Phenotyping for resource use efficiency traits from the lab to the field: traits and technologies

Fabio Fiorani

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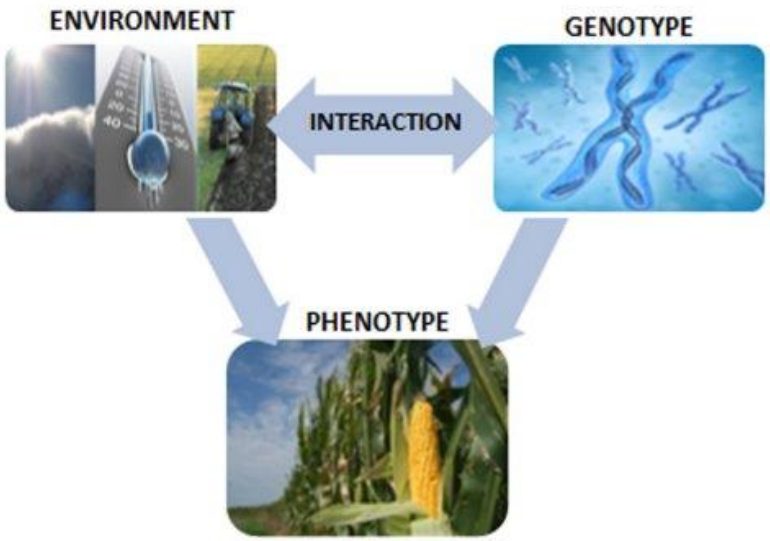
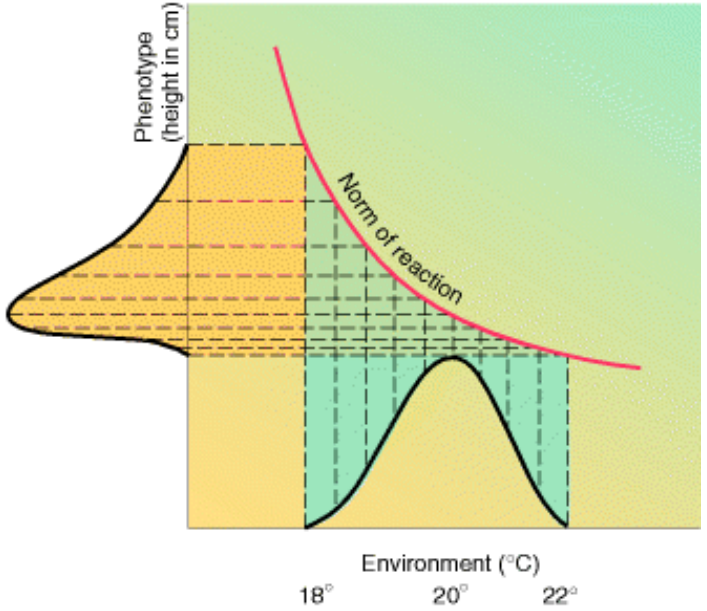
Phenotypes are quantitative and multi-dimensional

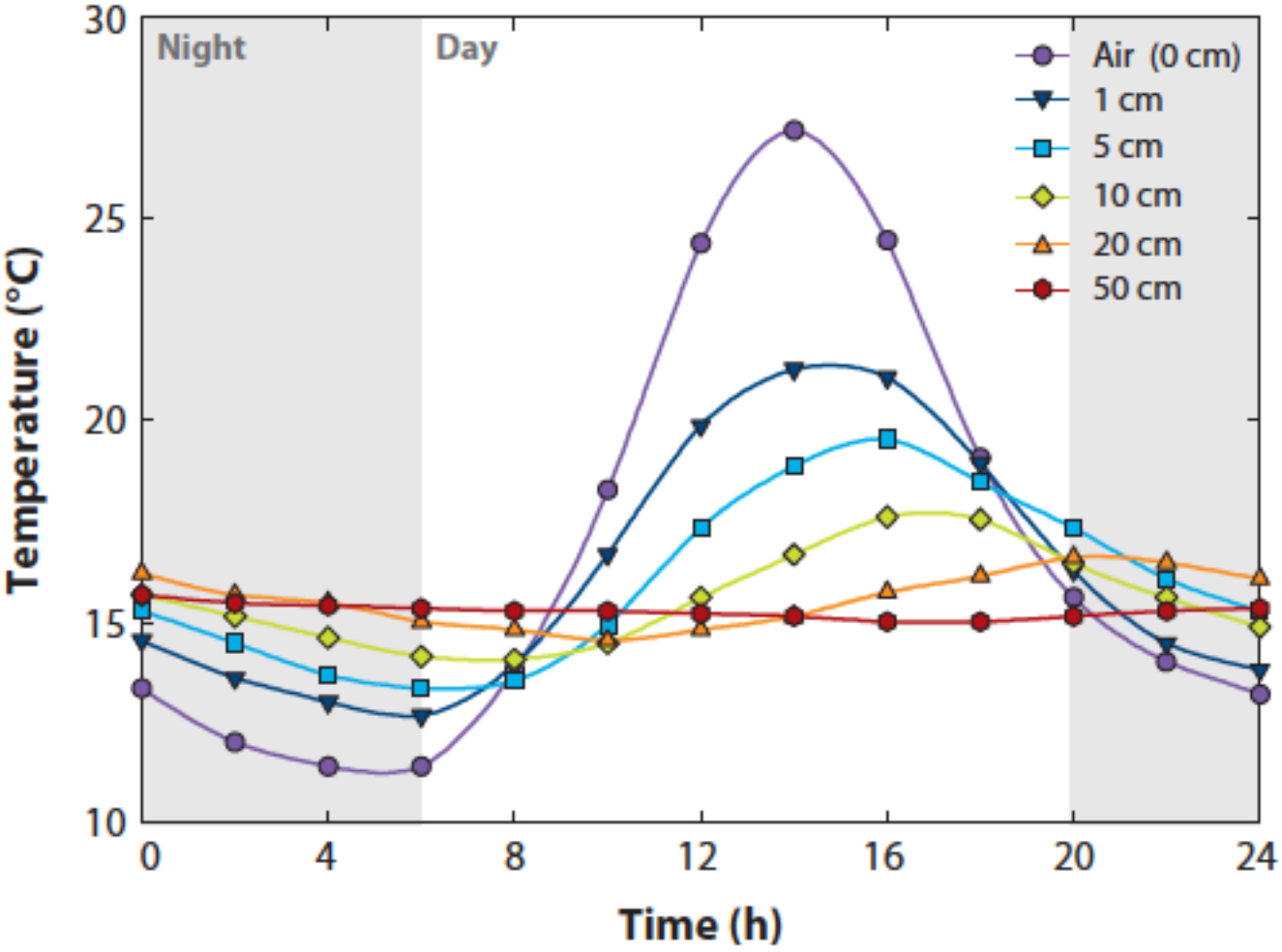




Griffiths et al. An Introduction to genetic analysis

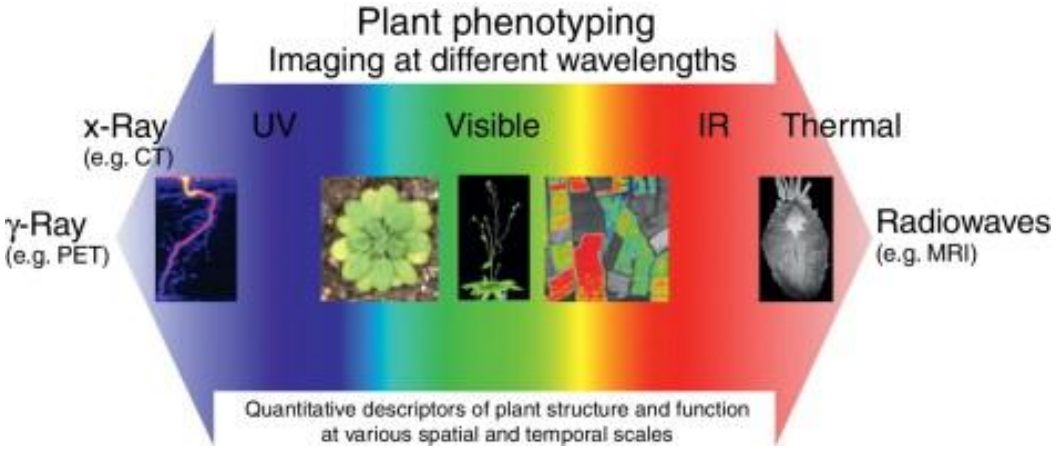
STUDYING PHENOTYPIC PLASTICITY TO THE ENVIRONMENT IS KEY TO UNRAVEL GENE-PHENE RELATIONSHIPS

Environmental factors vary in space and time



Walter et al., Annual Review Plant Biology, 2009

Non-invasive technologies are crucial to partly address the phenotyping bottleneck



