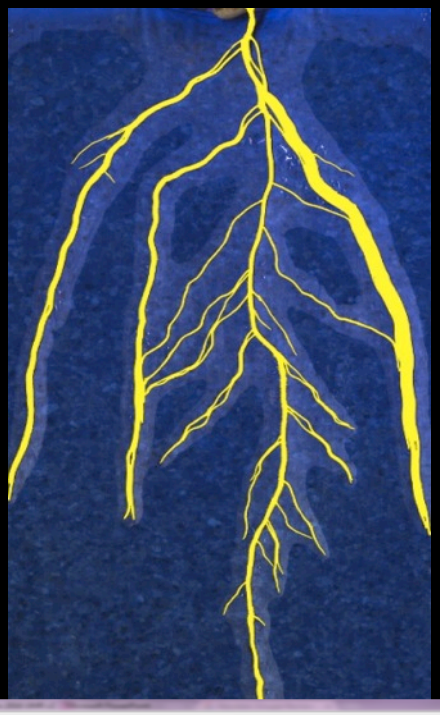


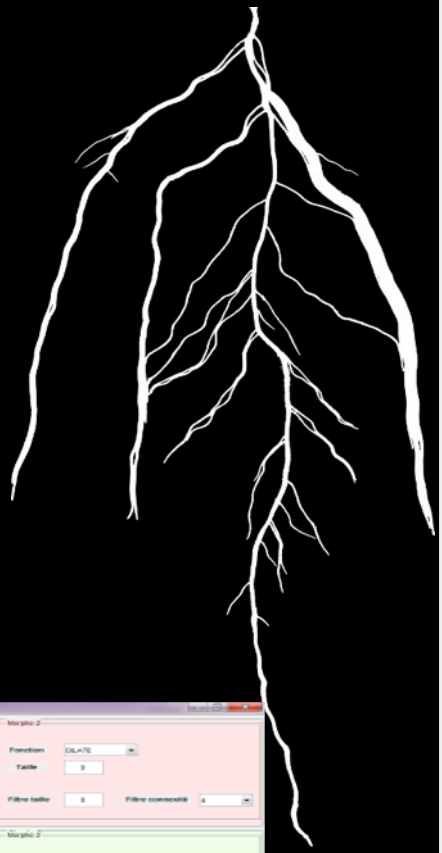
RhizoCab HT

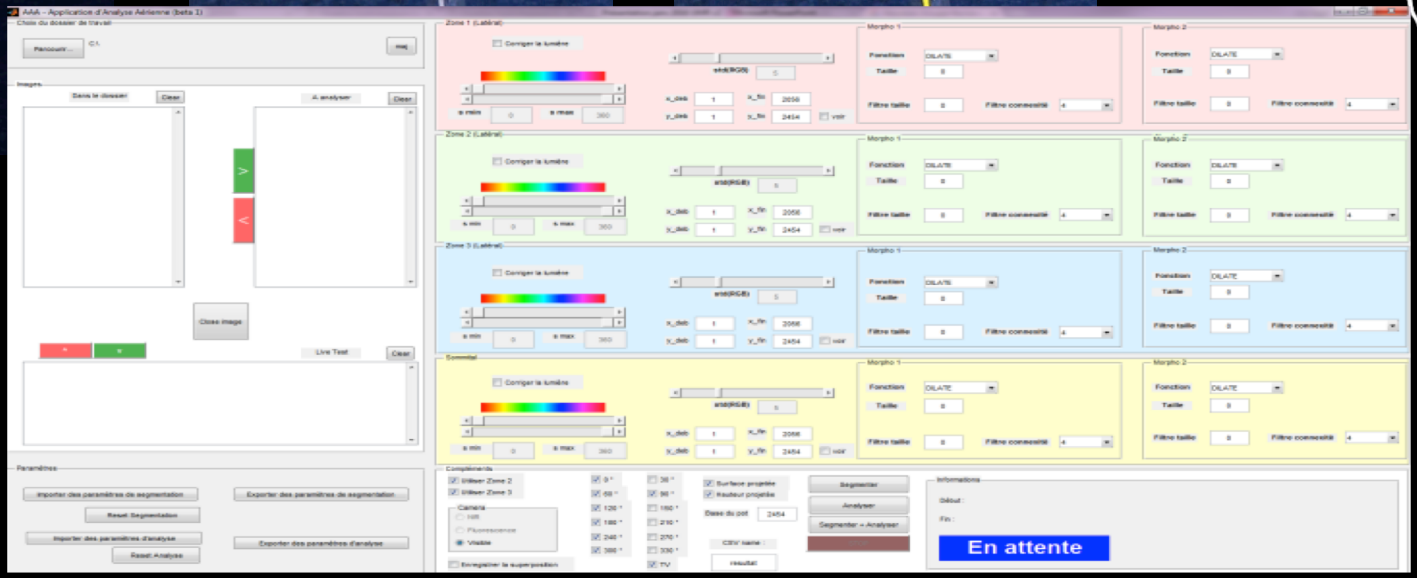
High throughput:
1000 RT/day, 5s/RT/WL
Medium resolution (42 µm)

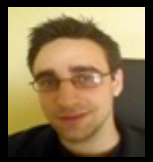


Segmentation software



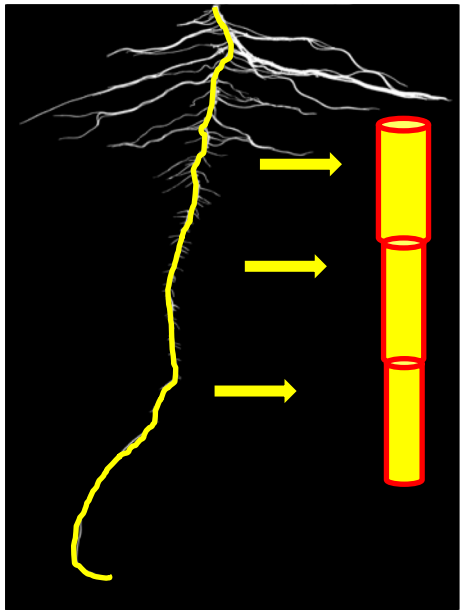


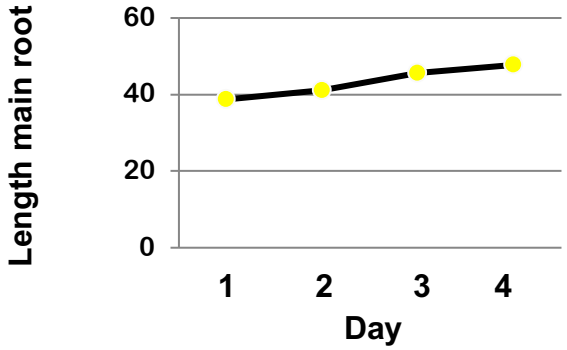


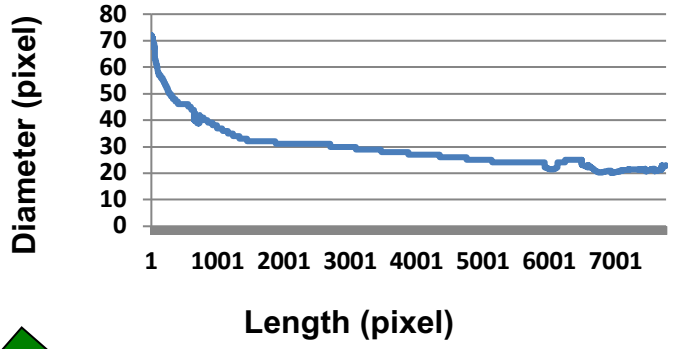


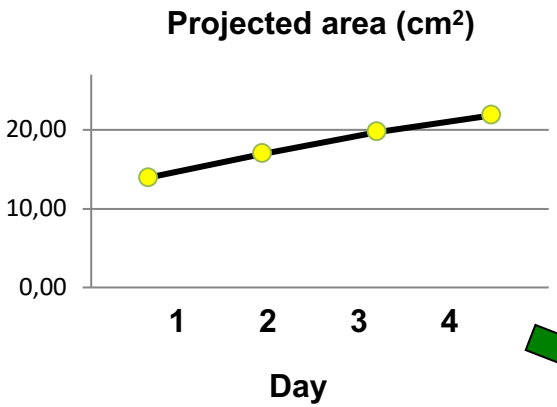
M. Lamboeuf

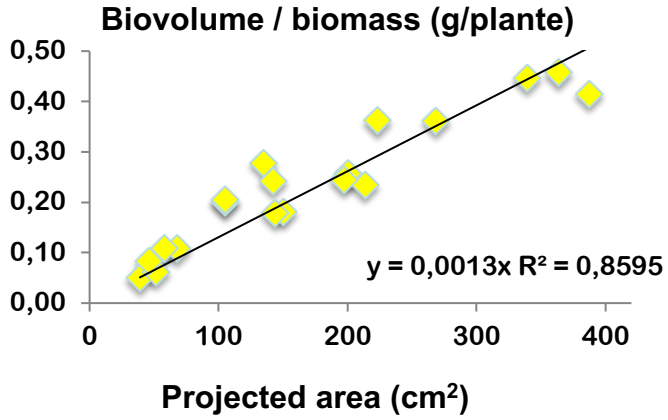
Roots: Length, diameter **=> projected area => biovolume**







