Computational advances towards identifying and quantifying *in situ* plant traits

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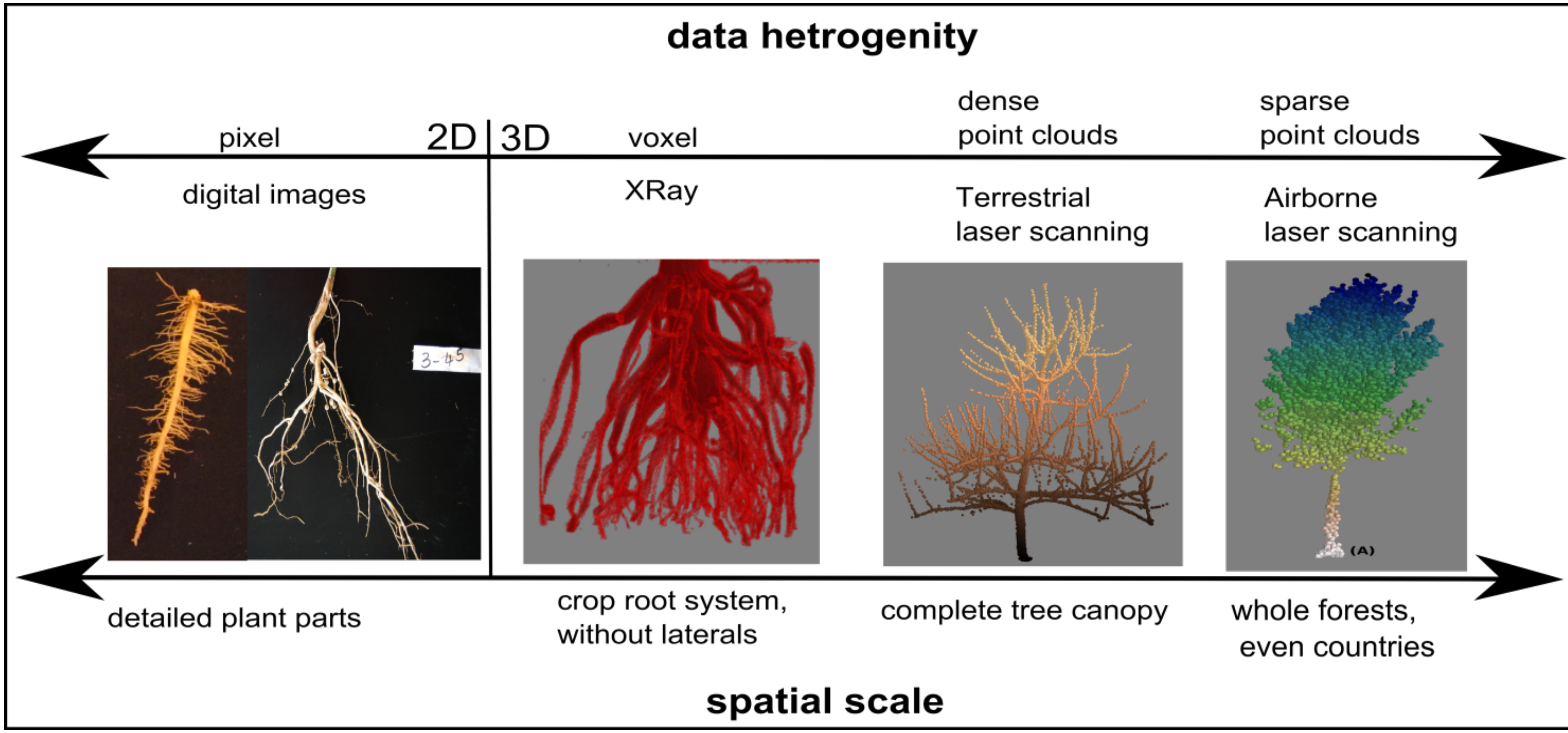
University of Georgia

UNIVERSITY OF GEORGIA

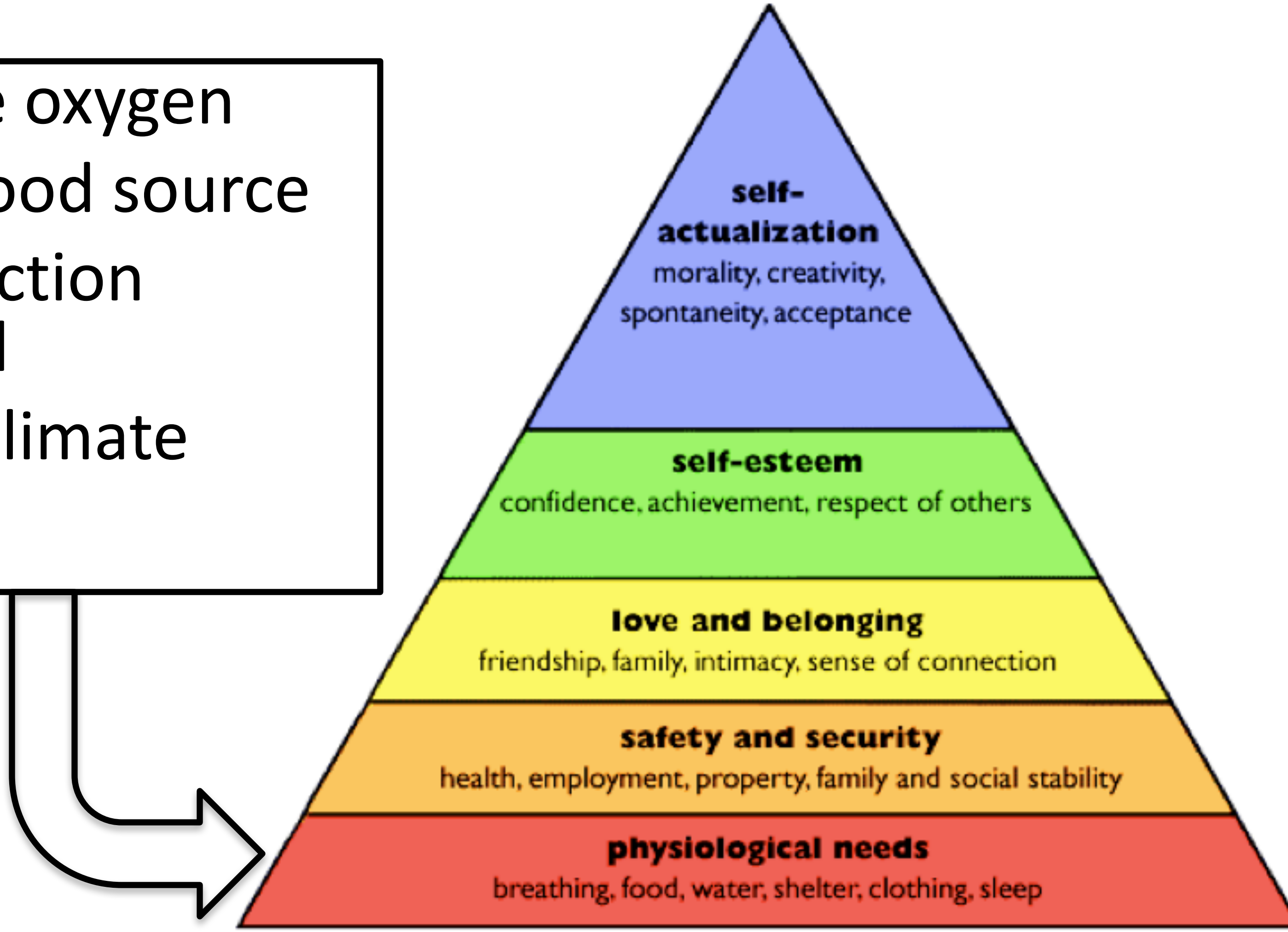
Overview



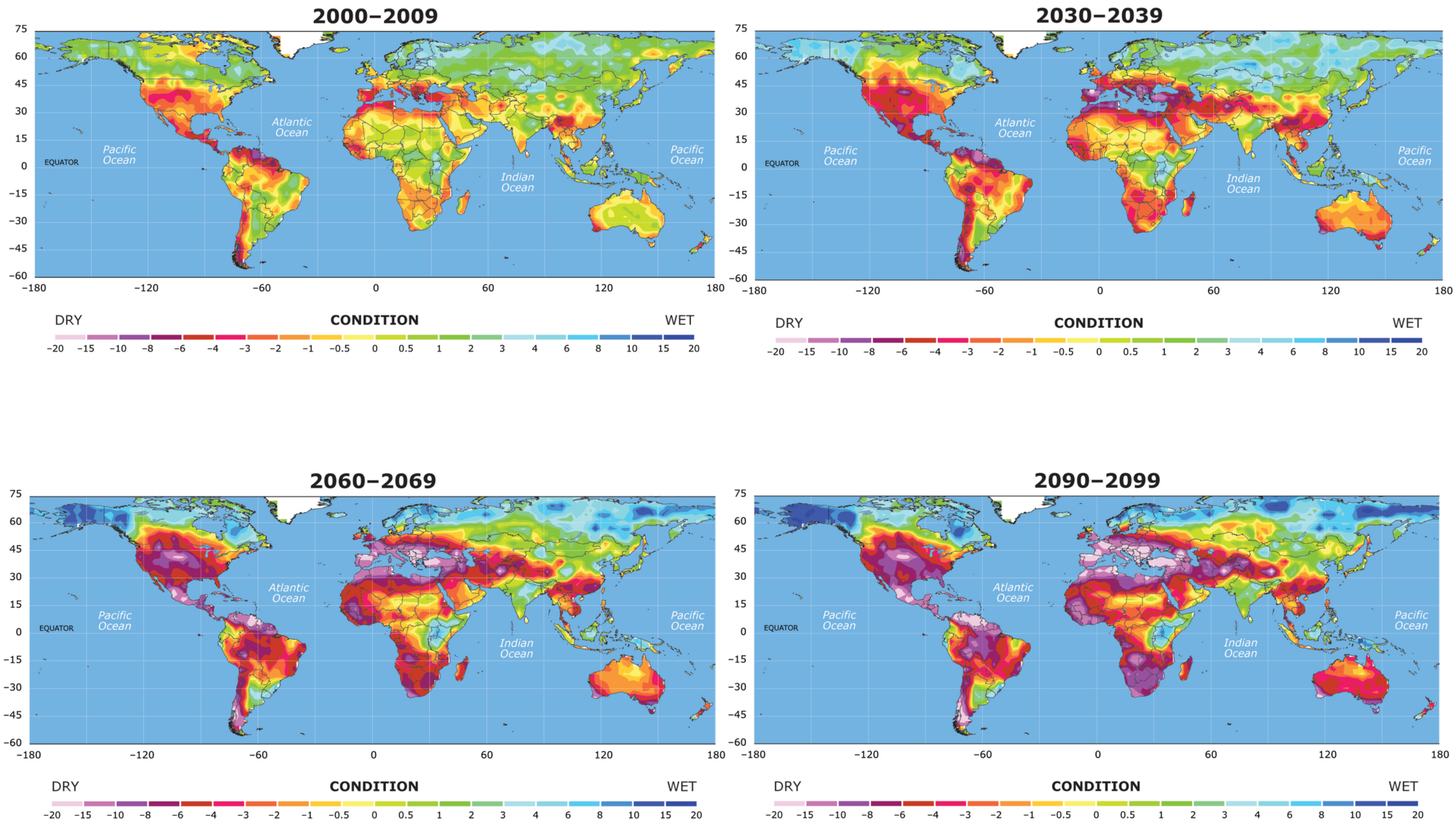
My interest: How to analyze plant shape in context?
My tools: Algorithms and math for imaging data and simulations
My context: Plants and their role in human life