QUANTITATIVE DESCRIPTORS OF PLANT STRUCTURE AND FUNCTION AT VARIOUS SPATIAL AND TEMPORAL SCALES

Fiorani, Jahnke, Rascher, Schurr, Curr Op Biotech (2012)

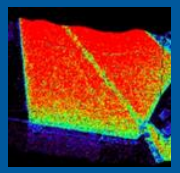
Plant sciences for improved resource use efficiency and optimized biomass

JÜLICH FORSCHUNGSZENTRUM

Biomass quality and alternative resources

Selection and screening of novel traits

Identifying novel traits



Service to plant science community

Next generation infrastructure and technologies

Deutsches Pflanzen Phänotypisierungs-Netzwerk DPPN

Associated partners (beyond Helmholtz)

Biochemistry and molecular biology

ITMC RWTH Technische Chemie

AVT Aachener Verfahrens-Technik

CEPLAS Cluster of Excellence on Plant Sciences

Breeding and agronomy

universitätbonn

INRES

Embrapa

Crop genetic resources

Global Crop Diversity Trust – A Foundation for Food Security

The Global Plant Council

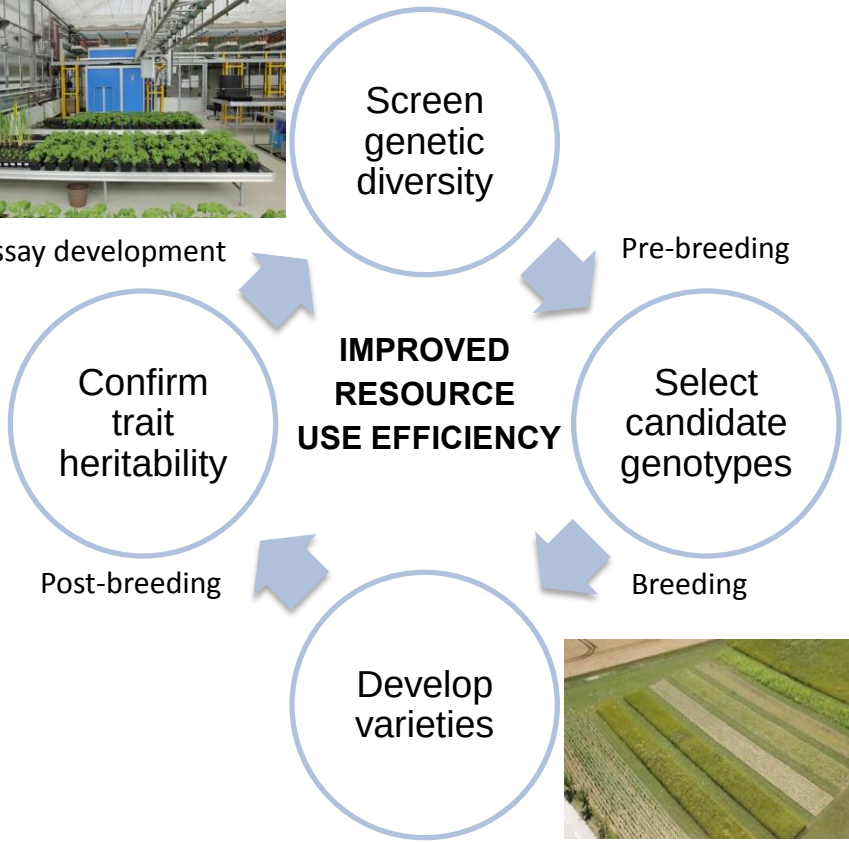
Technology platforms

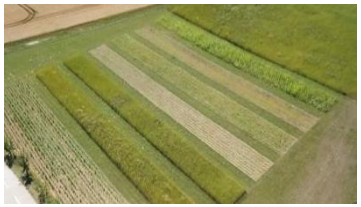
IPK Gatersleben

HelmholtzZentrum münchen – Deutsches Forschungszentrum für Gesundheit und Umwelt

Improving value of phenotyping for plant breeding programmes

Assay development





- Quantitative screening for optimized shoot biomass, photosynthesis and root architecture (low water and nutrients)
- Development non-invasive methods, standards, and infrastructure (HTP and functional mechanisms)

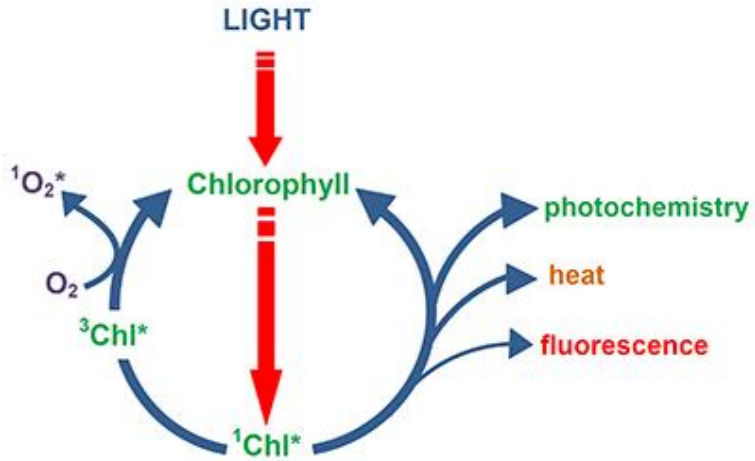
Focus on plasticity and heritability of shoot traits

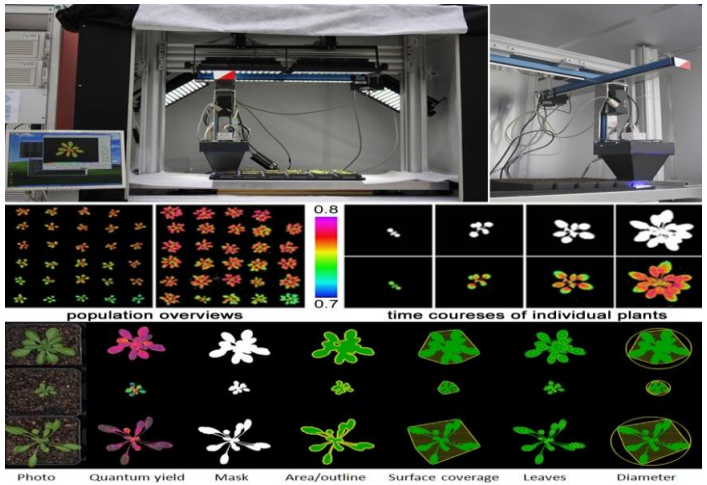
Shoot Traits/Parameters	Goal
Early vigor, shoot phenology	Reduce soil evaporation/Max. Harvest Index
Water relations	Increase Water Use Efficiency
Leaf senescence, flowering, and branching	Increase Nutrient Use Efficiency
Shoot architecture	Increase Light Use Efficiency
Shoot mechanical properties	Reduce lodging/Quality of renewable biomass

- Comparison and ranking of candidate genotypes greenhouse and field
- Quantitative assessment of Genotype x Environment interactions

Automated systems for shoot phenotyping

We established and automated screening system based on active fluorescence imaging to analyze shoot growth and PSII status



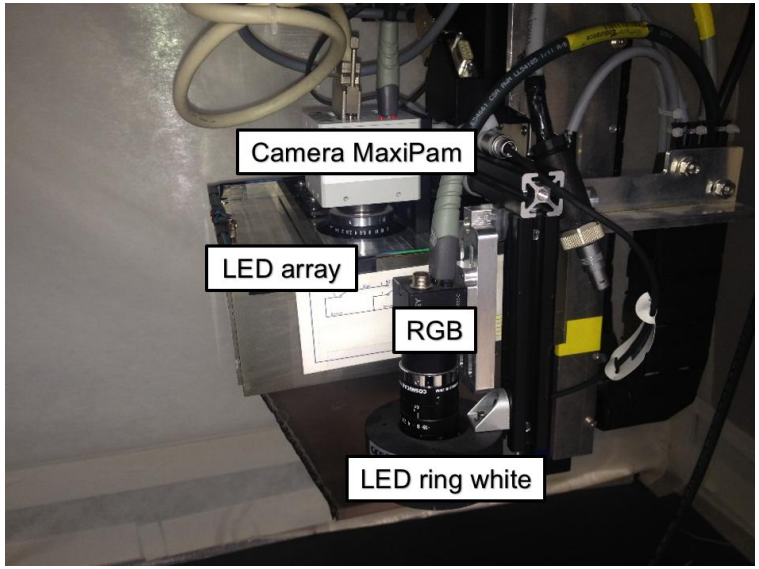


PSII dynamic responses as proxies for photosynthetic activity and photoprotection:

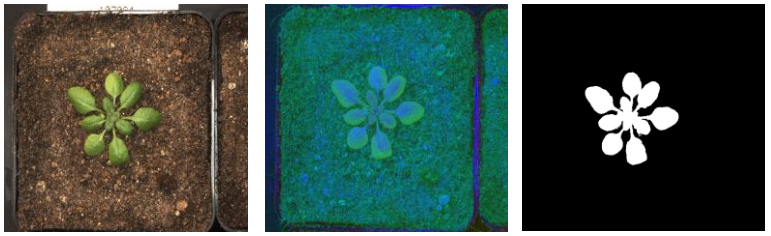
- Fv/Fm
- Electron Transfer Rate
- Non-Photochemical Quenching

Jansen et al, Funct Plant Biol (2009)

High-throughput screening with RGB cameras for small plants

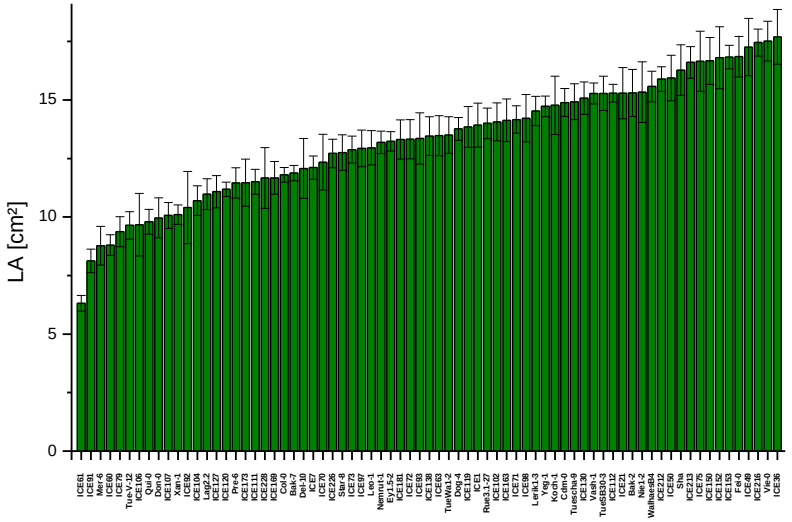


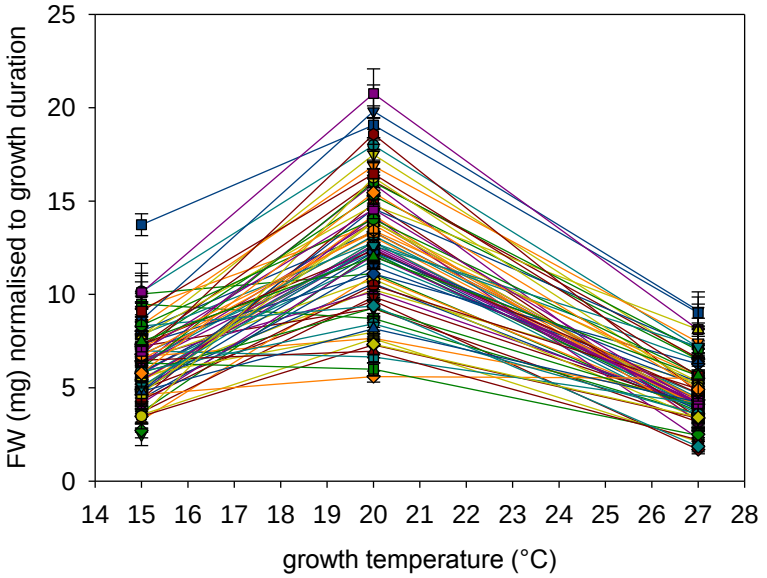
RGB HSV MASK



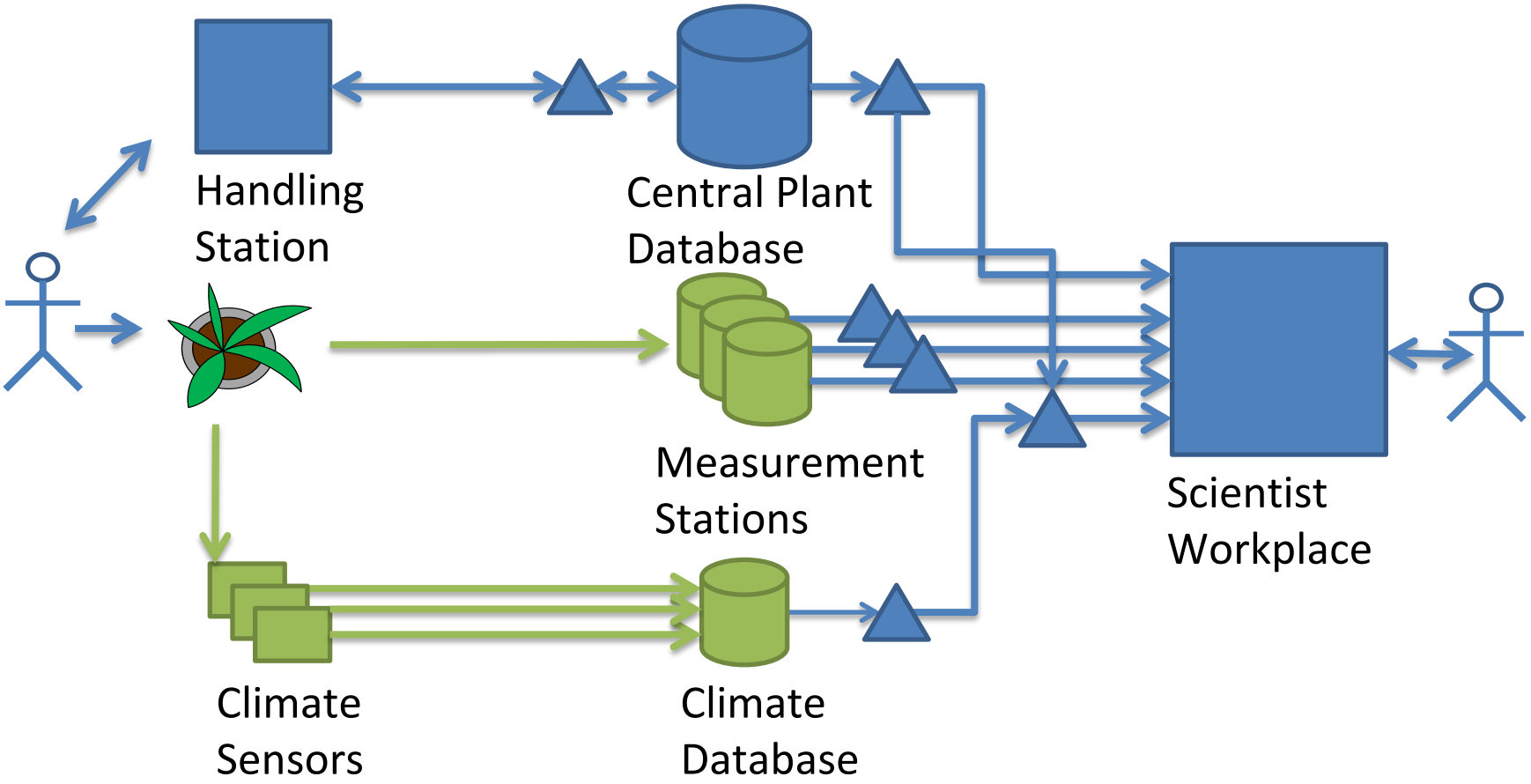
- pixelsize
- leaf area (mm^2)
- average red / green / blue channel value
- plantId, position, date, time, trayId