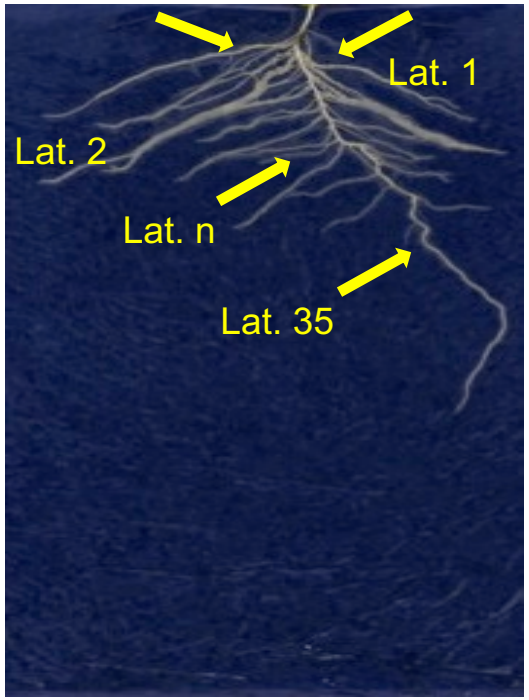


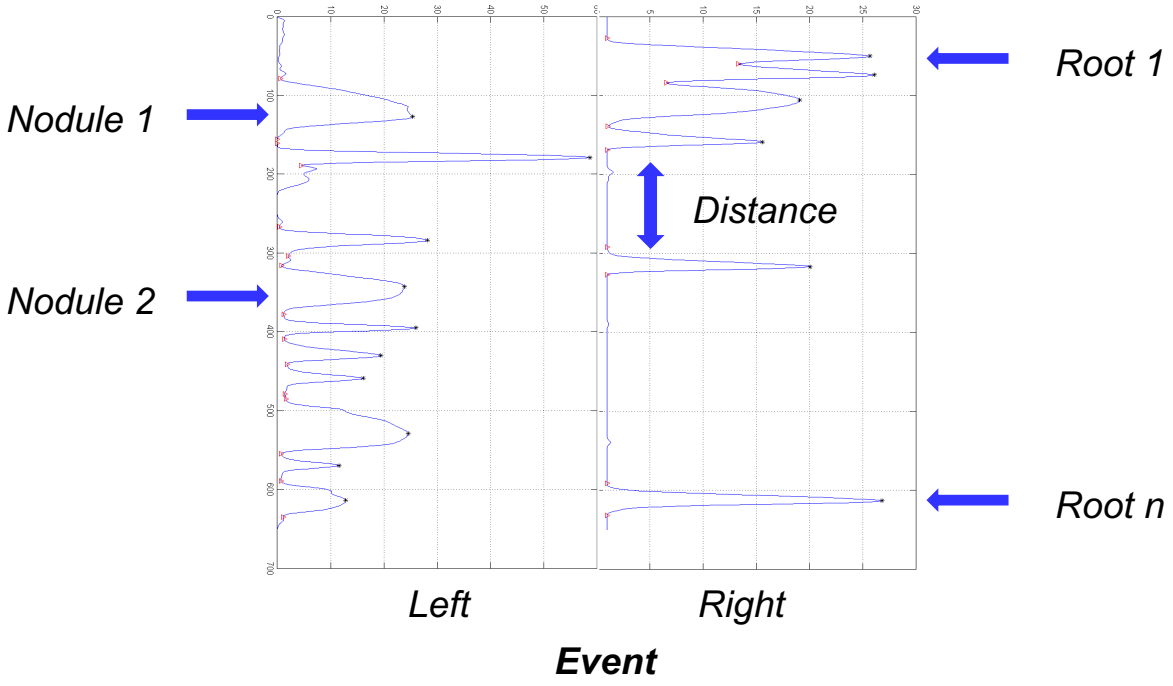


Dynamic trait characterization

Han et al, Machine Vision 2017

Roots, detect events: lateral roots and nodules detection

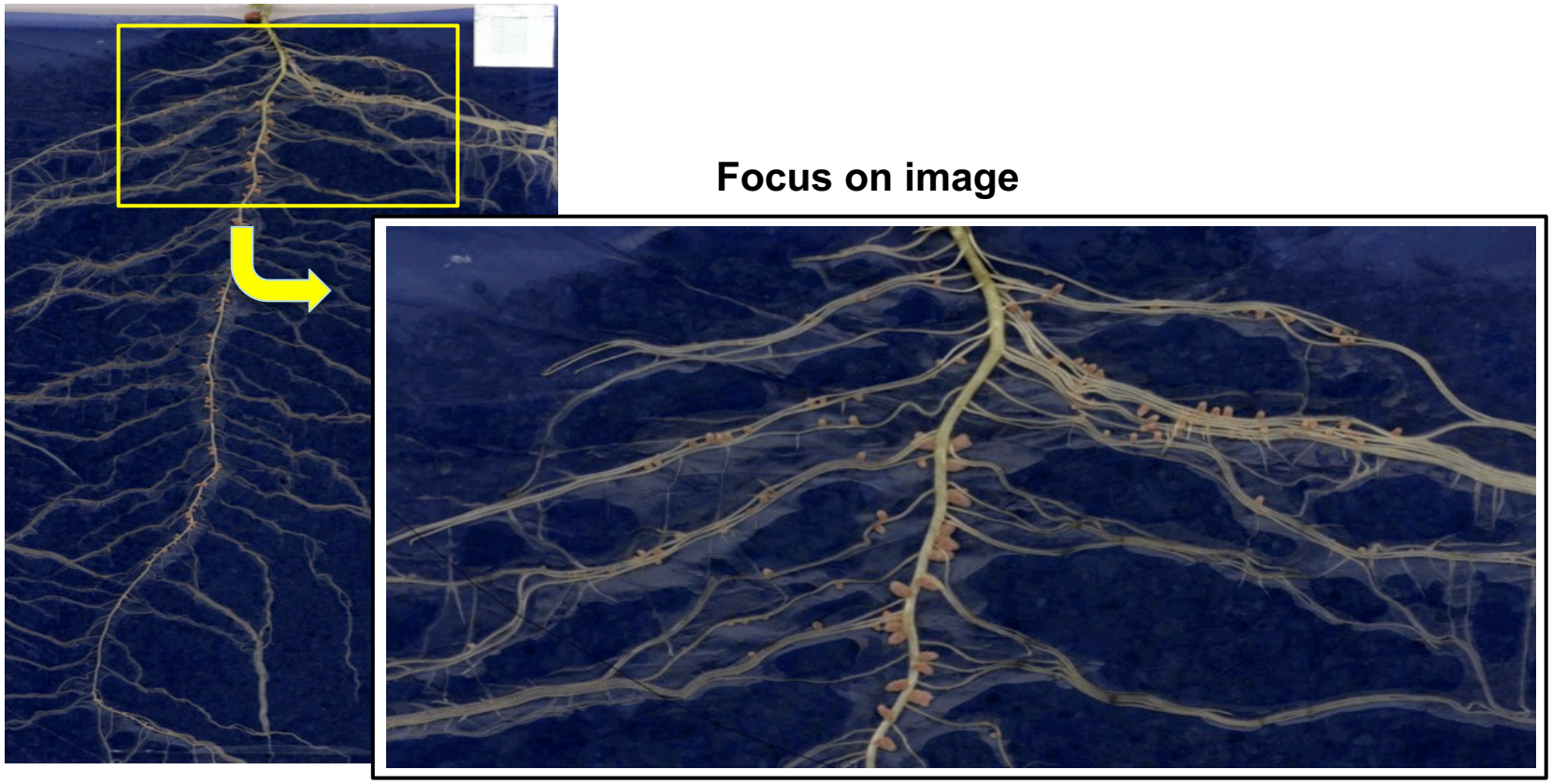


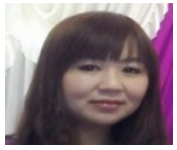


Nodules and lateral roots detection

Han et al, Machine Vision 2017

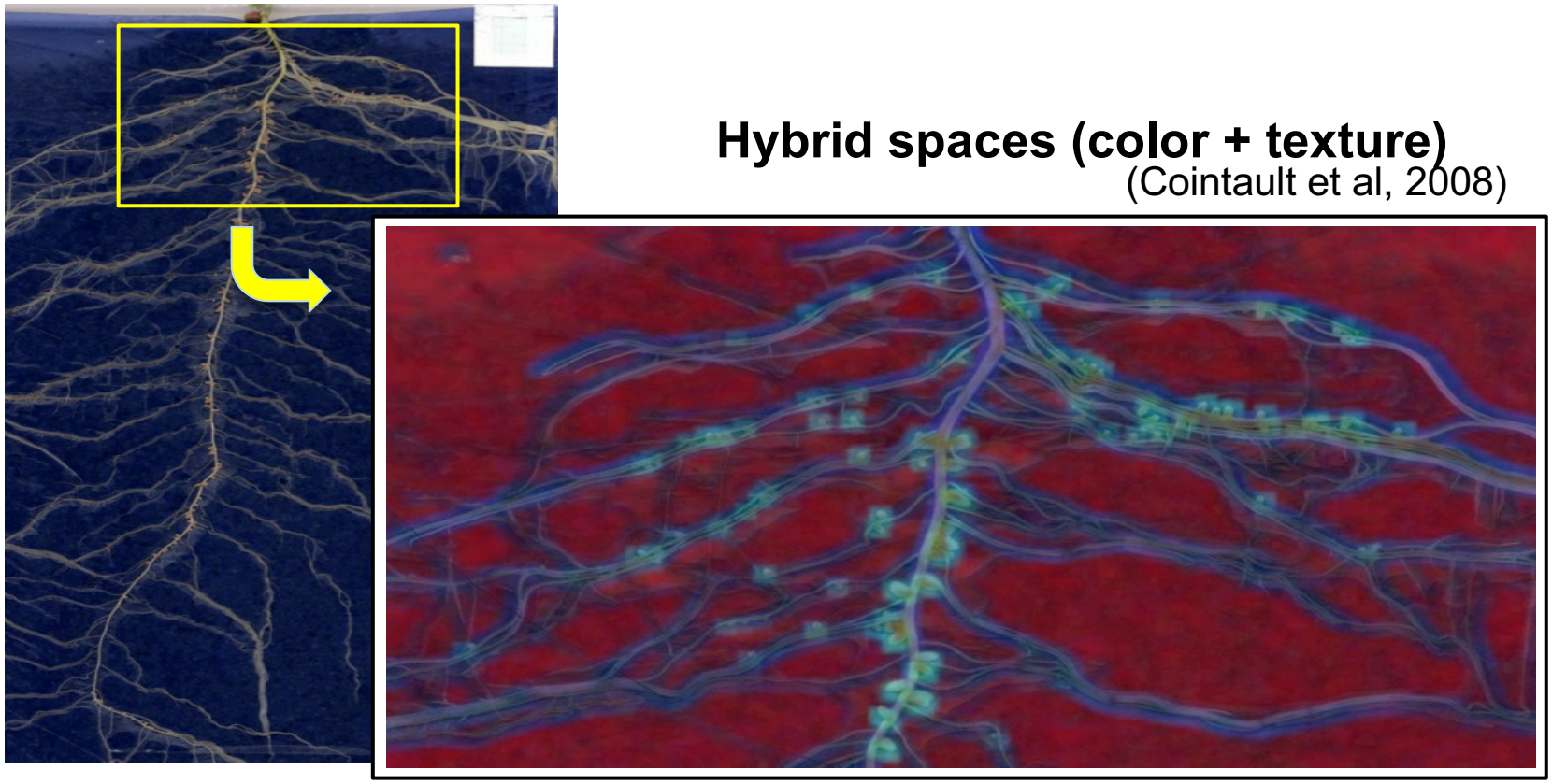