Human life relies on plants

1. Produce oxygen
2. Major food source
3. Construction material
4. Global climate
5. Energy

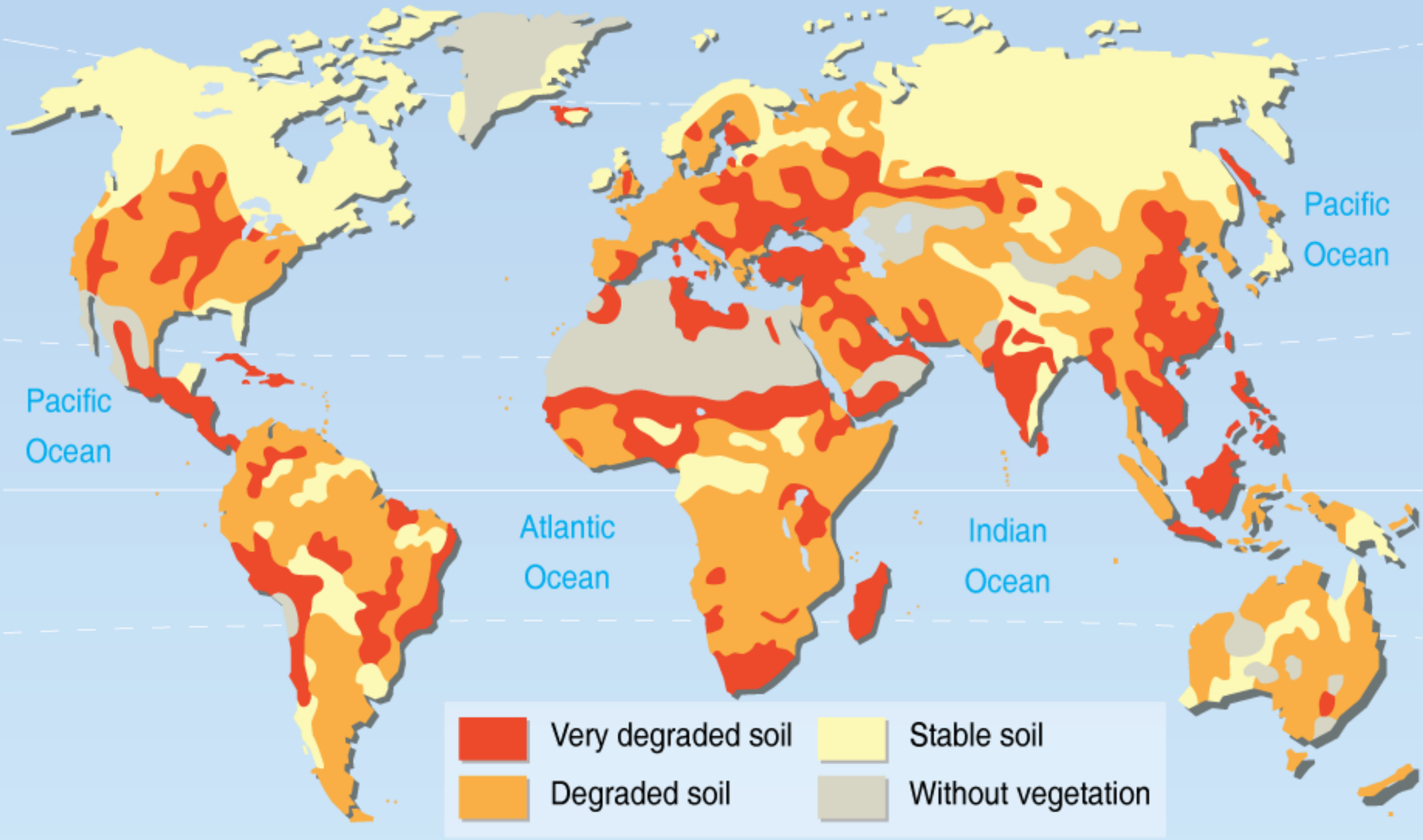


Global climate change will intensify drought in this century



Aigo Dai, National Center for Atmospheric Research, 2010 (moderate scenario)

Soil degradation



Source: UNEP, International Soil Reference and Information Centre (ISRIC), World Atlas of Desertification, 1997.

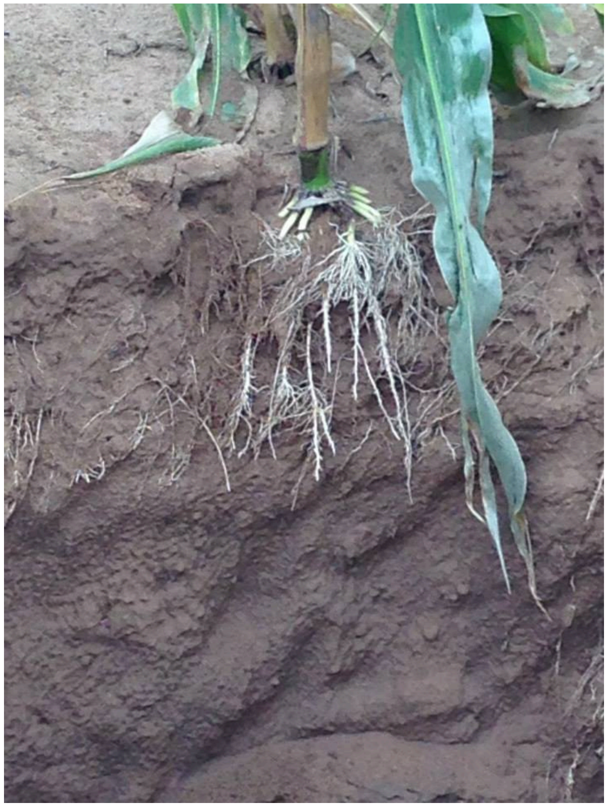
Philippe Rekacewicz, UNEP/GRID-Arendal

Shape effects of soil fertility are visual

Low nitrogen content

High nitrogen content

Importance of crop roots



- Crop yield must double by 2050* under increasingly limited soil conditions world wide
- Decades of shoot improvements
- Now: Increasing efficiency of water and nutrient uptake

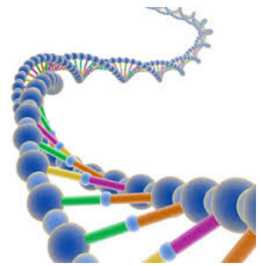
*Tilman, D., et al., *Global food demand and the sustainable intensification of agriculture.* Proceedings of the National Academy of Sciences, 2011. **108**(50): p. 20260-20264.

How to improve roots?

Phenotype = Genes x Environment

Same common bean genotype

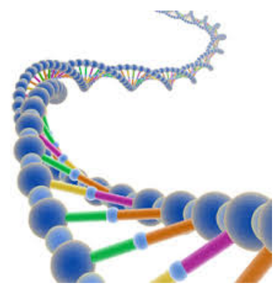
=



x

drought

=



x

well watered

Assumption: If an observed root trait variation is linked to genes, than the trait is possible to breed

Challenges

Lab

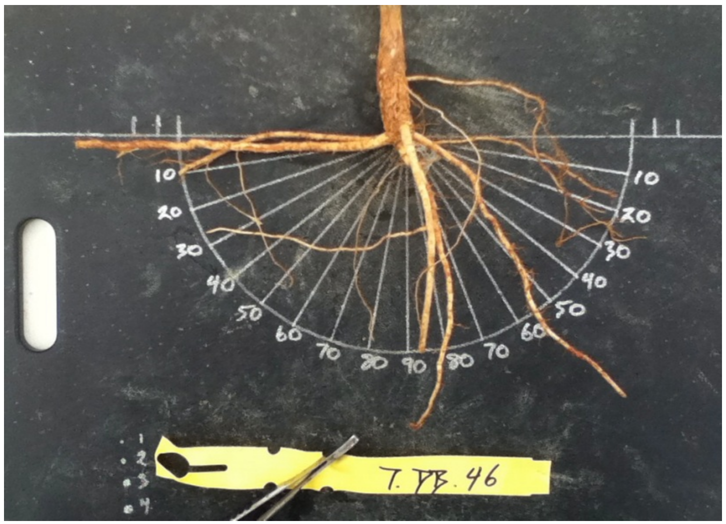
Field

- **Search** for links between root shape and genes
- **Develop** root shape descriptors for image data
- **Work** with the variations of mature roots in the field

Root traits of interest

- **Geometric traits** (e.g. angles, densities, diameters)
- **Topologic traits** (e.g. number of root types)
- **Mathematical functions** (e.g. cumulative width)

Roots in the field – the beginning in 2011



How to obtain images for automated analysis?