Temperature responses of natural variants in Arabidopsis



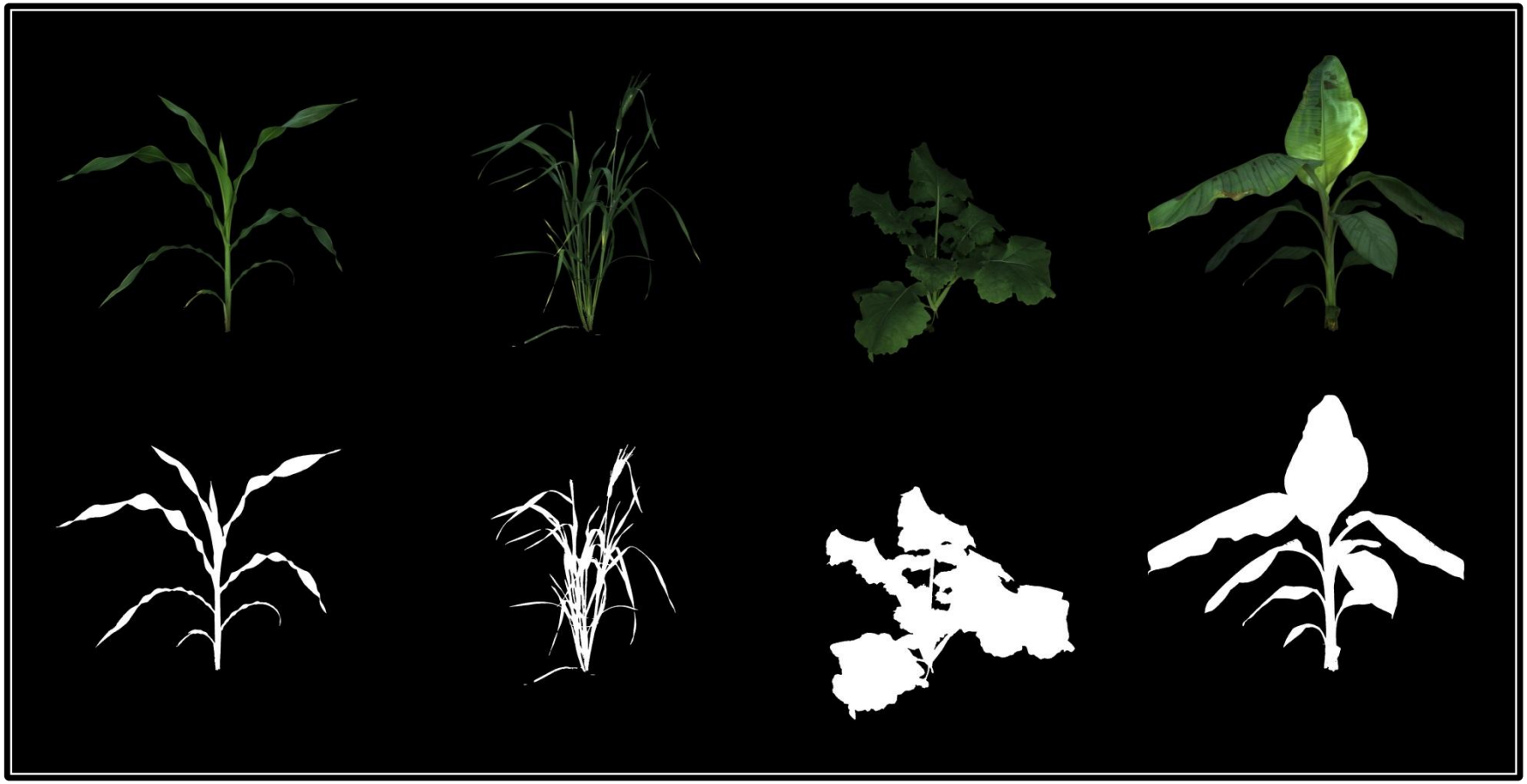


PhenOMIS database architecture
(Phenotyping Observation and Measurement Information System)



JÜLICH
FORSCHUNGSZENTRUM

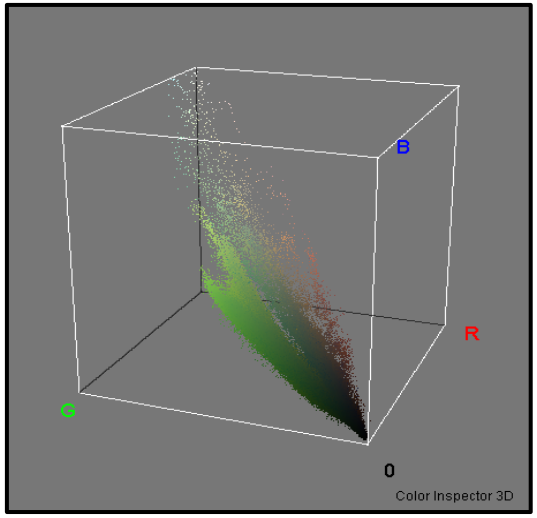
Reconstructing area development for diverse shoot architecture

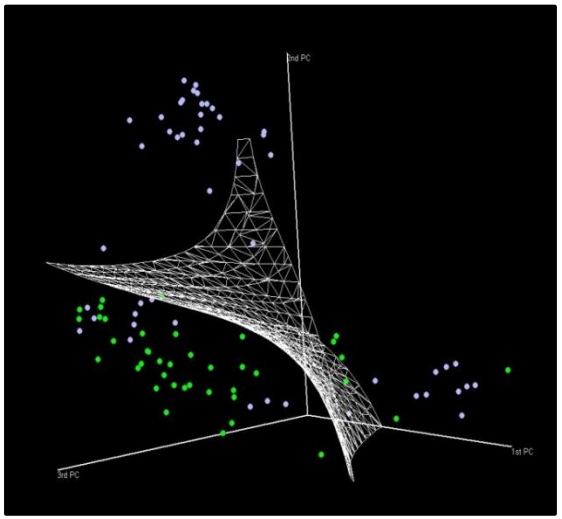


Automated systems for shoot phenotyping

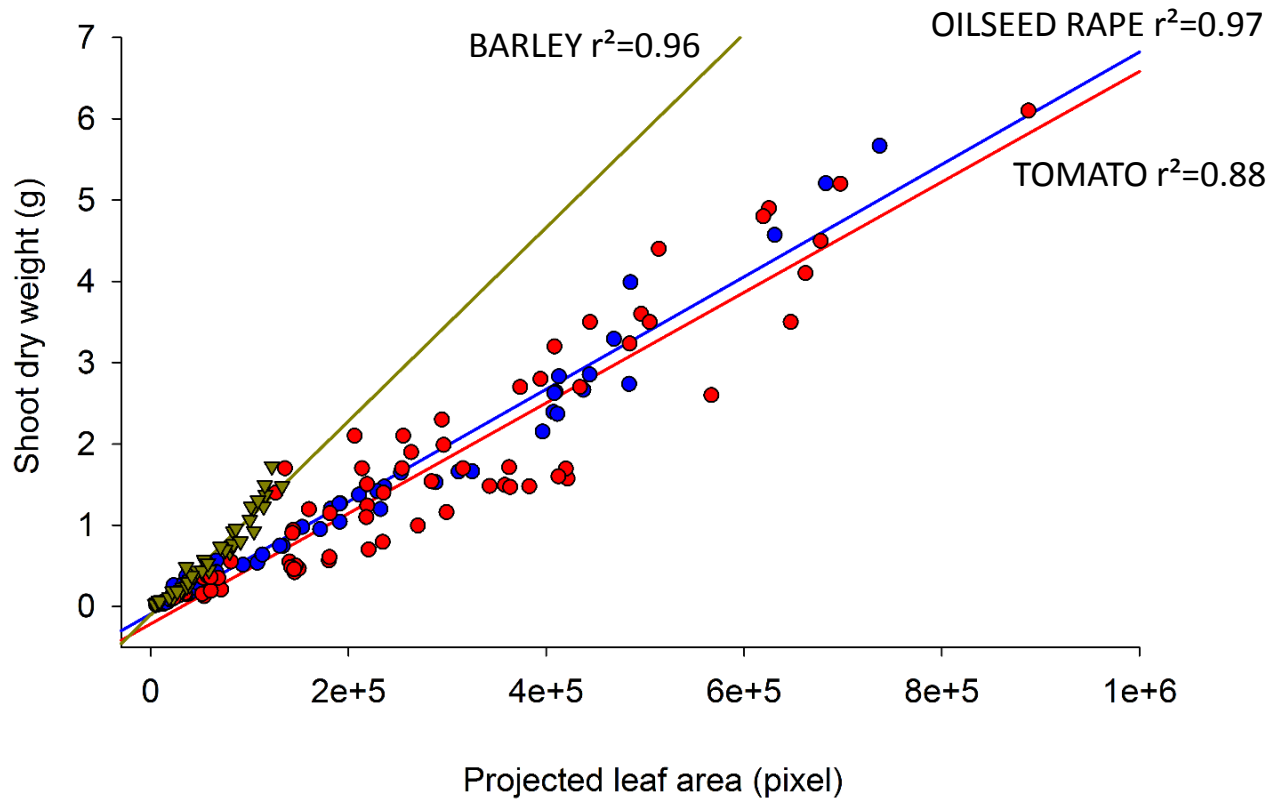
Feature extraction by Support-Vector-Machines algorithms

- Analysis of pictures by SVM Segmentation (Support Vector Machine - Segmentation)
- Dynamic differentiation between color points of plant and background in color space
- Separation of plant from background by color information of 2 different example pictures





Segmentation data correlate to leaf area and biomass



Biomass of crop plants compared to PLA at optimal view angles

Mitglied in der Helmholtz-Gemeinschaft

Mobile Devices

We developed an application (App) for mobile devices, with the possibility to segment and analyse the image directly on the device

Android OS

Development tools

File Size: 450kb
including supplemental files

Programming language

OpenCV
Image analysis library

Mobile devices – user interface

Segmented image

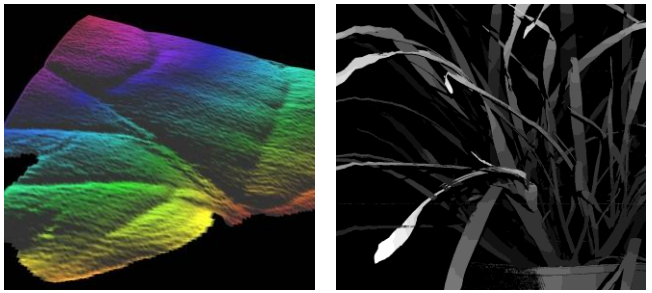
Application of novel methods to bridge existing gaps