Nodules: Number, projected surface, position, color





Han et al, Machine Vision 2017

Nodules: Number, projected surface, position, color



Hybrid spaces (color + texture)
(Cointault et al, 2008)

Han et al, Machine Vision 2017

Nodules: Number, projected surface, position, color

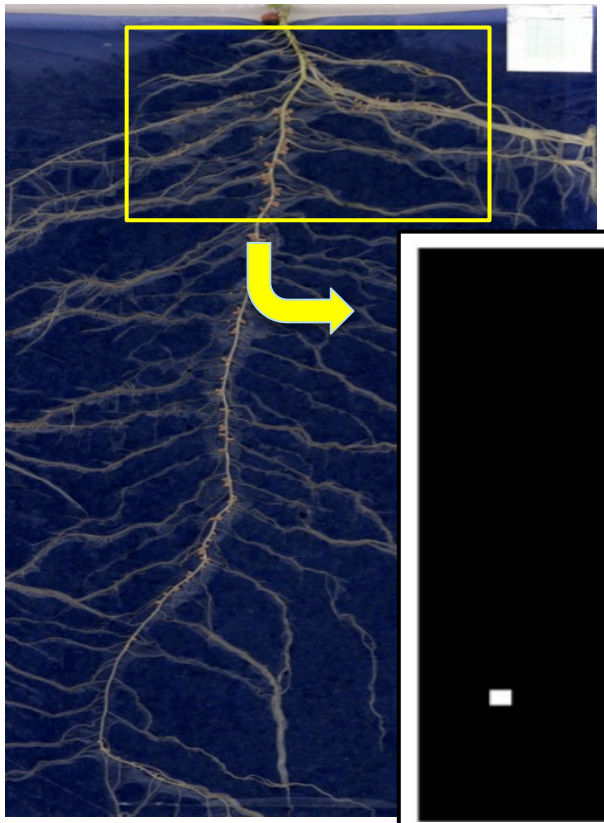
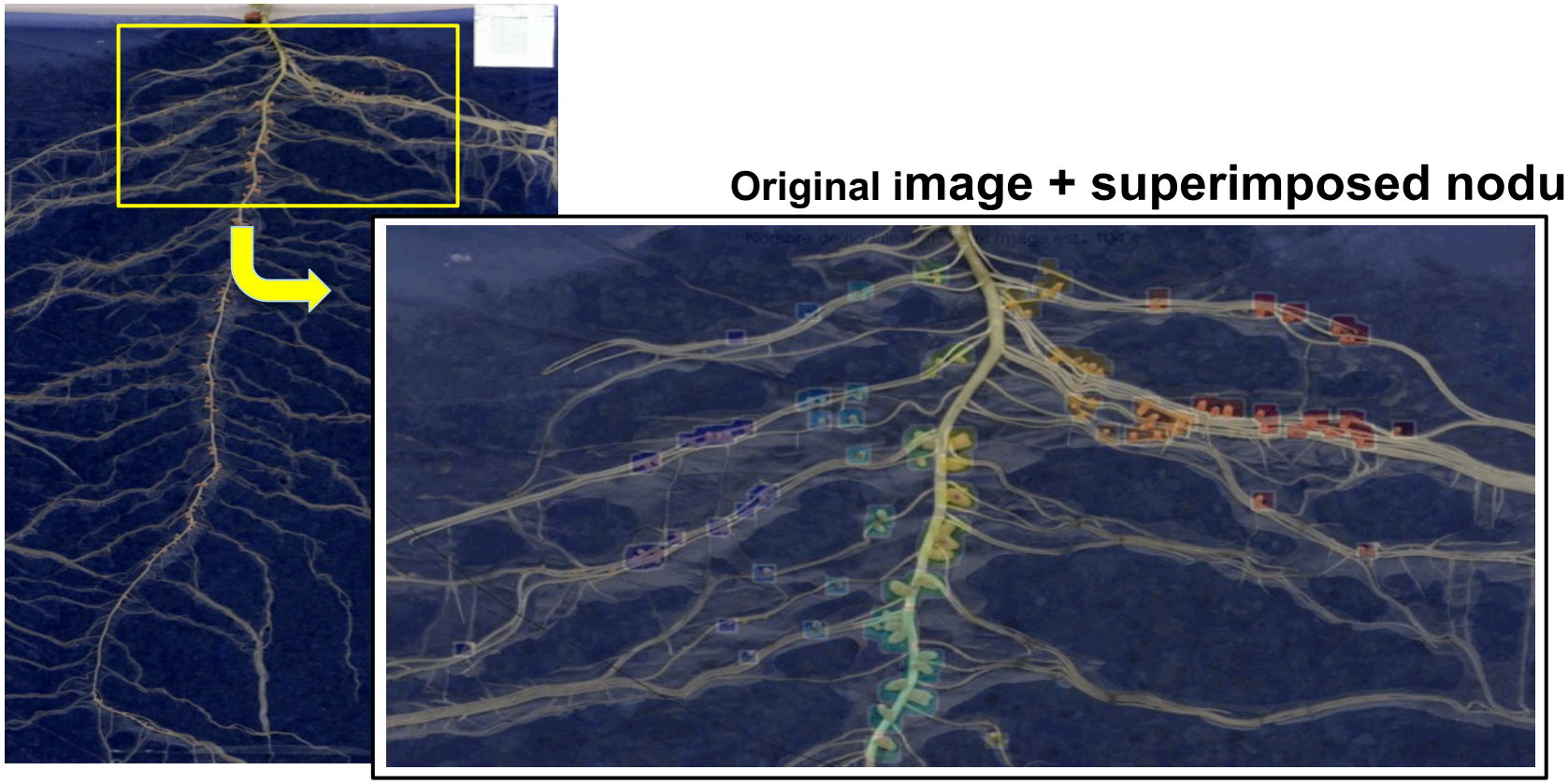