DIRT development

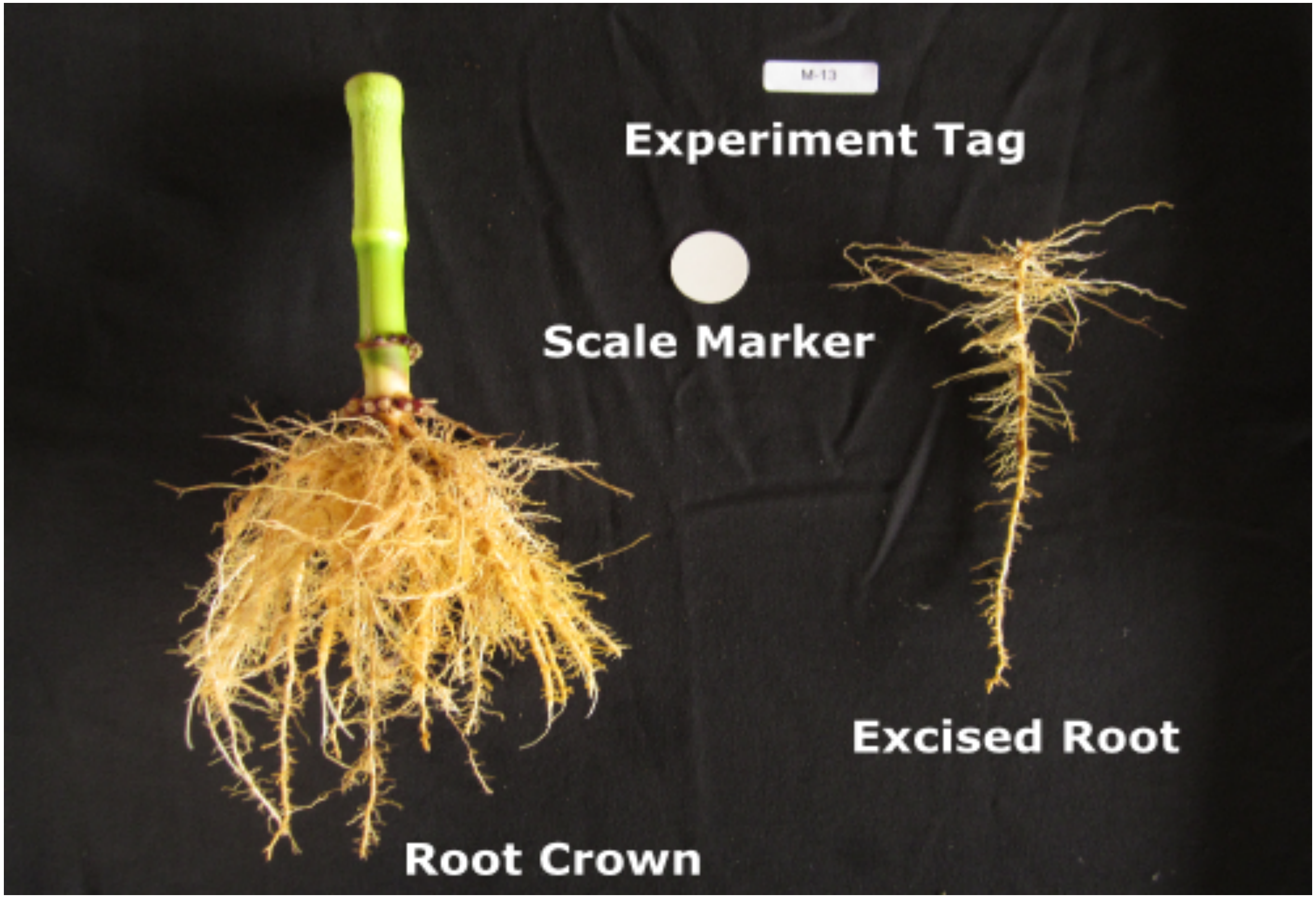
Dig

Wash

Measure

Or: automate

Easy non-technical imaging setup



Bucksch, A., Burridge, J. et. al, *Image-based high-throughput field phenotyping of crop roots.* Plant Physiology, 2014. **166**(2): p. 470-486.

DIRT: Over 70 root traits from 1 root system

Digital Imaging of Root Traits

Getting to the roots of the crops!

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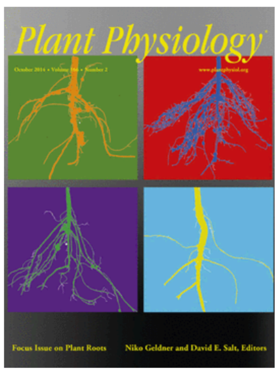
HOME ABOUT GET STARTED ROOTS COMPUTATION

Digital Imaging of Root Traits

Digital imaging of root traits (DIRT) is an automatic high throughput computing platform to measure phenotypic traits of monocot and dicot roots from digital photographs. DIRT extends and automates the extraction of phenotypic traits by utilizing high-throughput grid computing environment. Currently DIRT is available to our collaborators on the Georgia Tech PACE environment and to the public via the iPlant cyber infrastructure utilizing the TACC computing resources at UT Austin.



The obtained measurements are inspired by the Shovelomics field protocol used in many field experiments. Overall, DIRT derives over 30 phenotypic traits for monocot and dicot roots or excised root samples. DIRT is accessible online via this web application, which allows storage, organization and sharing of the image data and computing results.Our approach was highlighted on the Plant Physiology cover in October 2014.

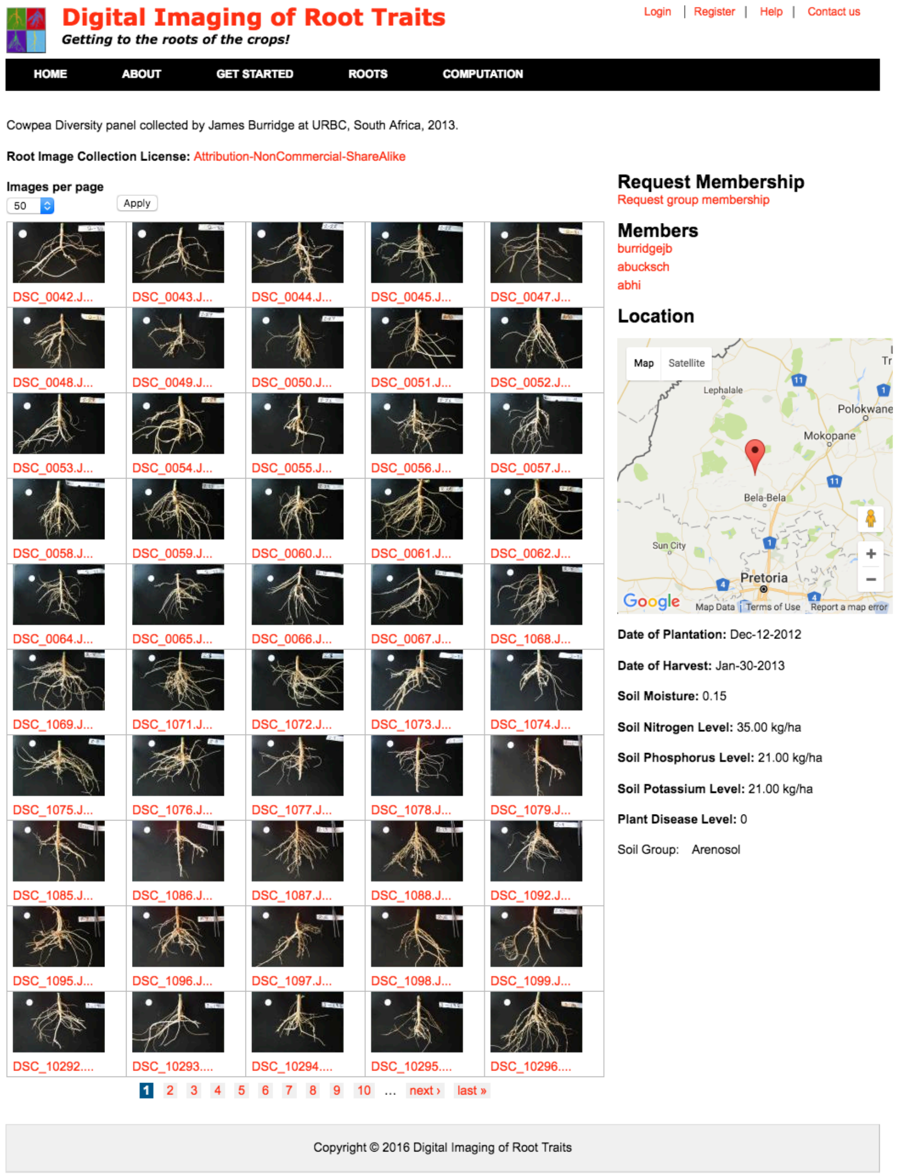
Unique features are:

- Automatic processing and trait calculation from large data sets (> 1000 images) imaged with the DIRT protocol
- Virtual experiments through recombining existing image data from all accessible experiments
- Storage, sharing and organization of images with in the whole user community, private or selected collaborators
- Output as excel compatible file
- Extensible with python through open source (Source Link)
- Visual and statistical result control of all processing steps

http://dirt.iplantcollaborative.org

Bucksch, A., Burridge, J. et. al, *Image-based high-throughput field phenotyping of crop roots.* Plant Physiology, 2014. **166**(2): p. 470-486.

DIRT organizes and computes big data



Bucksch, A., Burridge, J. et. al, *Image-based high-throughput field phenotyping of crop roots.* Plant Physiology, 2014. **166**(2): p. 470-486.