Optimize leaf and canopy orientation to improve light use efficiency

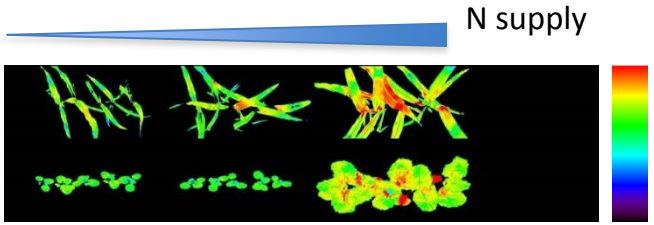
Characterize short- and long-term changes in pigment composition

Increase accuracy of quantitative measurements of shoot water content

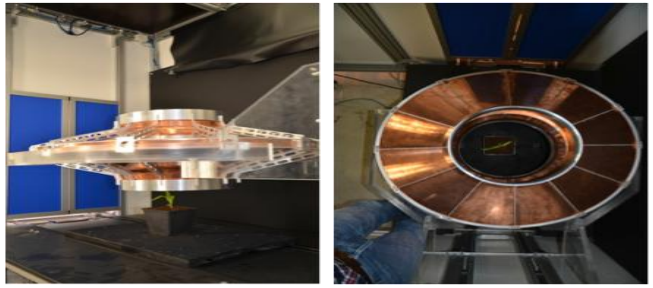
3D imaging



Multispectral imaging

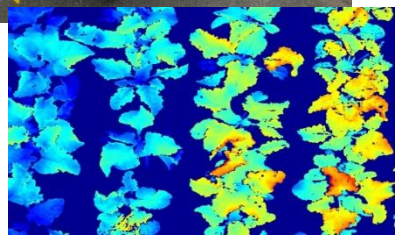


Cavity resonance

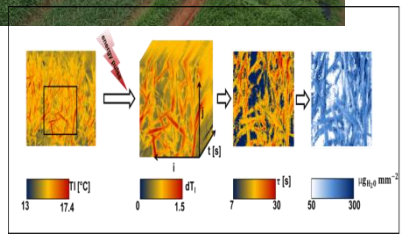


Field proximal and remote sensing methods at IBG2

Field-Mobile

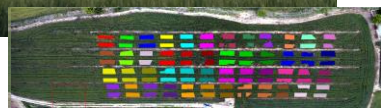


Field-Lift

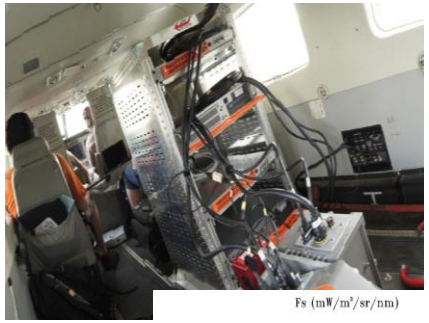


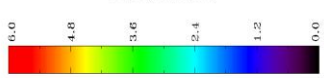
Field-Bee

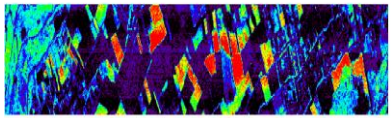
Field-Ship



HyPlant

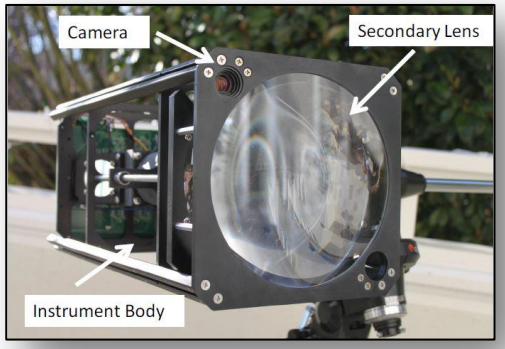




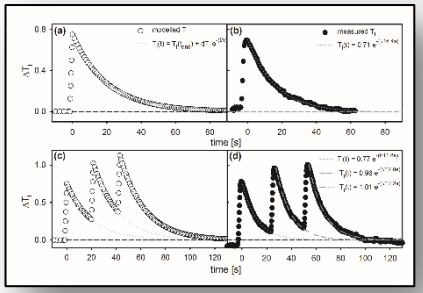


Field: Portfolio of measurement modes

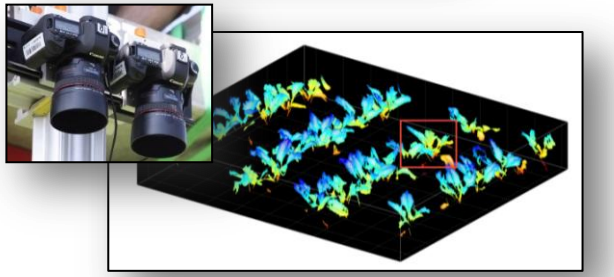
- Canopy photosynthesis
  - Laser-induced fluorescence systems (LIFT)
  - Passive, sun-induced fluorescence measurement



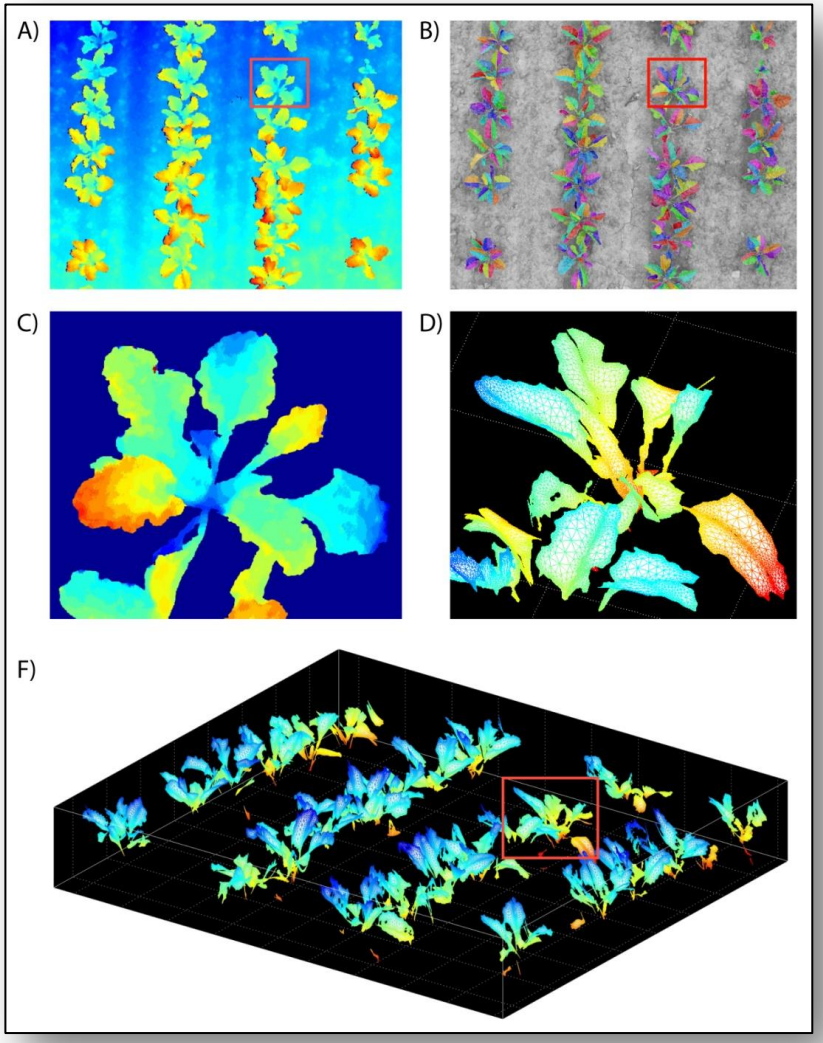
- Canopy water content and transpiration
  - passive thermography
  - active thermography



- Canopy structure traits
  - stereo cameras
  - LIDAR
  - structured light

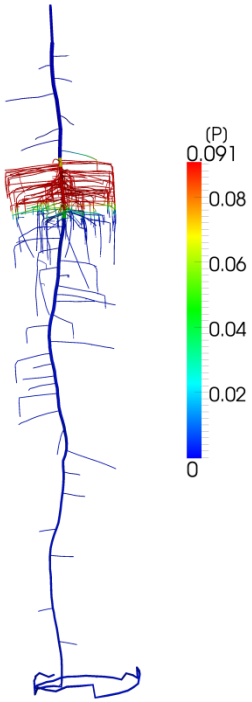


Stereo imaging enables quantifying 3D canopy structure

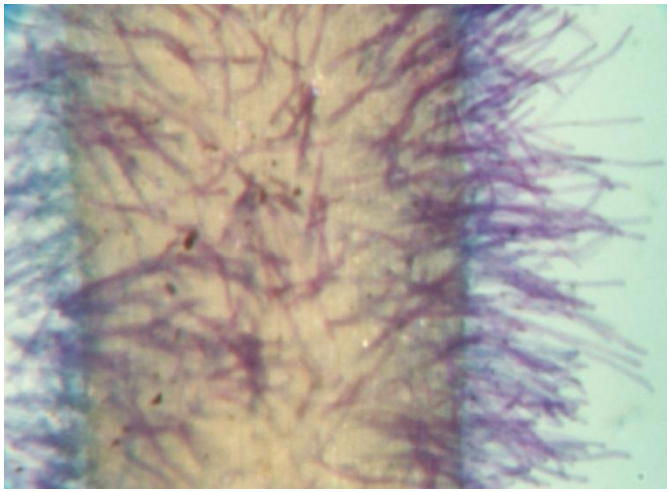


What below-ground root architecture targets for increased productivity?