Image with nodules

Han et al, Machine Vision 2017

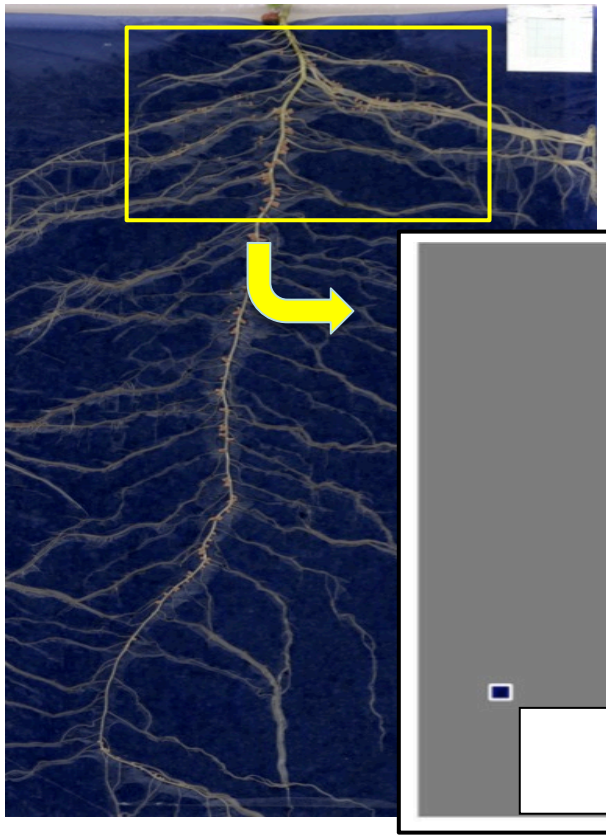
Nodules: Number, projected surface, position, color