DIRT tools

View | Edit | Outline | Devel

DSC_0065.JPG

Experiment Number: Tag text extraction Failed

Stem Diameter: 11.37

Simple Stem Diameter: 11.07

Projected Root Area: 5 392.84

Average Root Density: 1.17

Mean Tip Diameter: 0.34

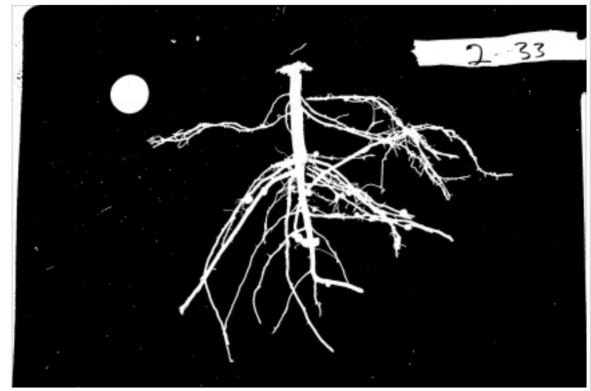
Median Tip Diameter: 0.30

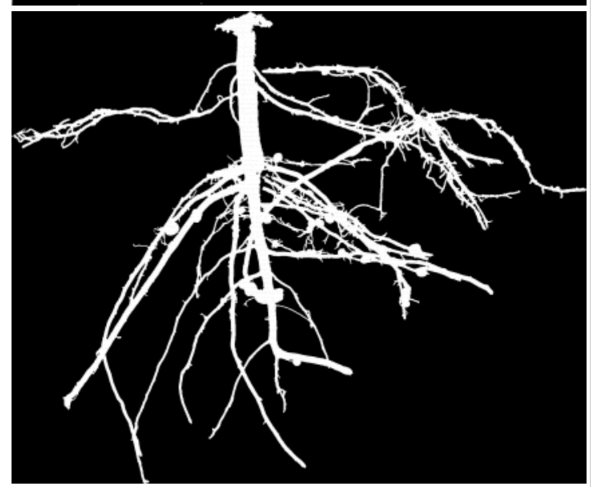
Maximum width of root system: 209.14

Median width of root system: 96.73

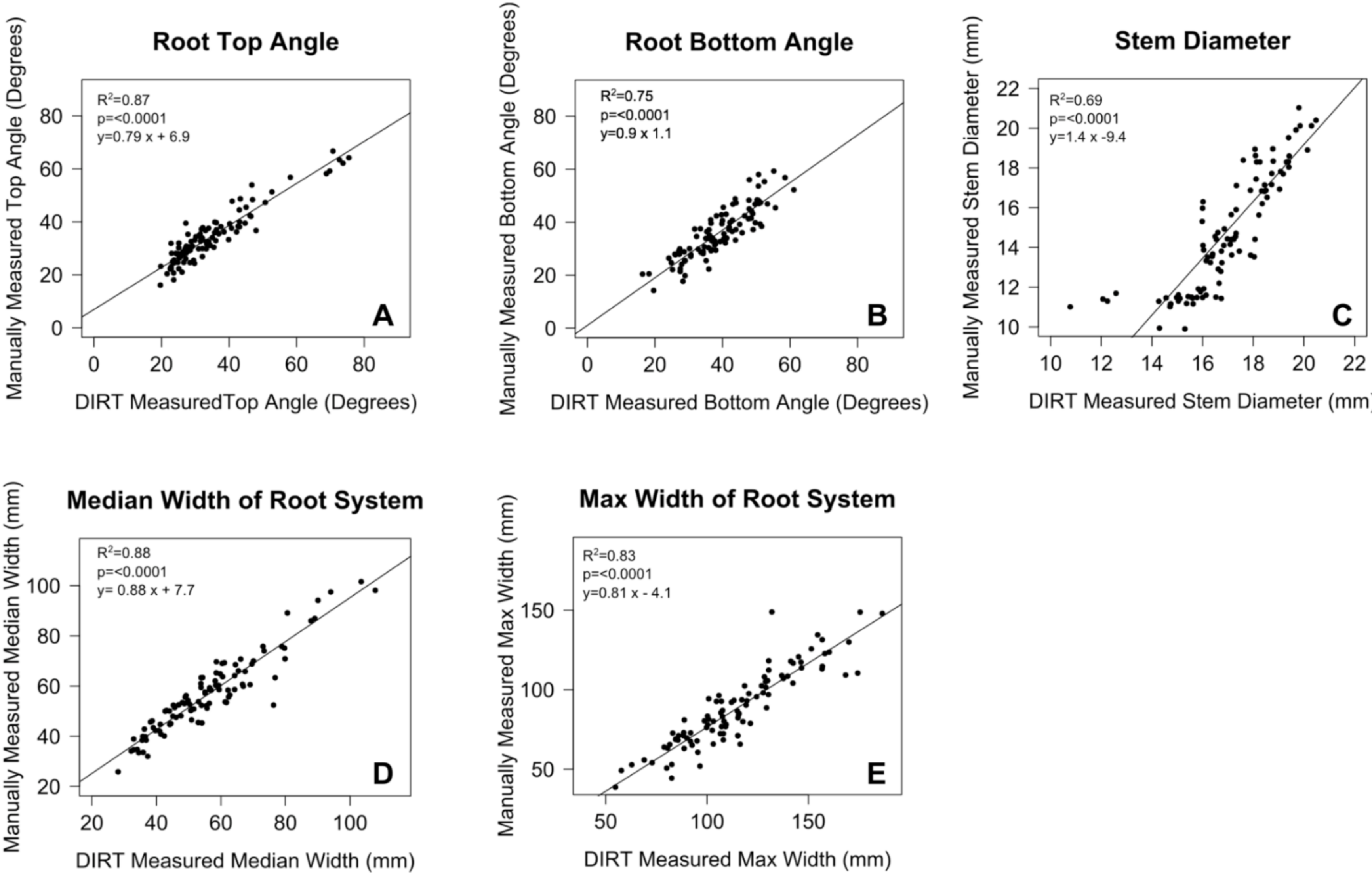
Member of Computation: Cowpea-Diversity-SA-2013

Traits File: 55822fe94a167_traits.rsml



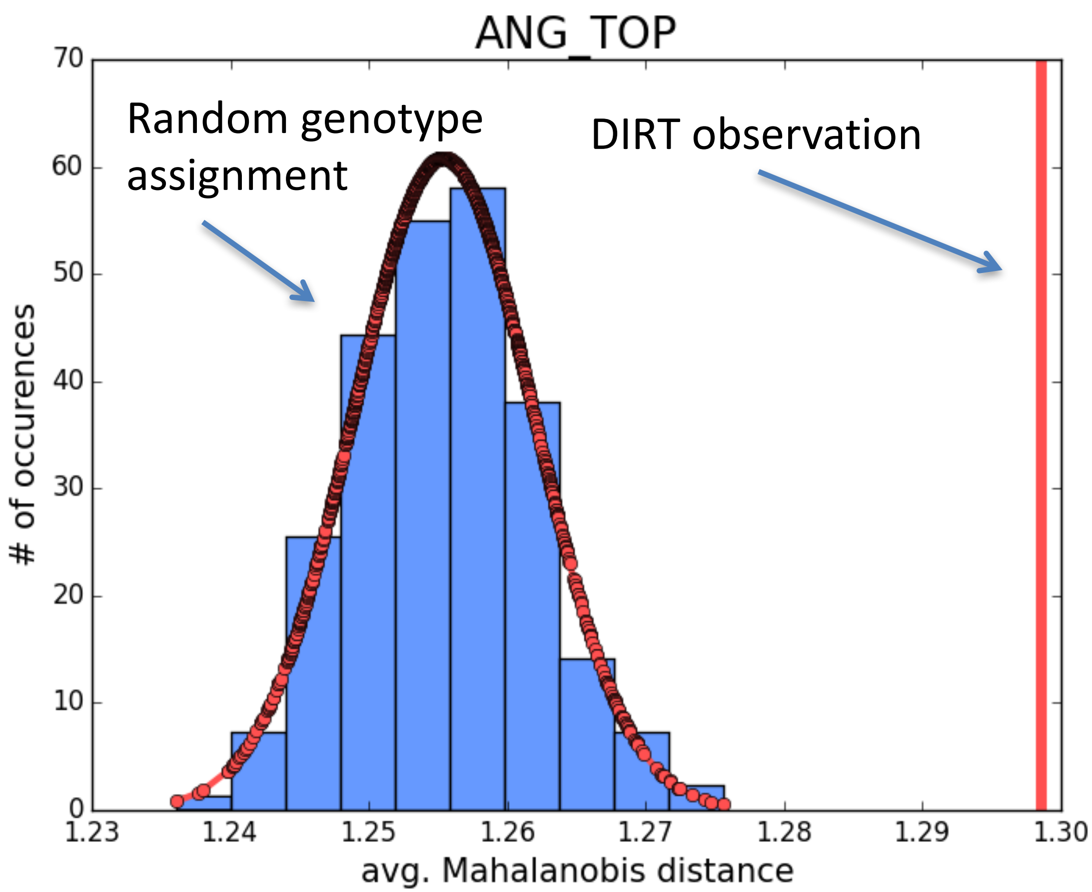


Manual vs. image based correlations



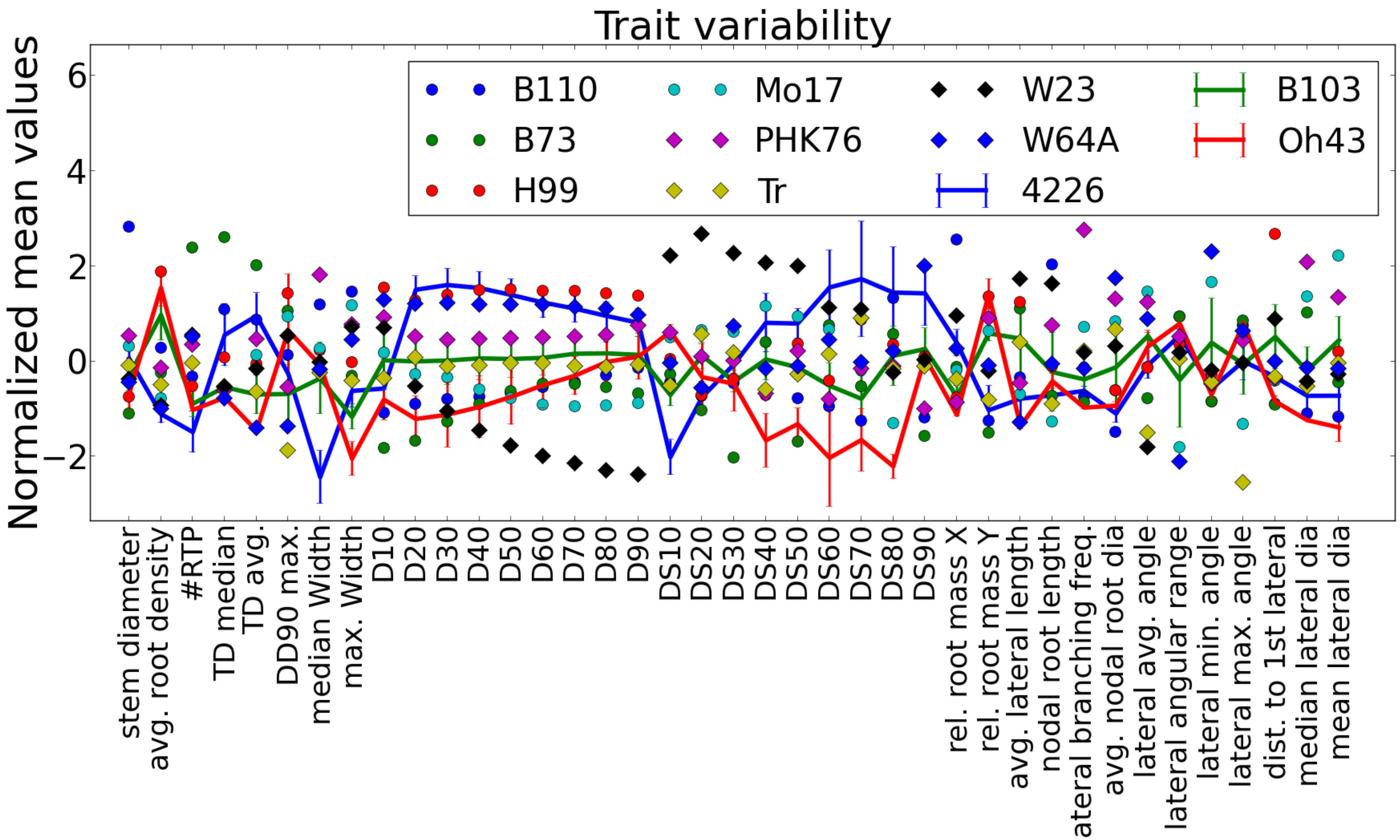
Das A., Schneider H., Burridge J., Martinez Ascanio A. K. ,Wojciechowski T., Topp C. N. , Lynch J. P., Weitz J. S. , Bucksch A. *Digital Imaging of Root Traits (DIRT).* 2015 Plant Methods 11(51)