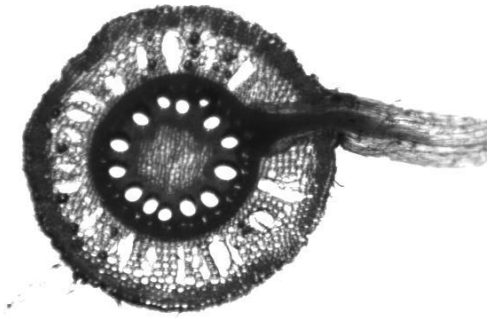
Nutrient foraging



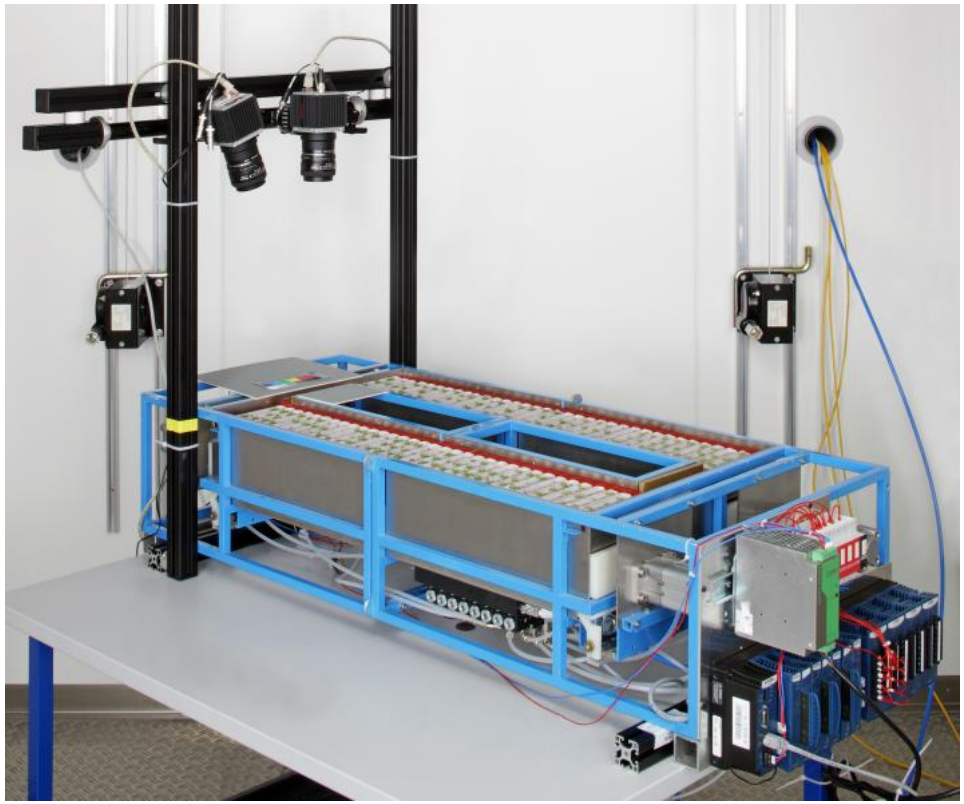
Effective uptake of nutrients

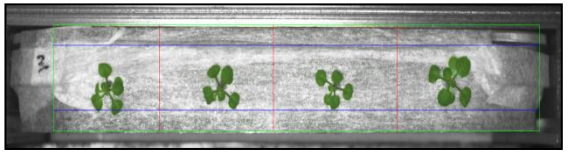


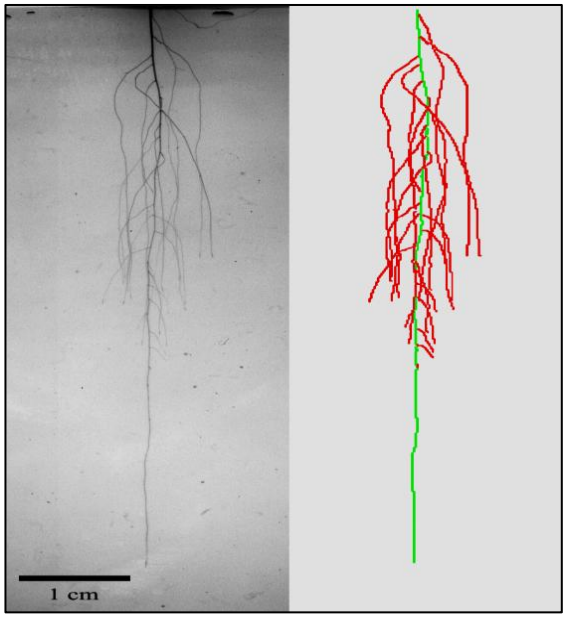
Metabolic efficiency



SCREENROOT-SP: Dynamic analyses of small plants root and shoot systems growth and geometry







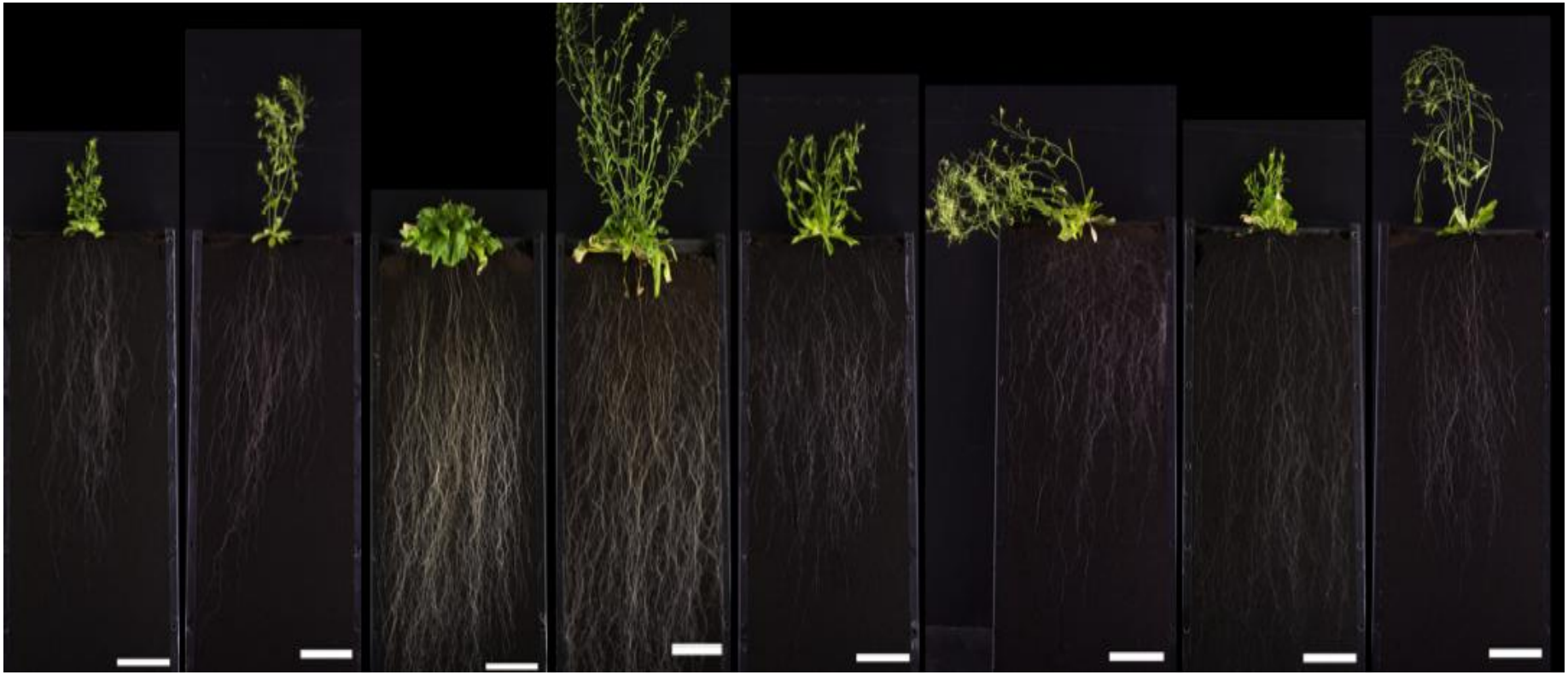
(200 plants – 14 min)