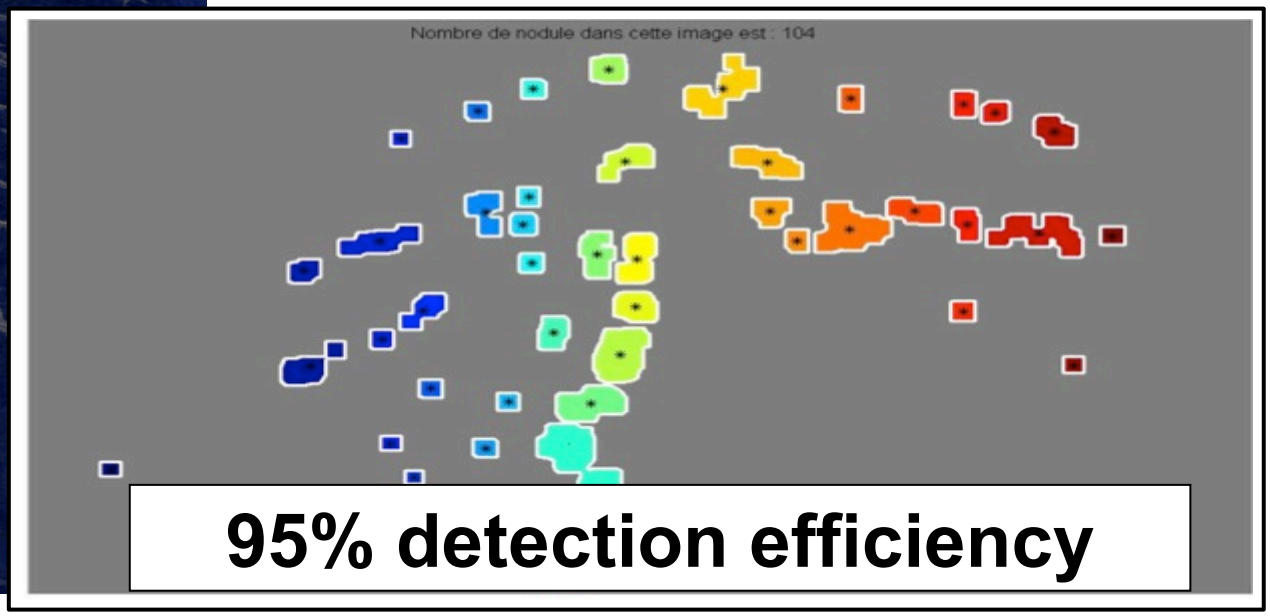
Original image + superimposed nodules

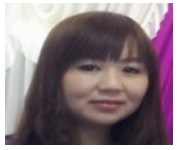
Han et al, Machine Vision 2017

Nodules: Number, projected surface, position, color



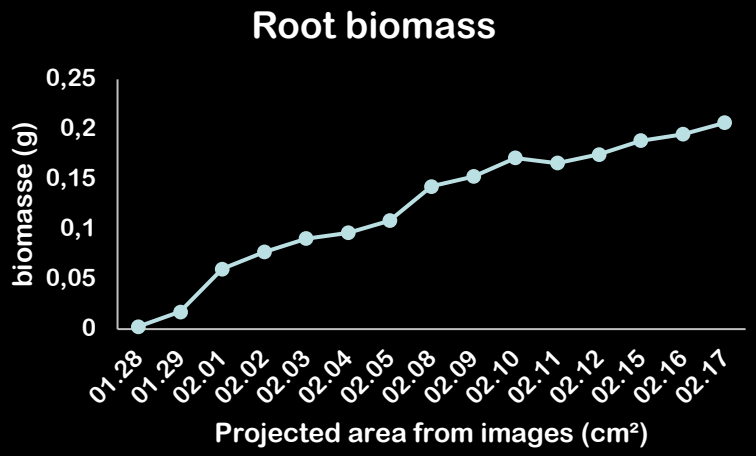
Nodules detected

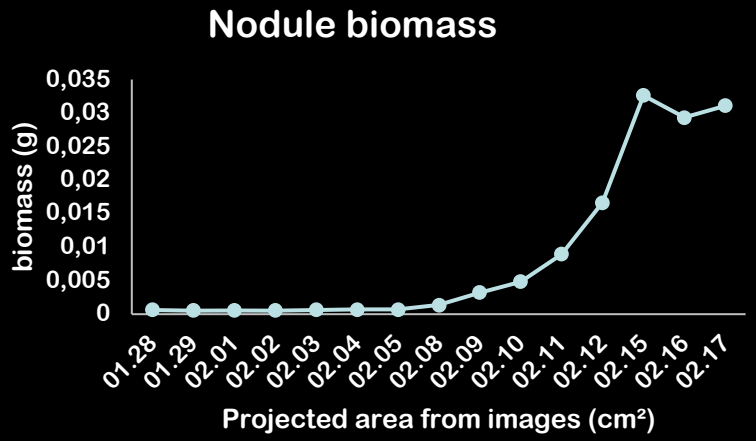


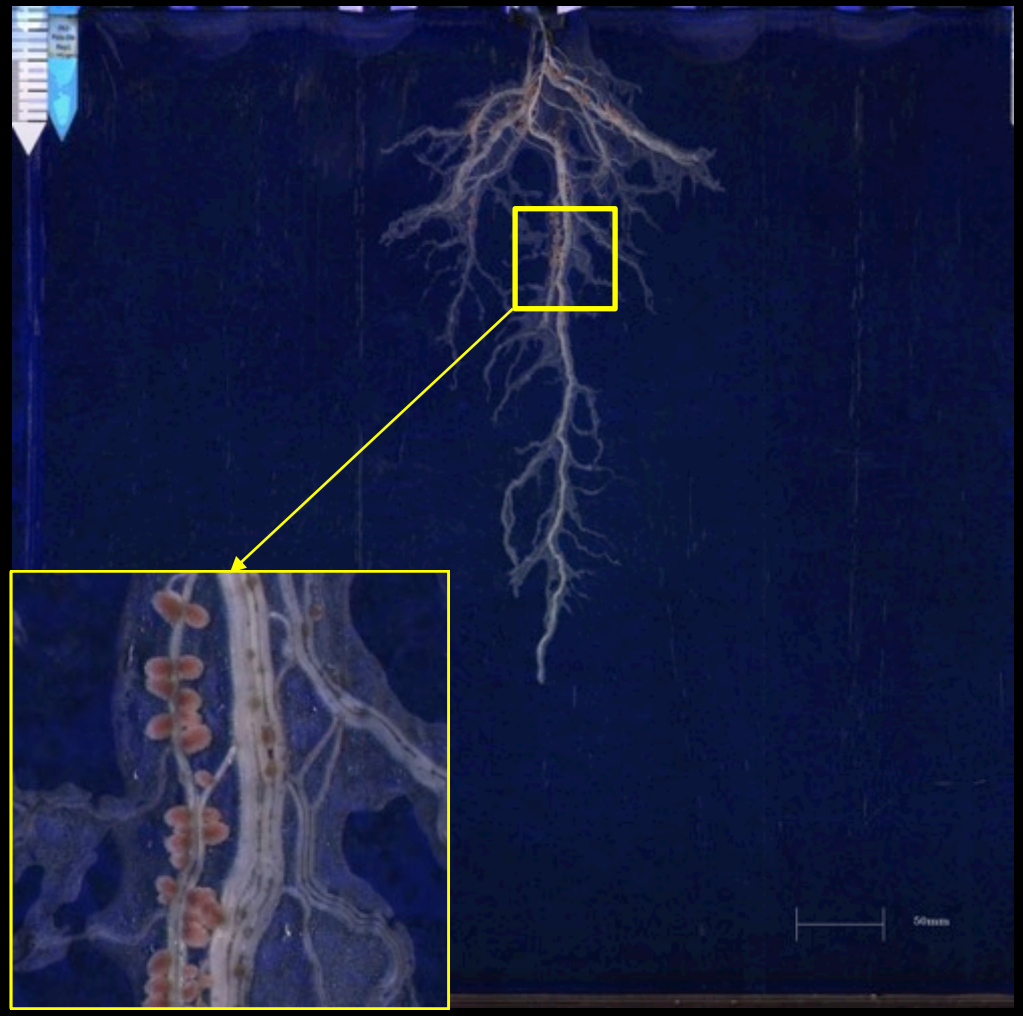


Han et al, Machine Vision 2017

A simple example: root and nodule dynamics

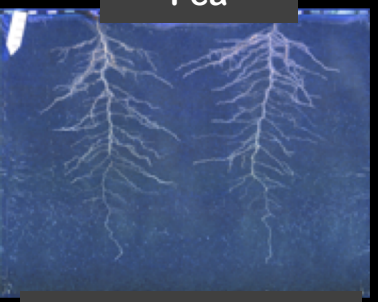




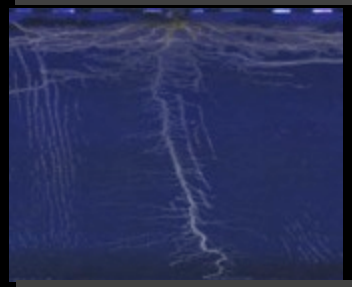


Which species?

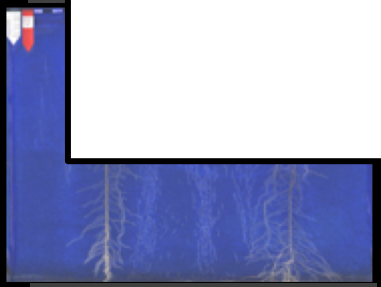
Pea



Vesce Commune

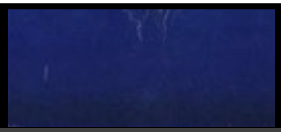


Tomato



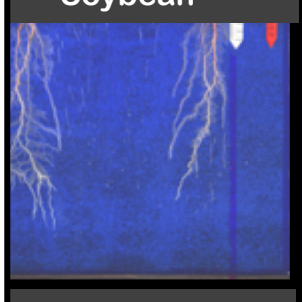
Wheat

Medicago



Brachypodium

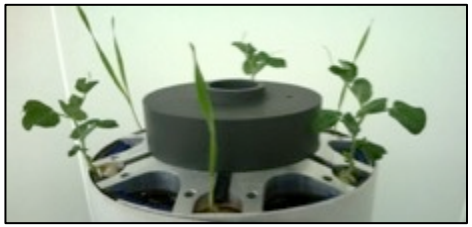
Soybean



Maize

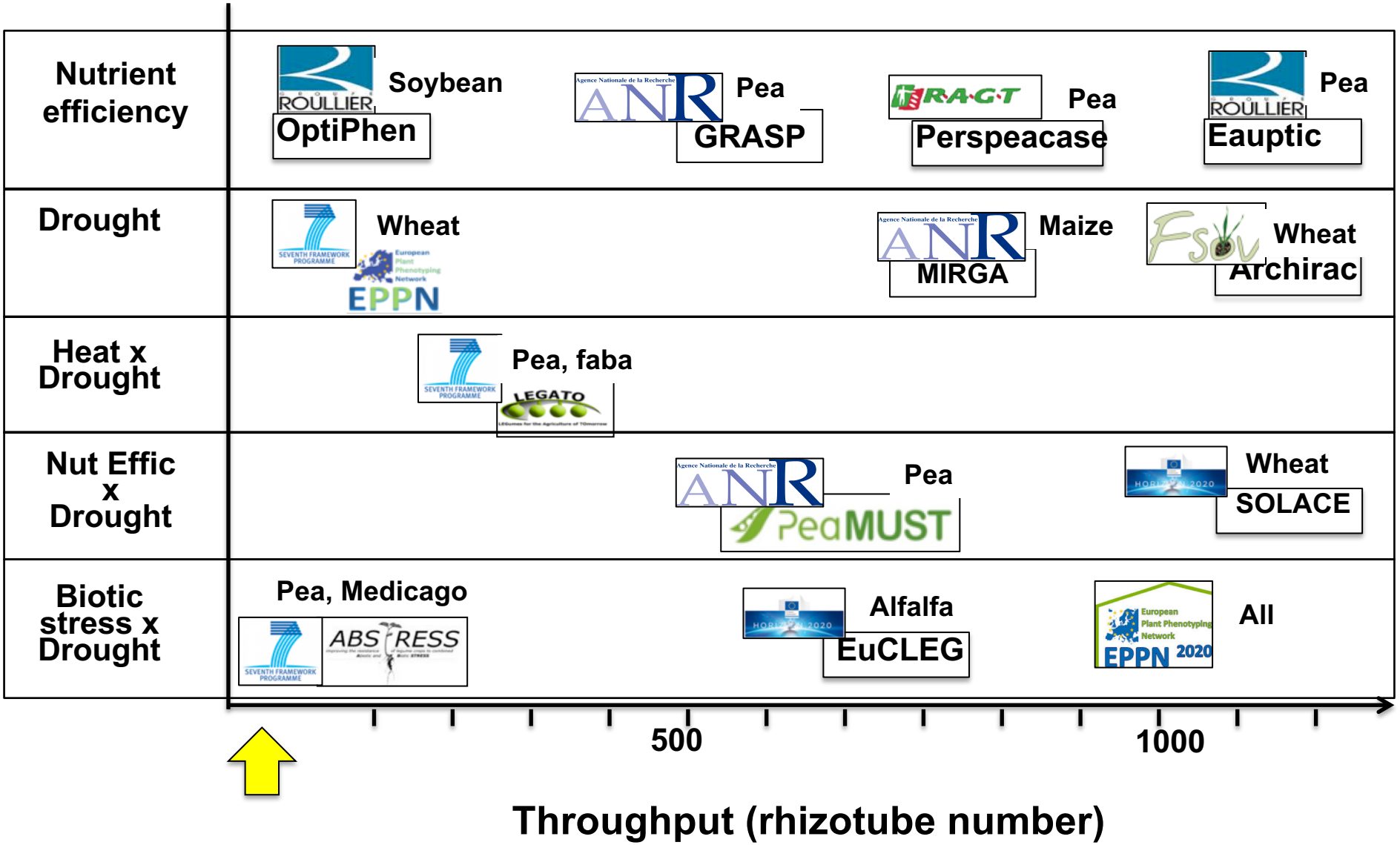
Grape

Alone…



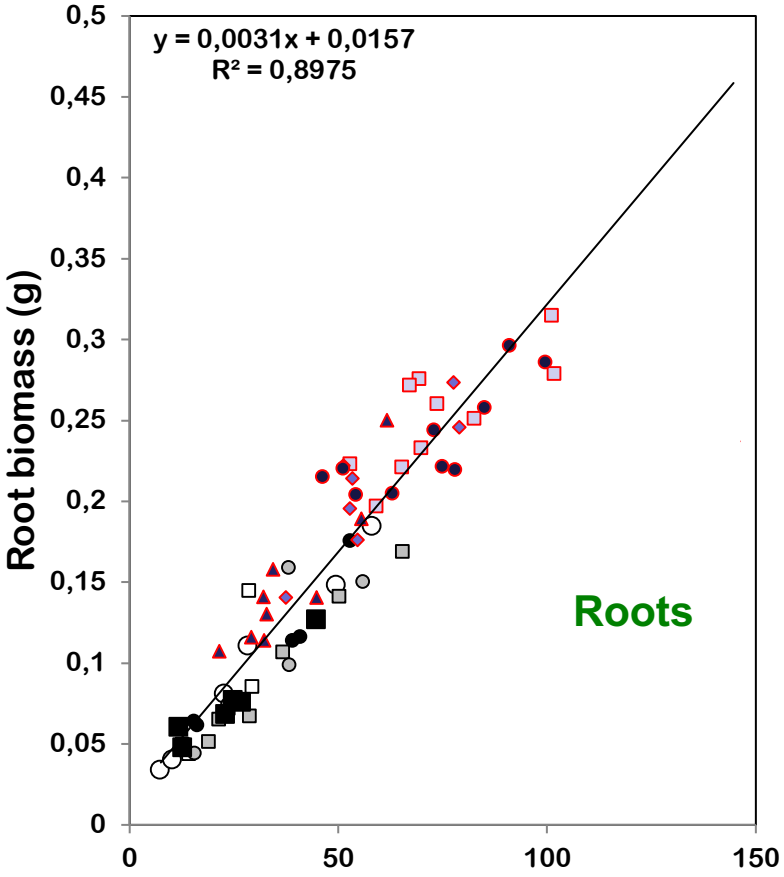
… or in association

Increasing throughput...