Field observations are not random

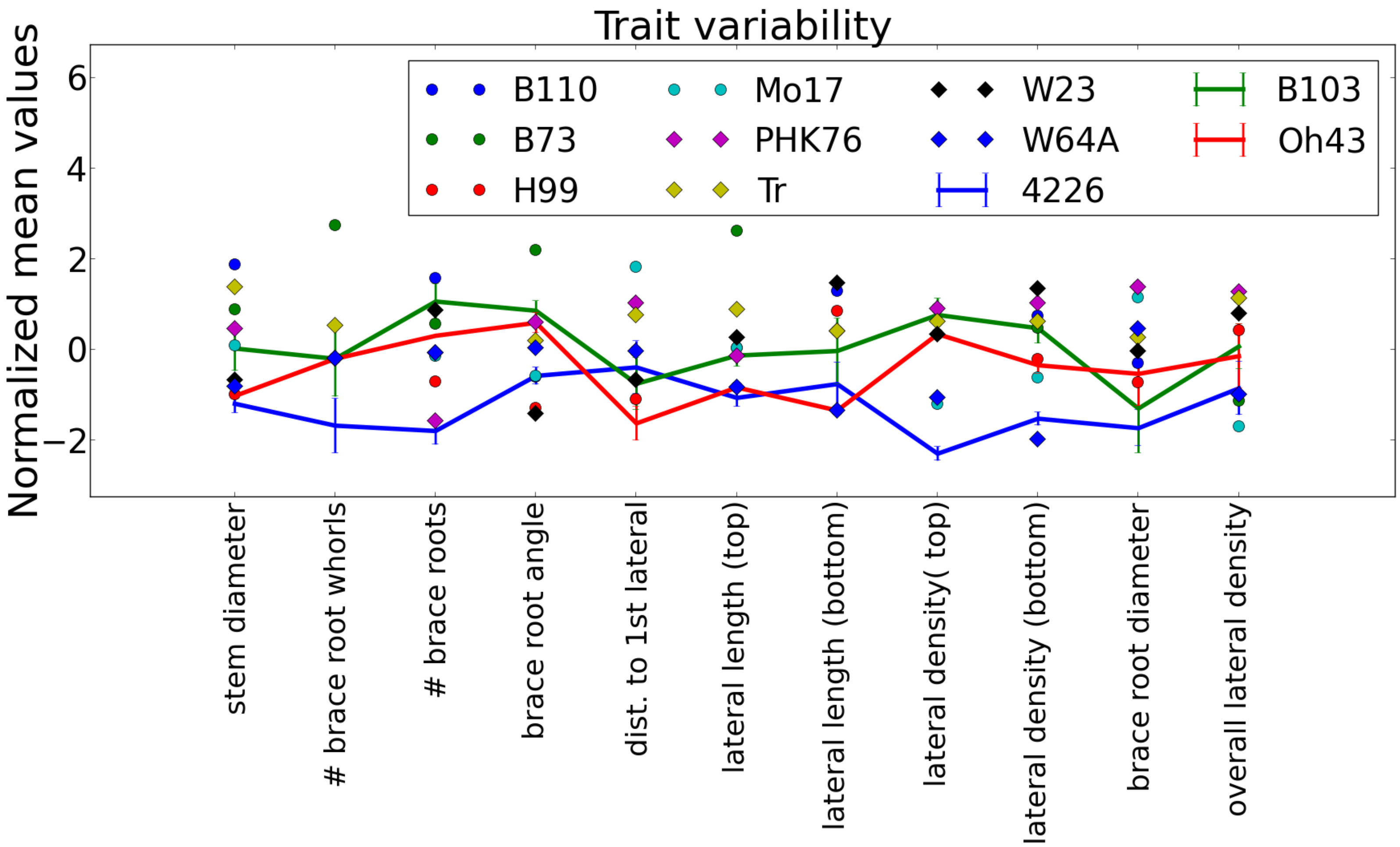


- Permutation test of 2800 maize roots
- 752 genotypes
- drought/well watered
- Genotype labels shuffled 1000 times

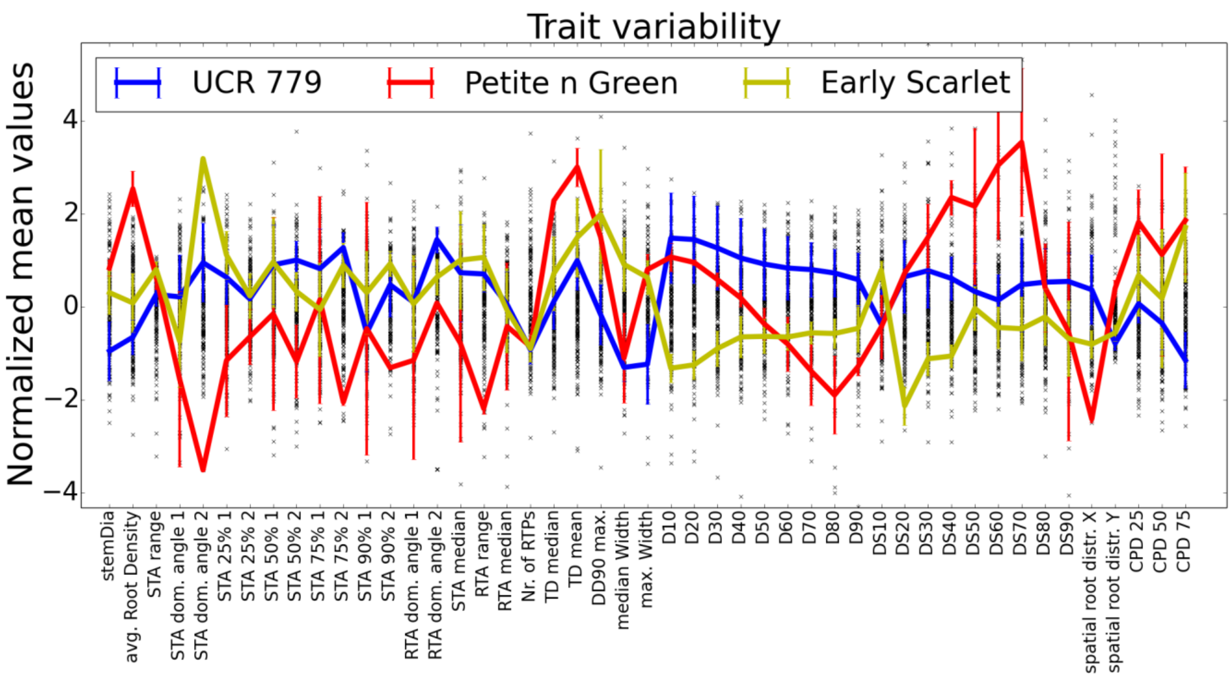
DIRT trait variability – brace root



Shovelomics trait variability – brace root



Distinguish 188 cowpea genotypes



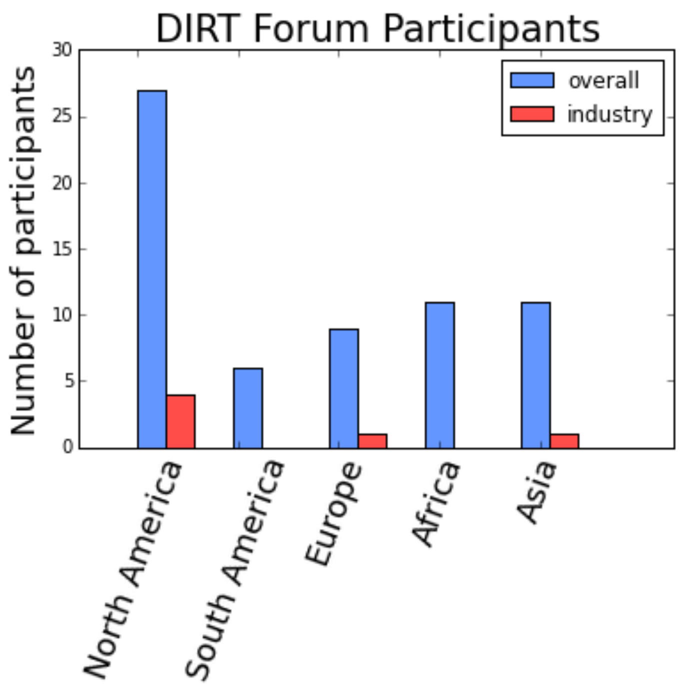
Shovelomics
5 genotype combinations could not be distinguished with field measurements

Gia Roots
128 genotype combinations could not be distinguished

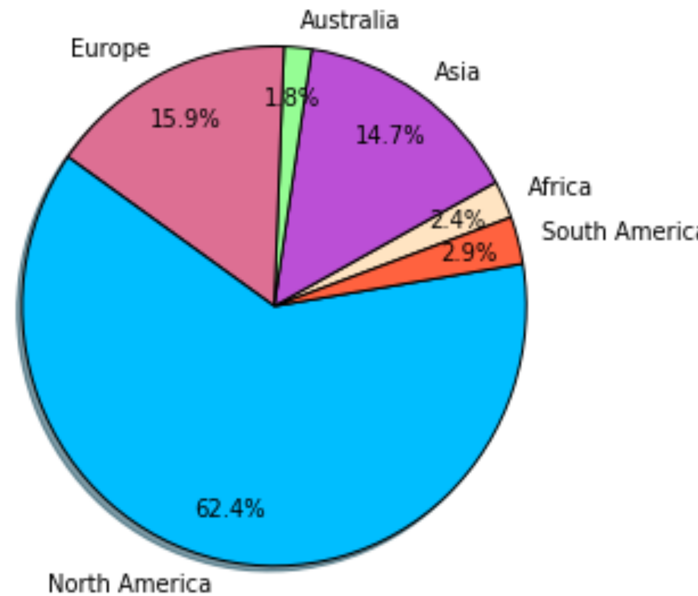
DIRT
All 188 genotypes distinguish at least in one trait