for agar-grown plants

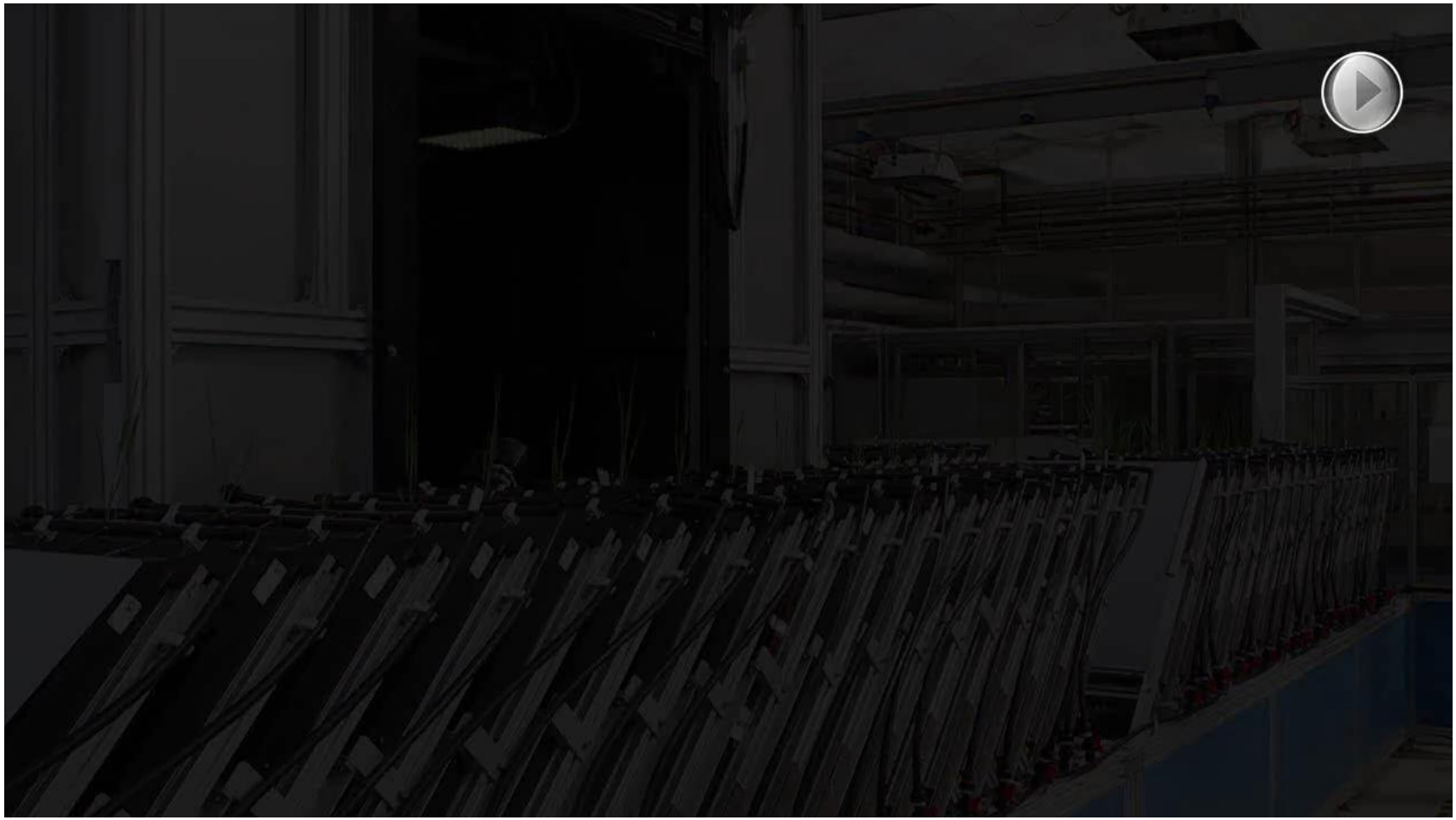
automated analysis of time series

for root and shoot parameters

Observing roots using soil and transparent interfaces



GROWSCREEN-RHIZO: a new automated system for 2D imaging of roots and shoots



Nagel et al. 2012

GrowScreen Rhizo workflow

Image recording

Acquisition Server

Cut

Image enhancement

Intensity Correction

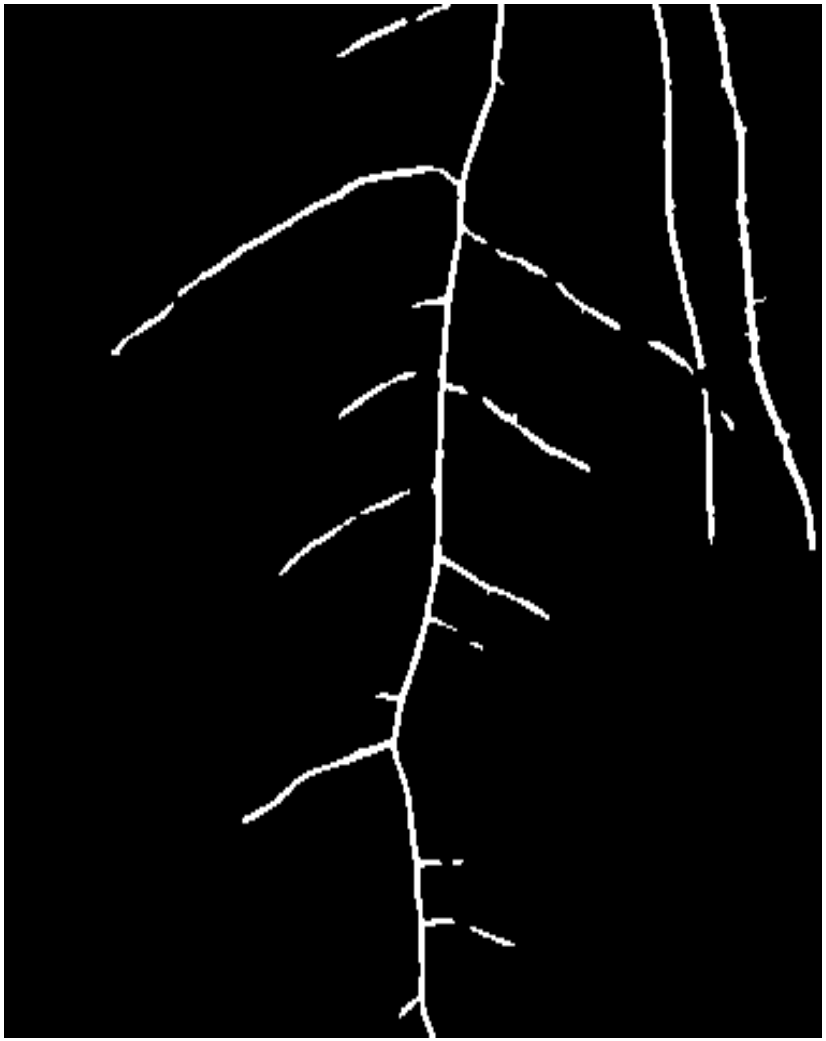
Segmentation

Feature based SVM

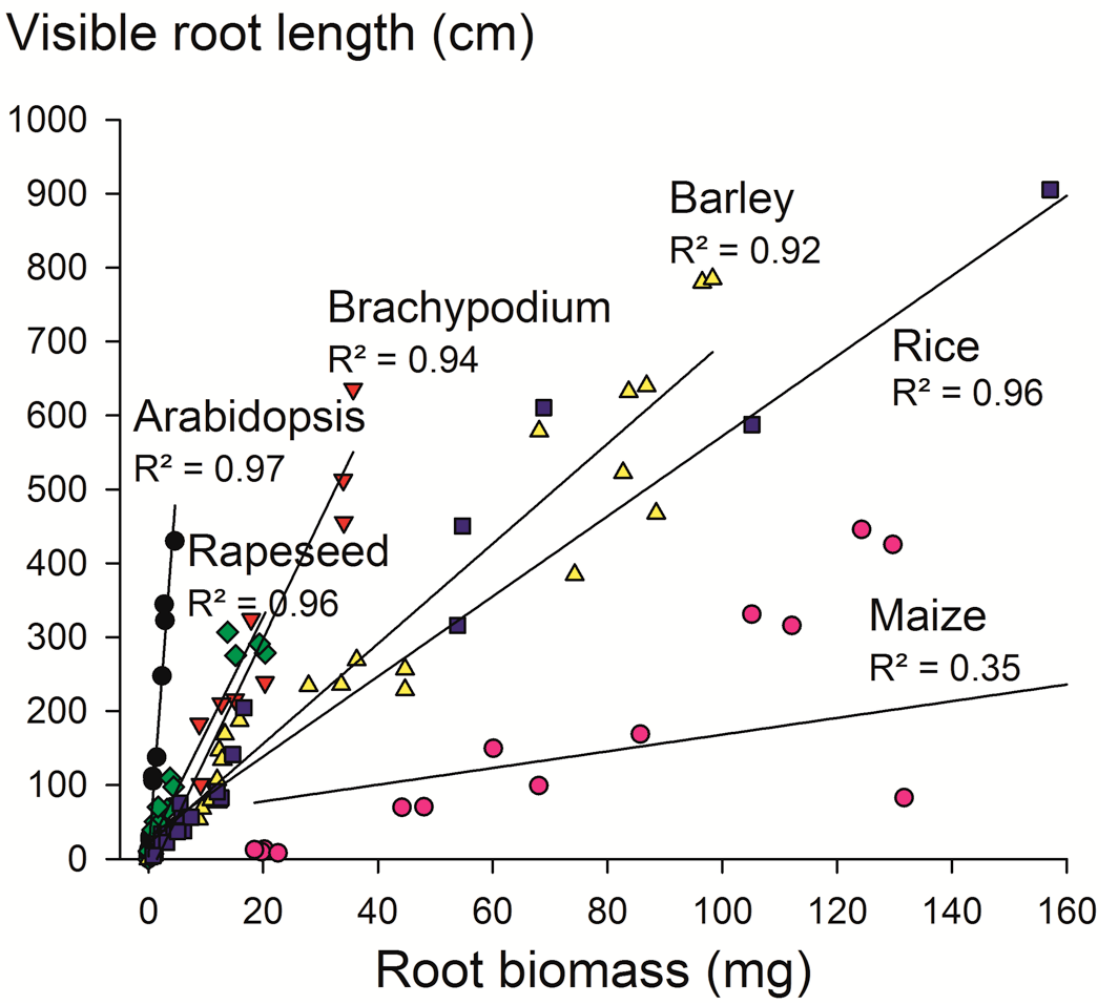
Thinning

Paint

Analysis

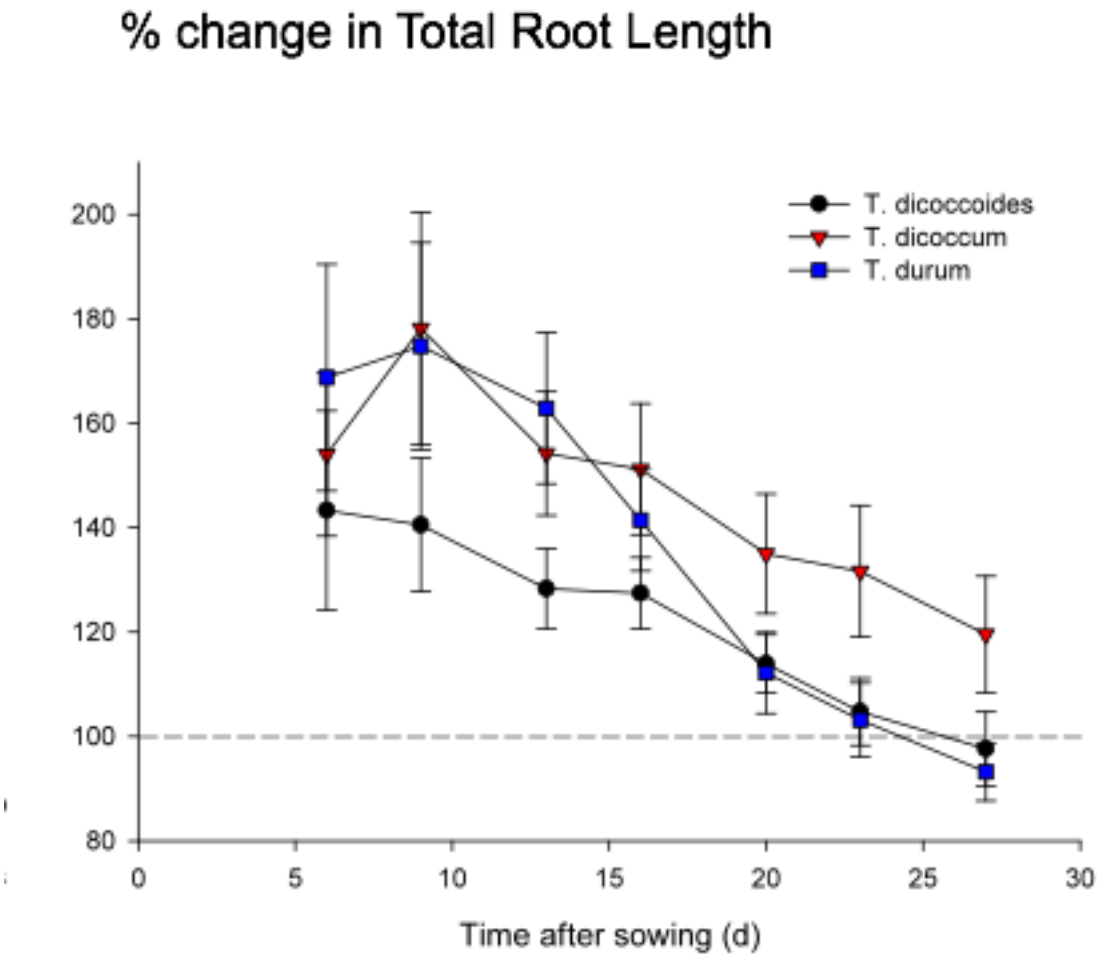


Visible root length correlates with global root parameters

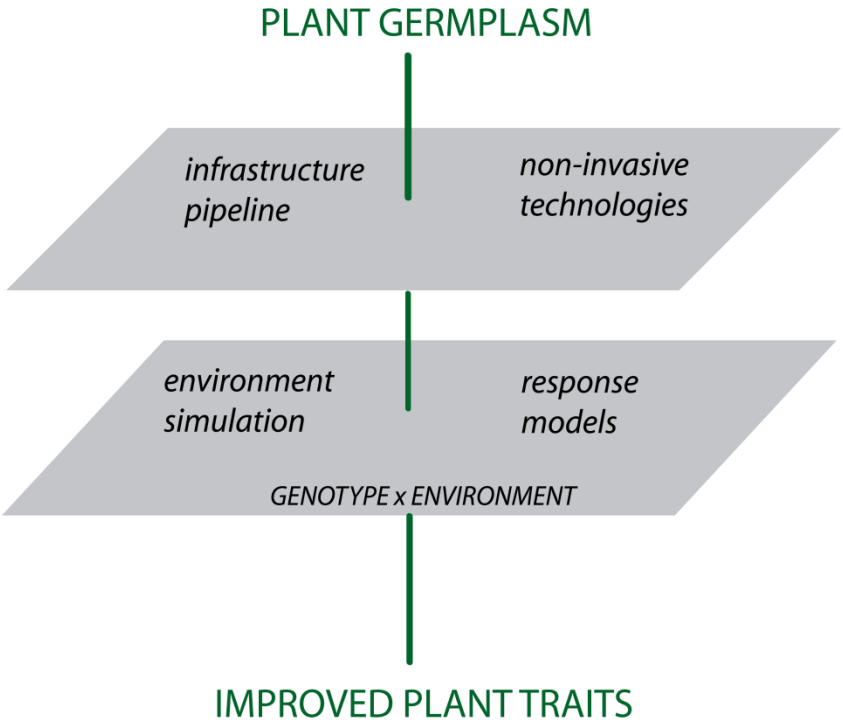