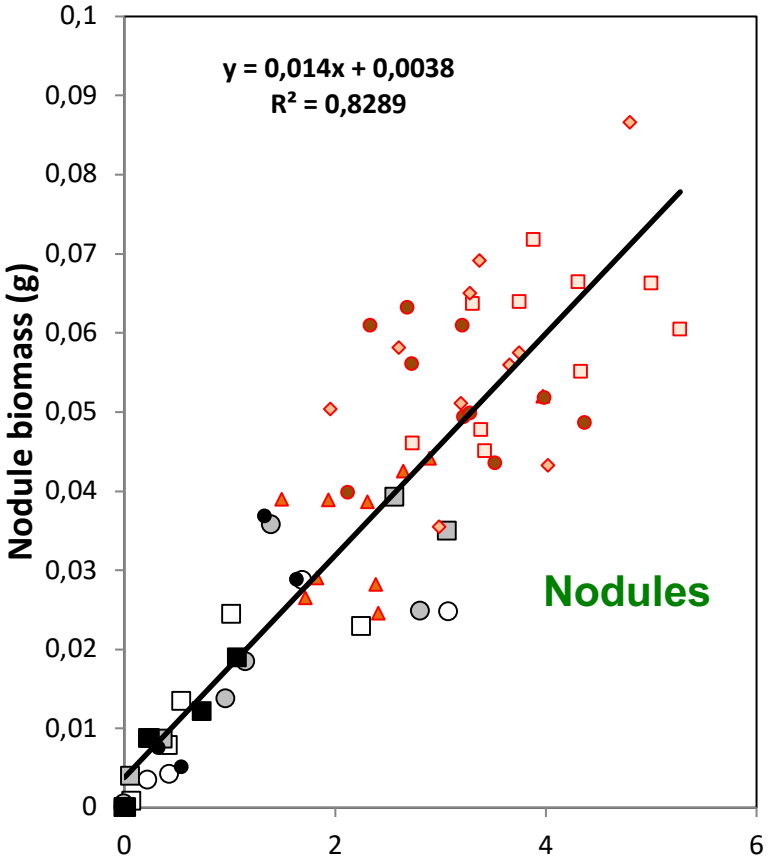


Some results: Pea

Genotypes with contrasted architectures: pea



Spencer
Kayane
Safran
James
Myster
Balltrap
Geronim
Dexter
Isard



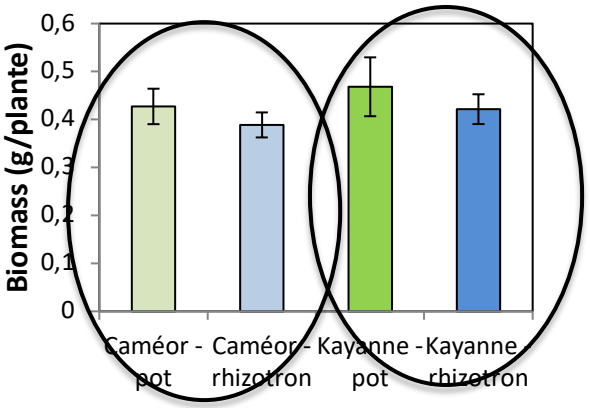
Bourrion & Prudent, unpublished

RhizoTubes vs Pots ?

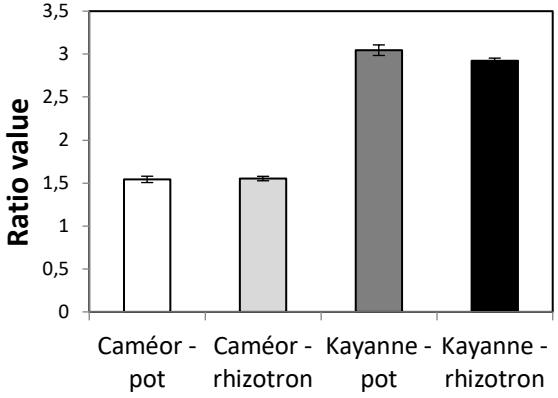
Similar traits in pots and RhizoTubes: pea

C. Jeudy

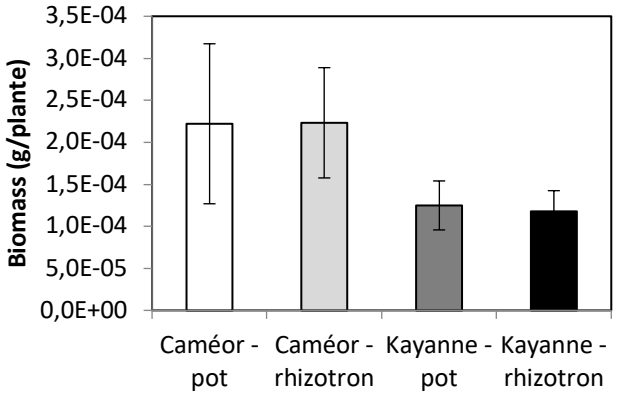
Plant biomass



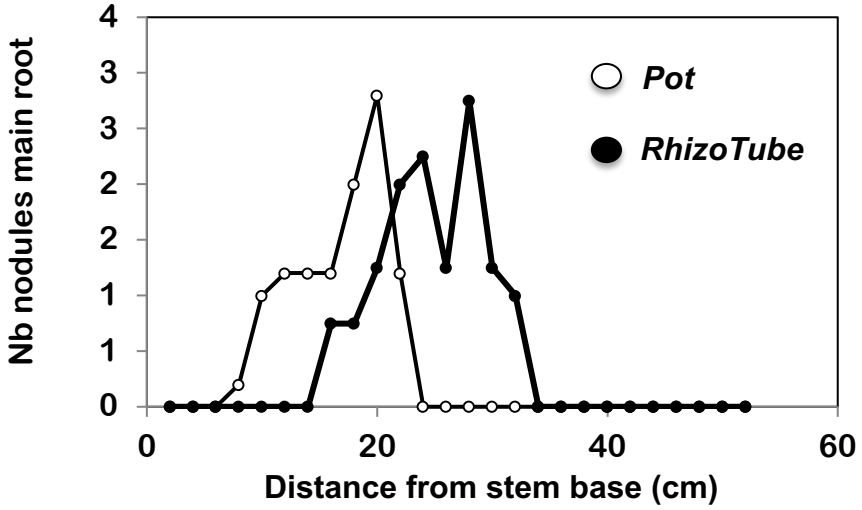
Shoot/root biomass

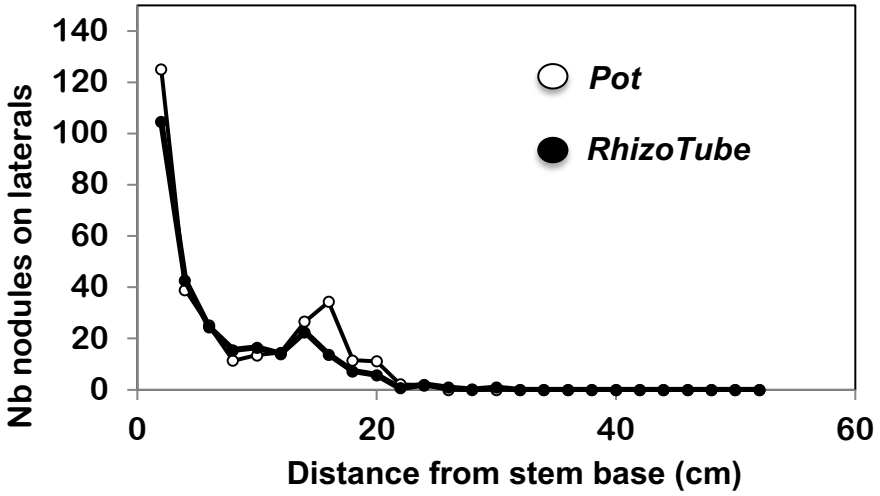


Mean nodule biomass



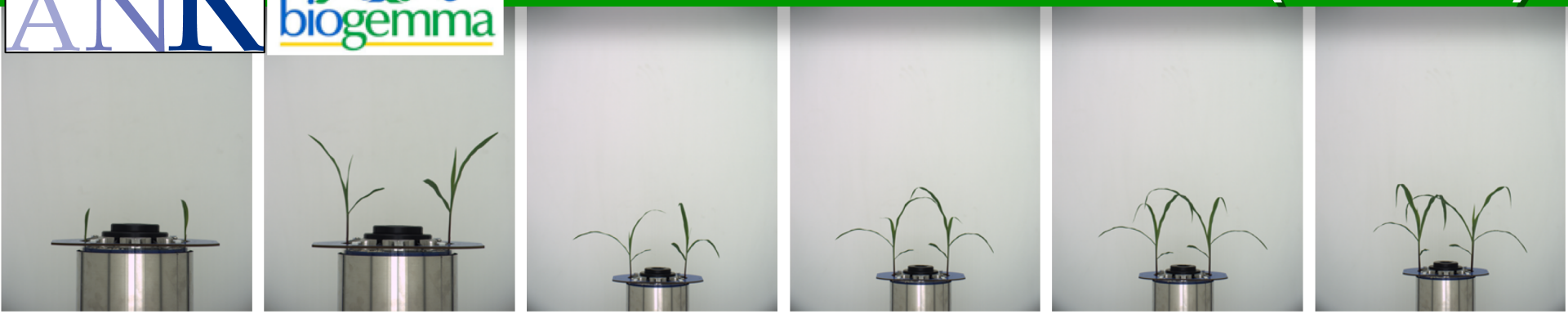
Same distribution profile!