A. Bucksch, J. Burridge, L.M. York, A. Das, E. Nord, J.S. Weitz, J.P. Lynch (2014)*: Image-based high-throughput field phenotyping of crop roots.* Plant Physiology, 166, pp. 470-486

DIRT worldwide

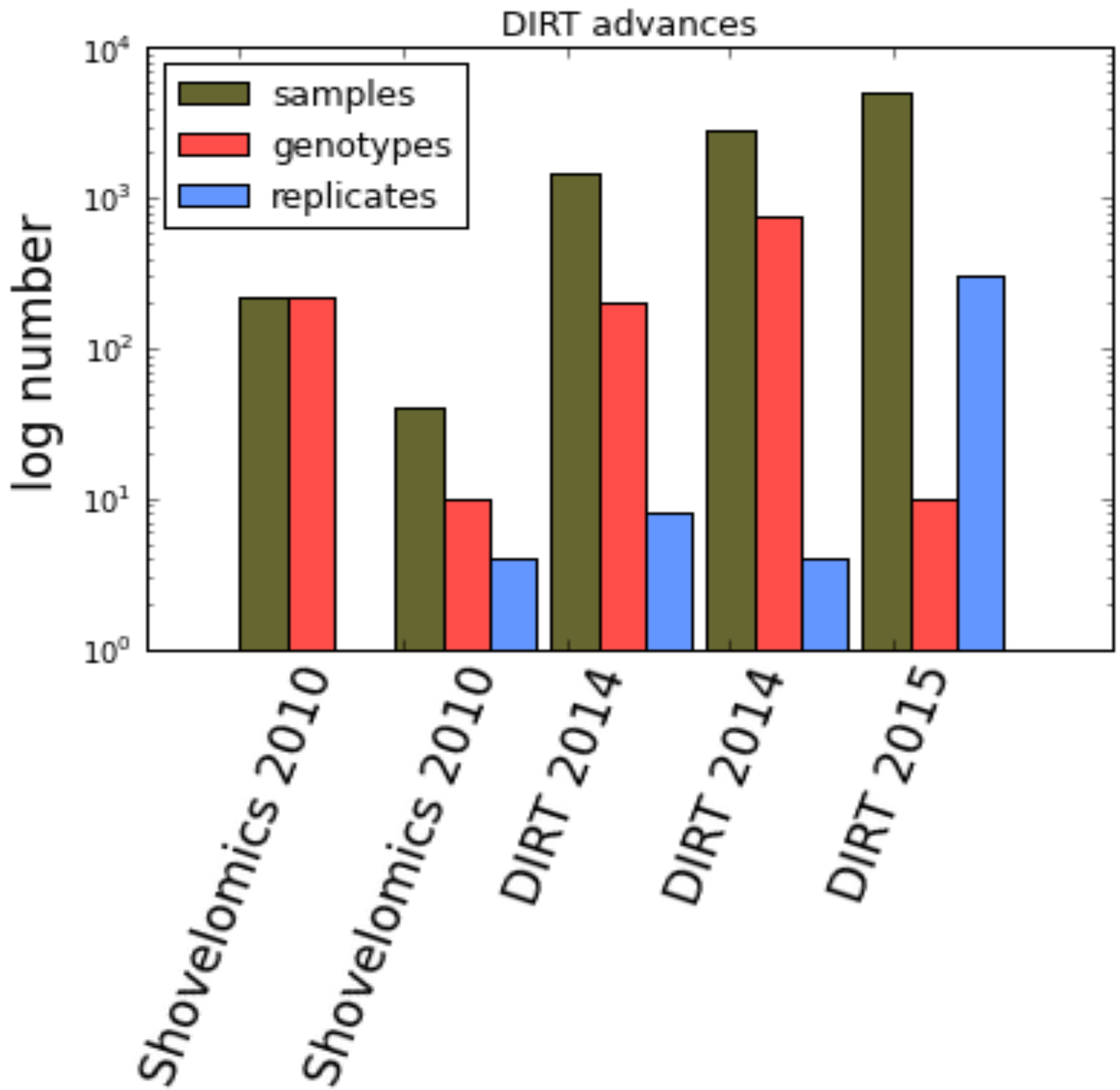


Participants at the iPlant Focus Forum January, 29 2016

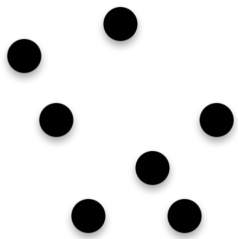


DIRT Users December, 1 2016

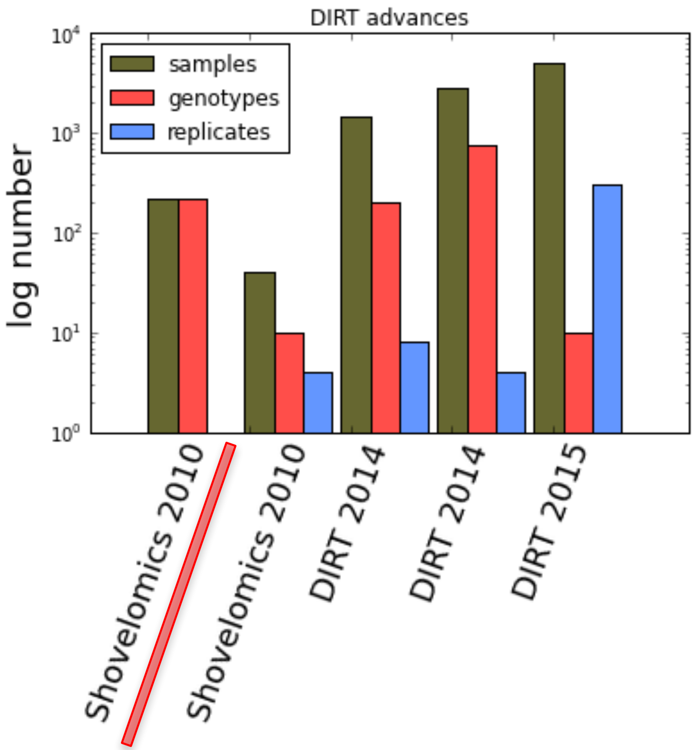
Advances in numbers: from 10s to 1000s



From random scatter to distributions



Scattered single points



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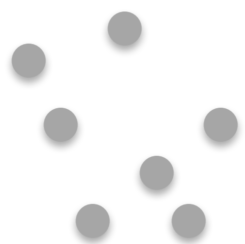

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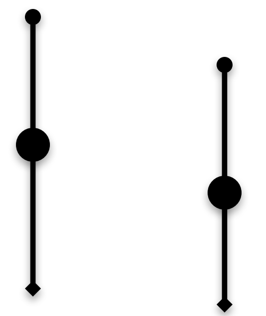
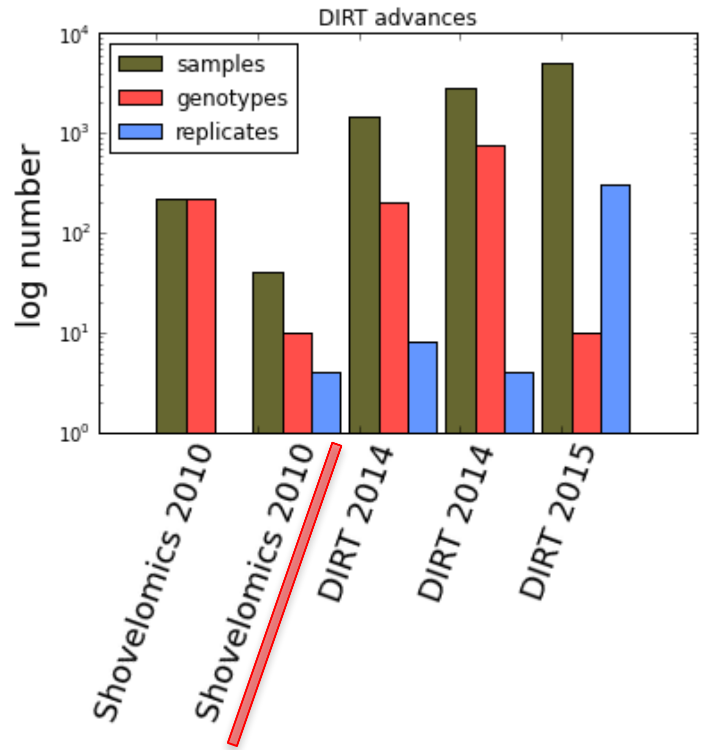


Few average points with large standard error



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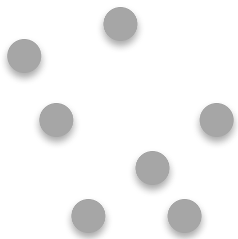

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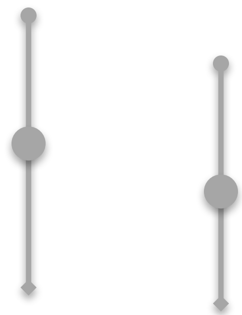