Nagel et al. 2012

Dynamic responses to low nitrate supply



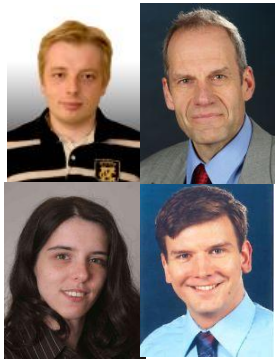
Optimal N

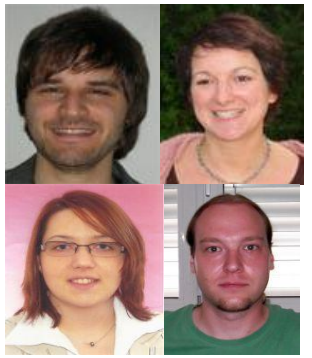


Fiorani and Schurr, Annual Review Plant Biology, 2013

- Design novel assays to quantify individual and combined effects of limiting environmental factors
- Enable multi-trait based selection with novel platforms for simultaneous phenotyping of shoot and root traits
- Build analytical framework from single plants to canopies within integrated greenhouse-field programs

Phenotyping requires multiple competences and long term sustainability





SHOOT & ROOT BIOLOGY

SYSTEMS AUTOM.

IT & IMAGE ANALYSIS

DATA ANALYSIS