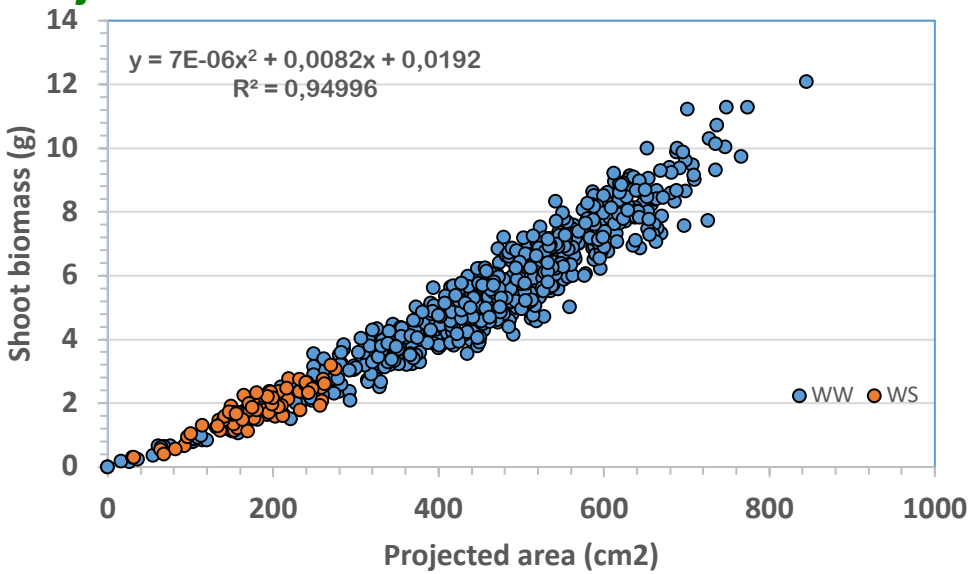
Jeudy et al, Plant Methods 2016

Some results: Maize (MIRGA)

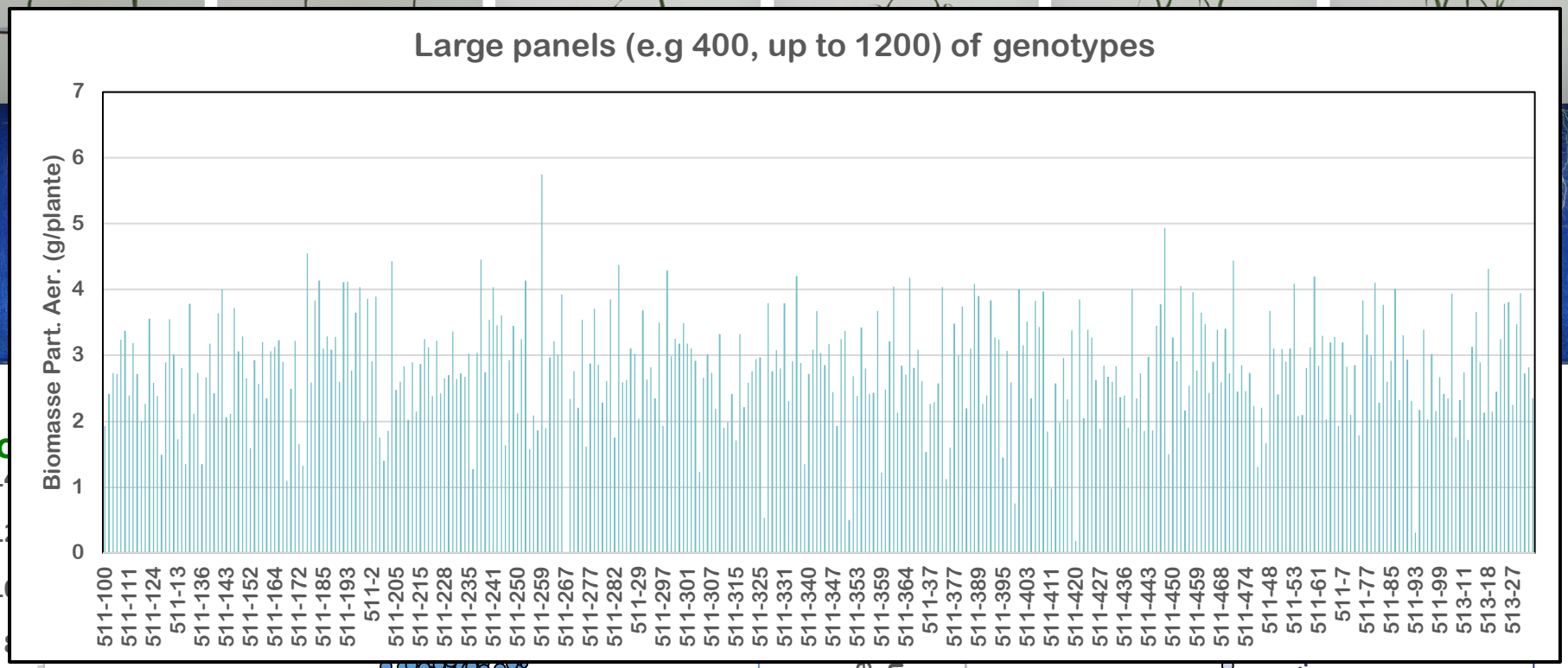


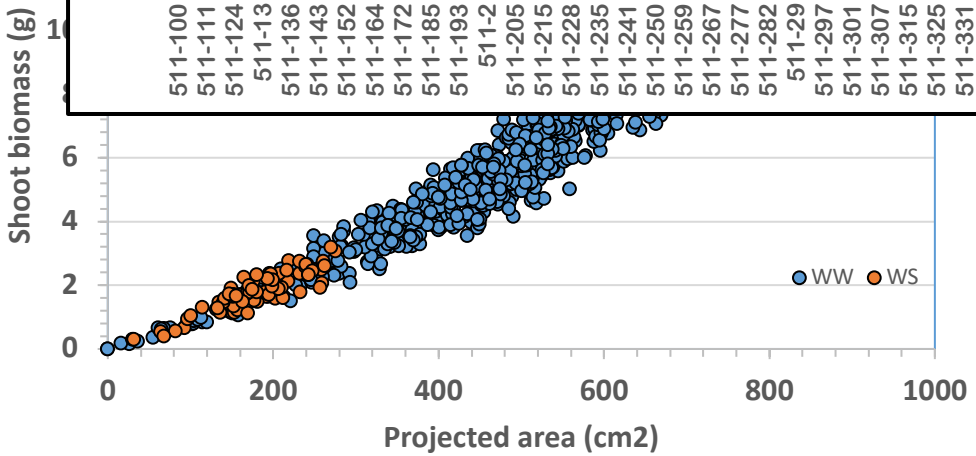
18th June | 20th June | 22nd June | 23rd June | 24th June | 25th June

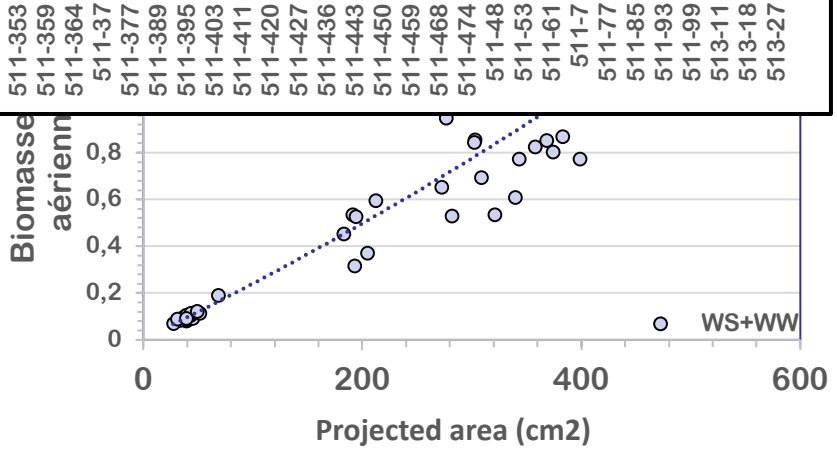
Projected area vs shoot biomass



Some results: Maize (MIRGA)