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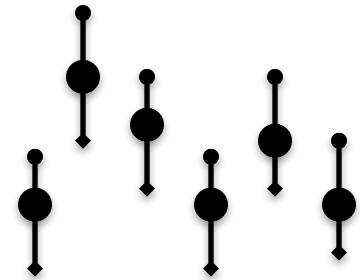
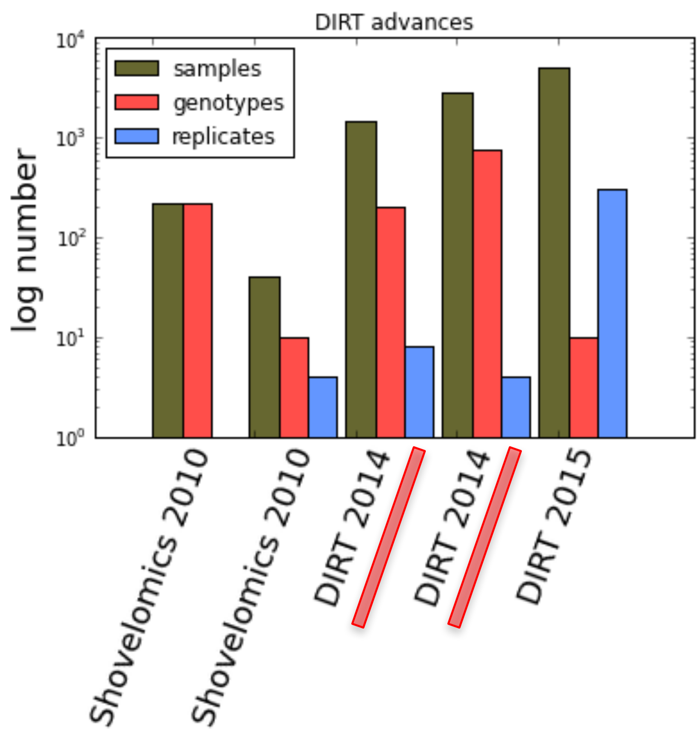
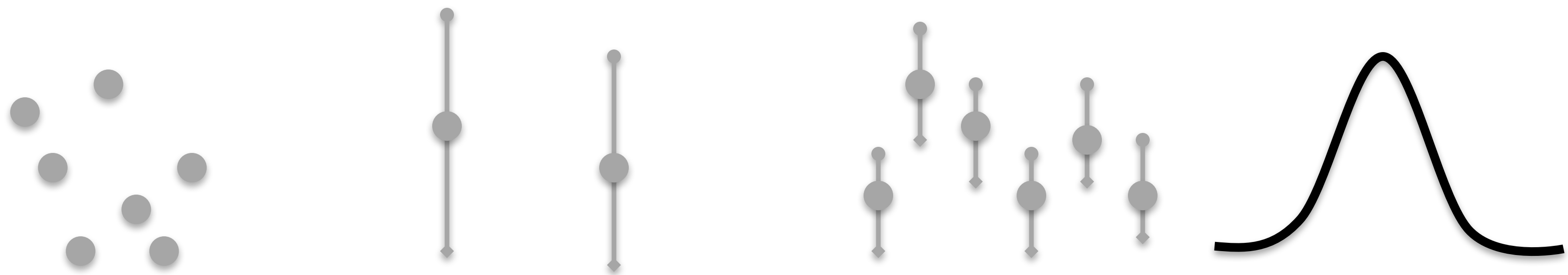


Many average points with standard error



From random scatter to distributions

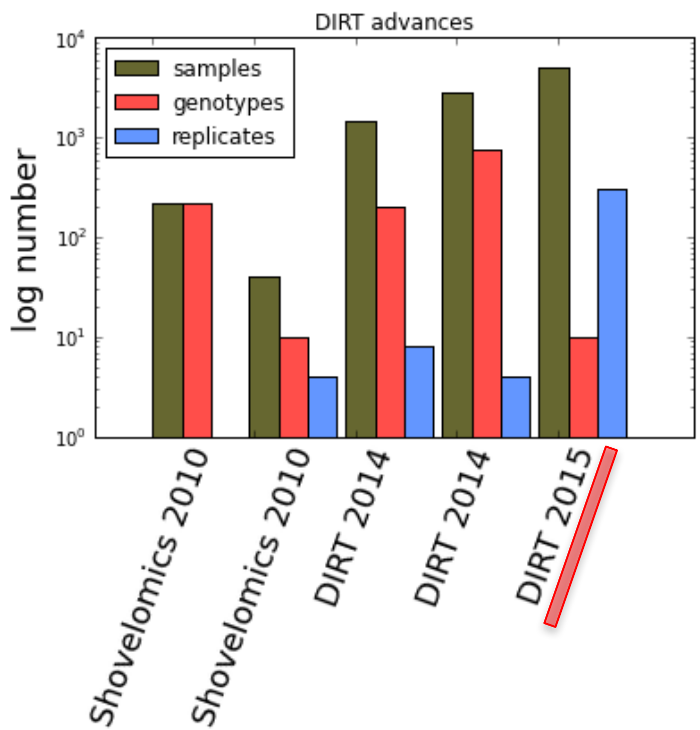


Scattered single points

Few average points with large standard error

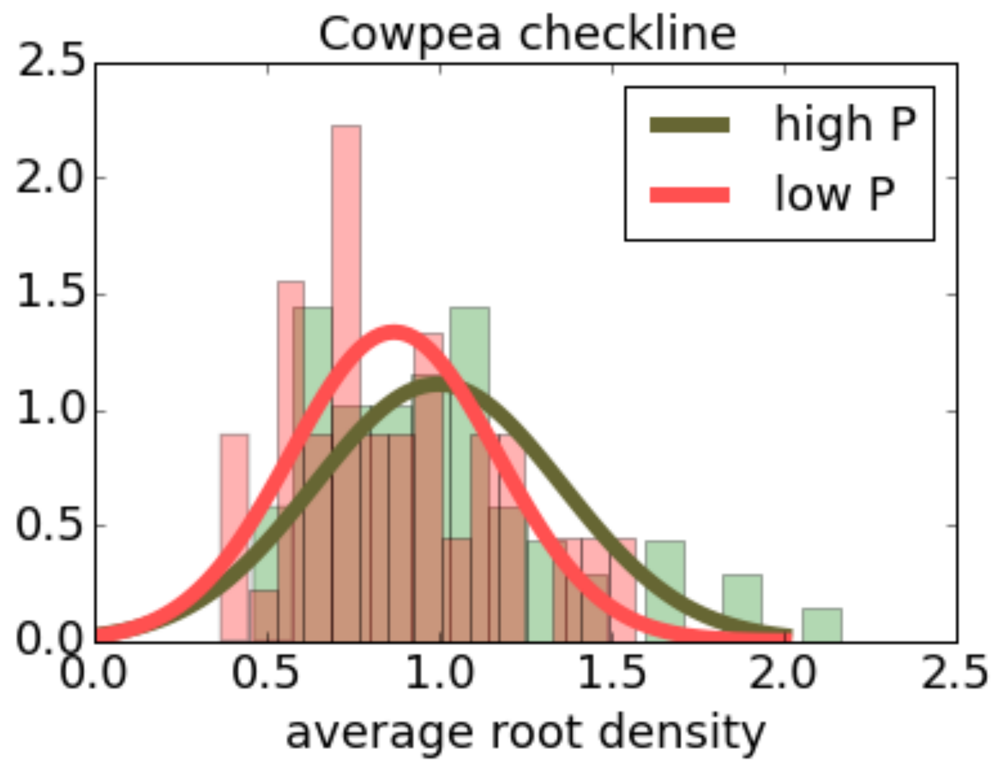
Many average points with standard error

Full phenotype distributions

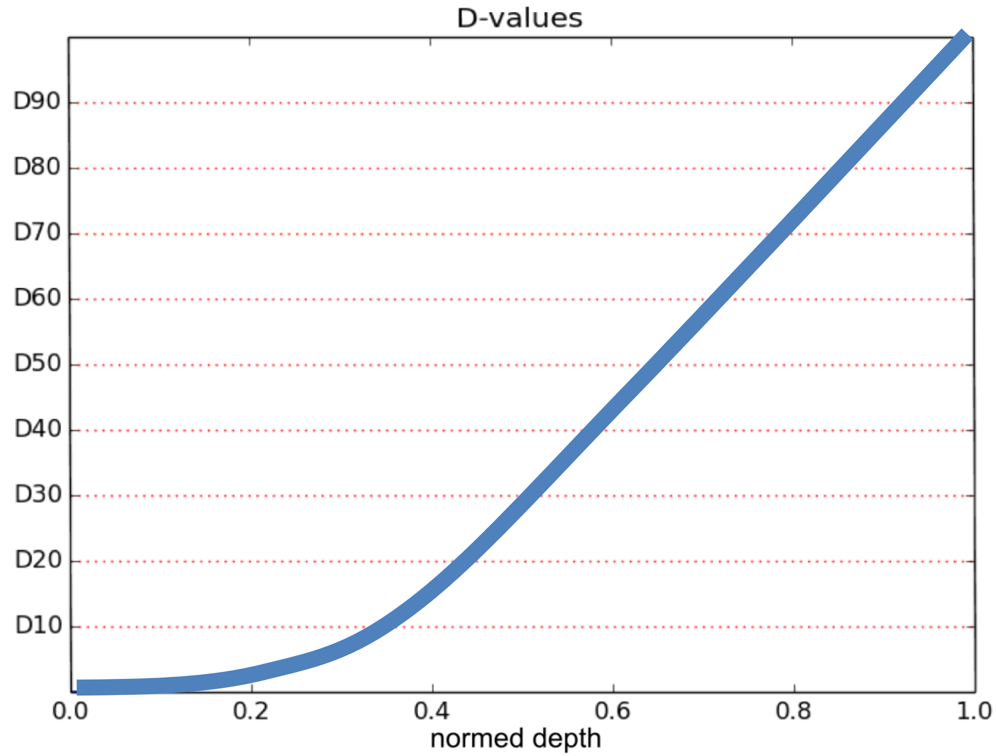


First link between plant morphology to agro-ecology

- Means are similar (P>0.5)
- Kurtosis significant (P<.001)
- cowpea genotype with high/low Phosphor
- Strong indicator for spatially distributed phenotypes and community structure



Mathematical function as trait: D-value



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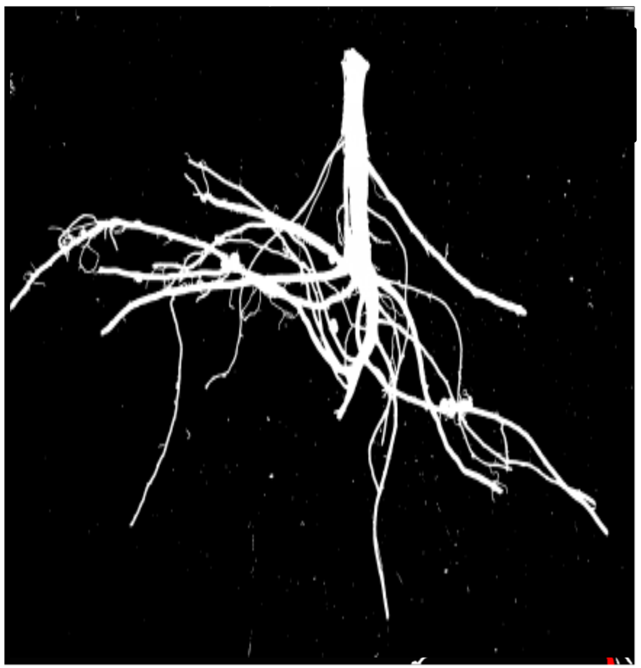