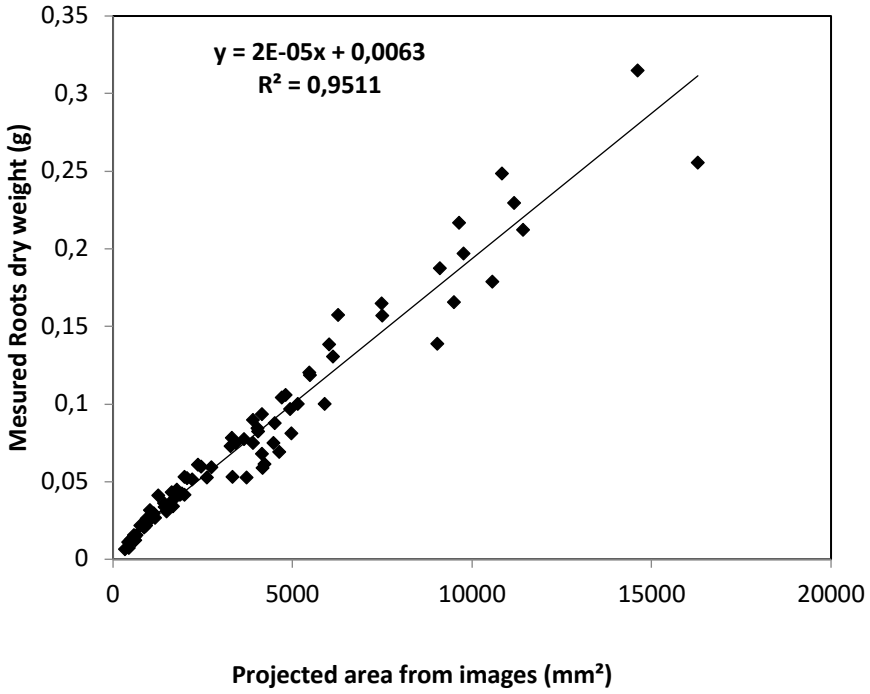
Some results: Maize (EPPN)

Projected area vs root biomass and length: wheat

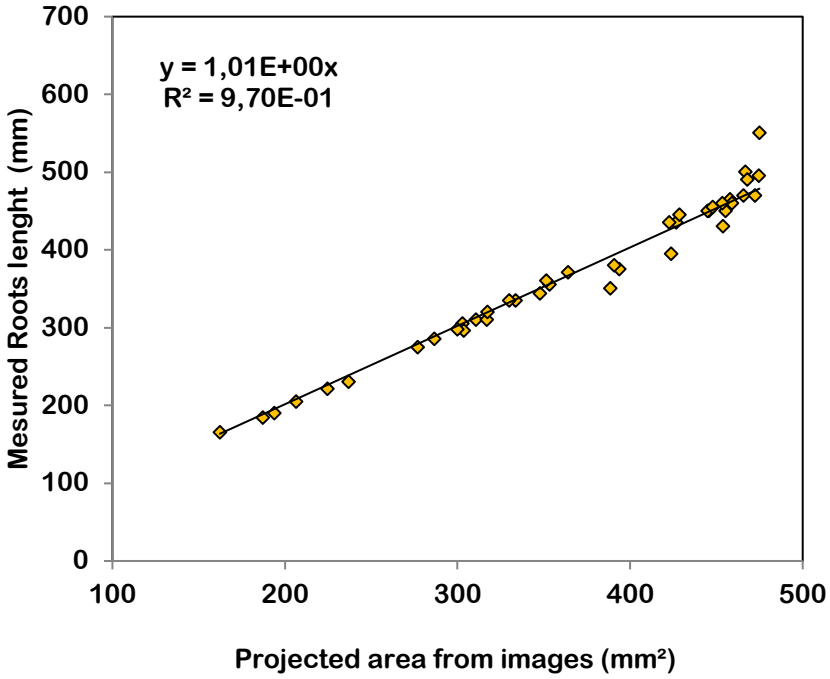
EPPN Project, Josh Klein AARO Volcani Israel

Josh Klein

Root dry matter



Root length



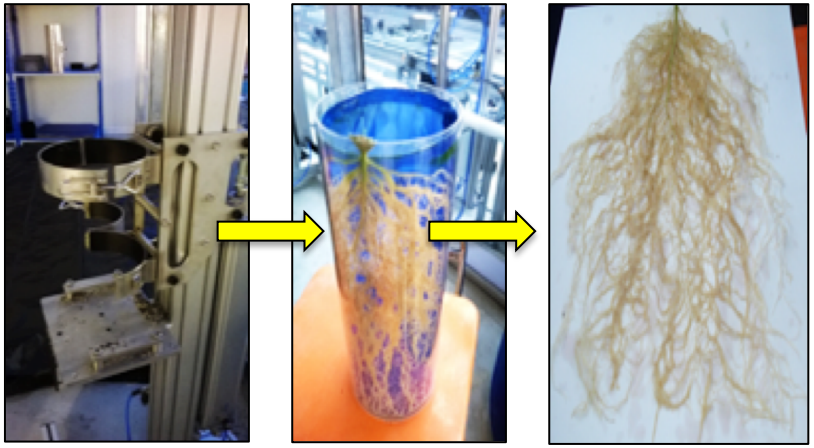
Christmas wishes…and what you'll get under the tree

Automatic trait quantification	Done	Nearly done	… soon
Root projected area	X		
Total root length	X		
Root convex hull	X		
Root exploration dynamics (H and V)	X		
Root density		X	
Root number (incl. typology)		X	
Root angle		X	
Root diameter		X	
Nodule projected area	X		
Nodule number (inc.typology)	X		
Nodule biovolume (inc. classes)		X	
Nodule number, position on each root			X
Nodule efficiency			X
Mycorhizes, hyphae		X	
Germination checkup	X		

Upstream and dowstream

Mounting

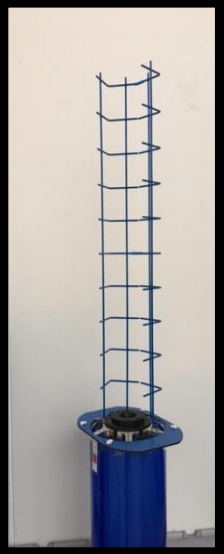
Empoting



Fast root recuperation
(allows ‘omics)

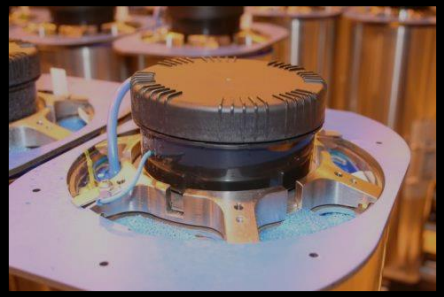
Others

Germination chamber



Tutors

Tram Hydroponic RhizoTubes



Buubling pump

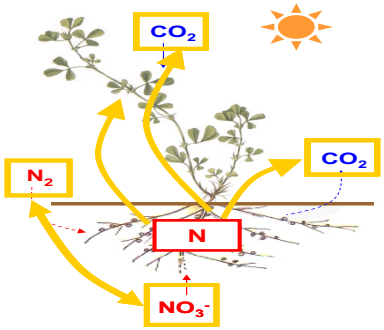
Energy base

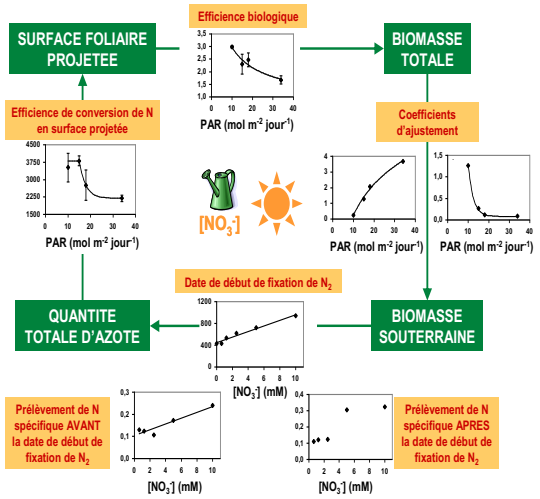
Food for thoughts…

Combine approaches

Phenotyping Approach + **Analytical approach** + **Models**

(e.g. fluxomics)





Identifying differences among genotypes

Interpreting the detected difference

Salon et al, Journal Exp Bot 2017

That's my last slide !!! Happy ?

The Group…

C Bernard

C Jeudy

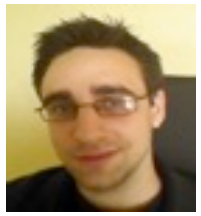
J Martinet

K Palavioux

S Han

JC Simon

F Cointault



M Lamboeuf

C Baussard

The GEAPSI Group…