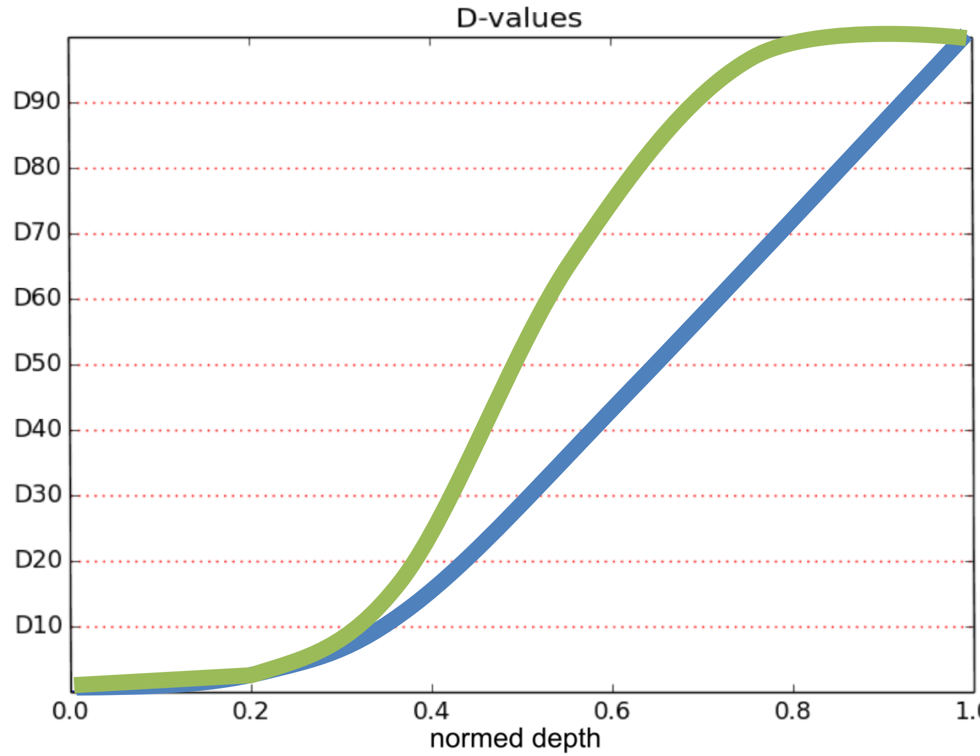

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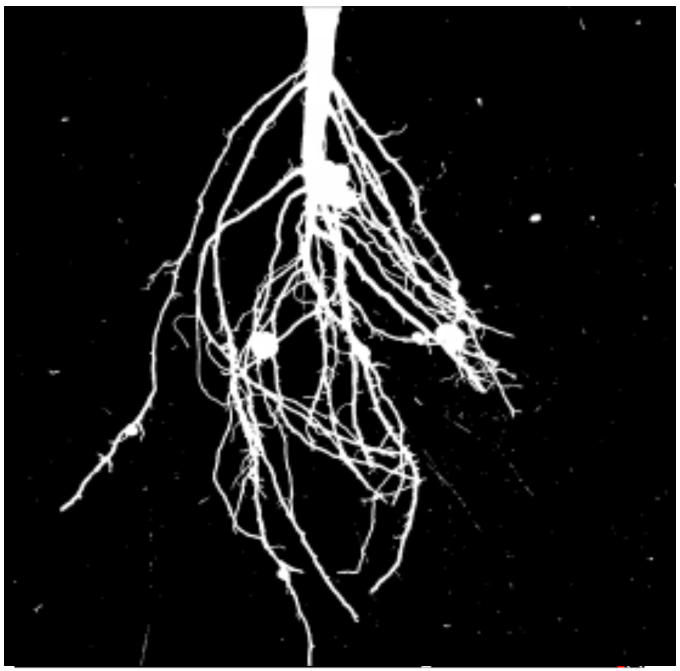

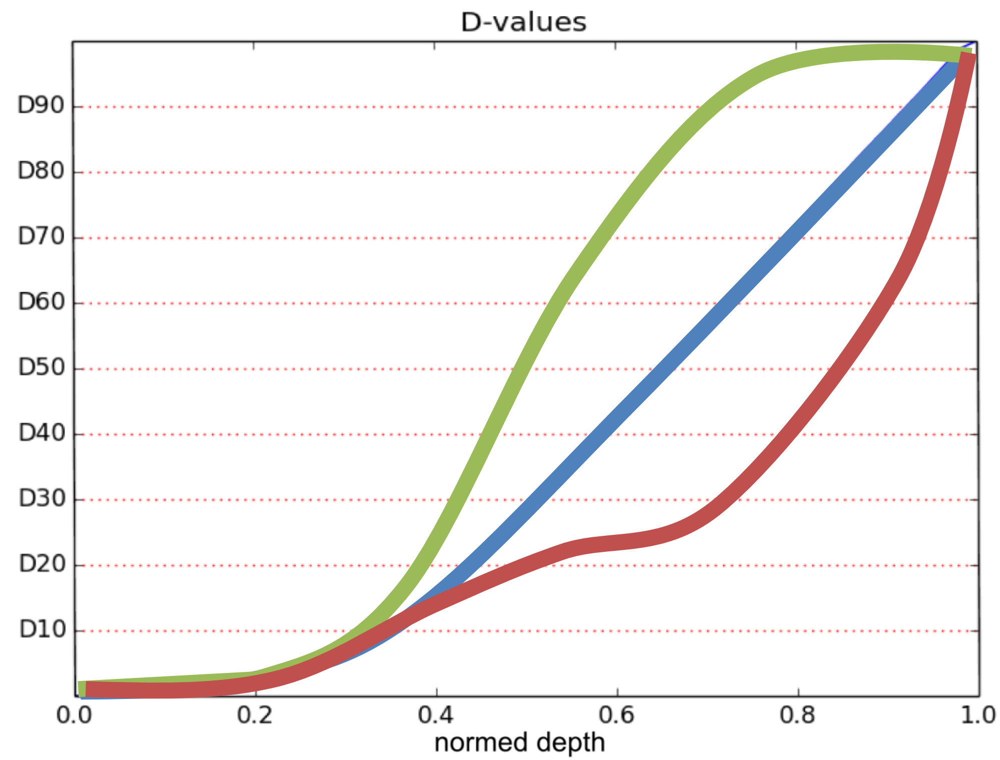

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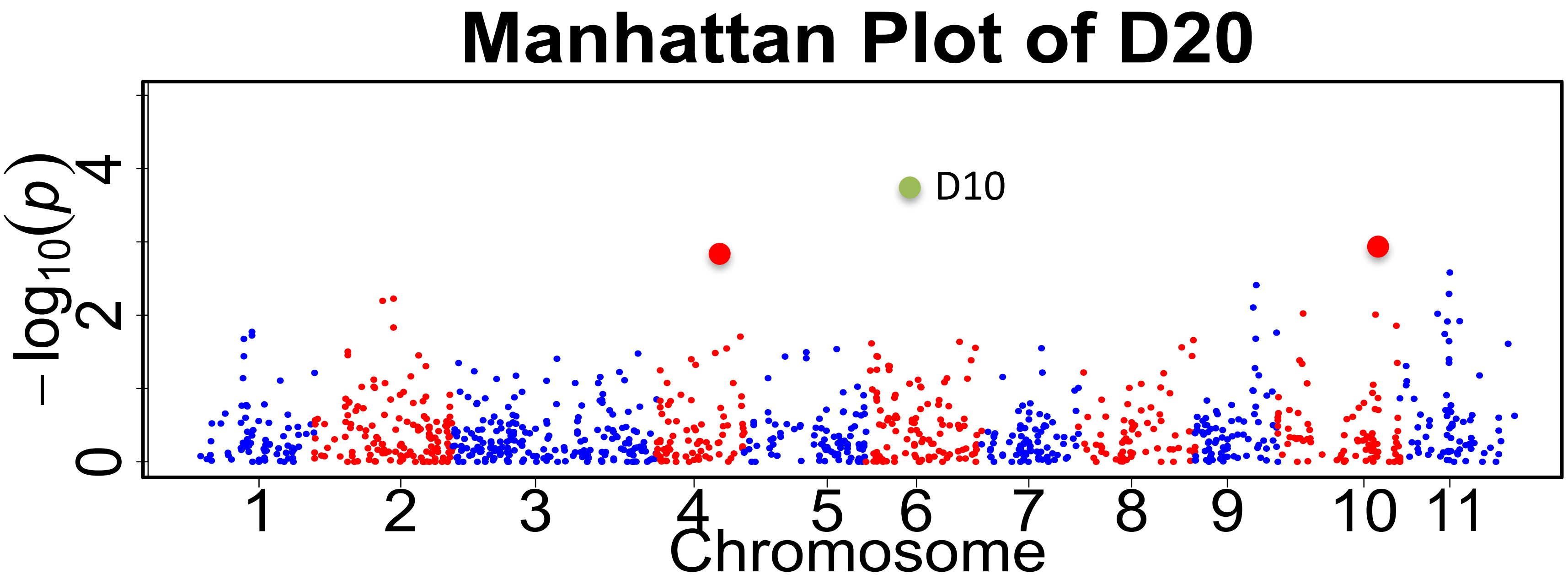
Organismal relation = genetic relation?



- **200 genotype cowpea diversity panel, 8 replicates, water stress and well watered**
- **Mathematical function characteristics reveal genomic regions**
- **Linked to *striga* resistance**

J. Burridge, H. Schneider, B. Lam, P. Roberts, A. Bucksch, J. Lynch
The Agronomic Impact of Genetically Controlled Cowpea Root Architecture (Theoretical and Applied Genetics)

How often do ideotypes occur?

Bean ideotype

2000 times one genotype in a grid

Tagging every plant with location

Morphotypes in common bean

Shallow morphotype

Ideotype

Skinny/bushy morphotype

Skinny morphotype

Bushy morphotype

Ongoing work

- Shape descriptors for tuber crops like cassava, yam and sweet potato in 2D/3D if possible
- Including hormonal and soil processes into simulation
- Robust analysis of branching structures
- Understanding phenotype plasticity within one genotype with known neighborhood.
- Open source community for DIRT

Computational Plant Science Lab

www.Computational-Plant-Science.org

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