Focus Group Y-4: Optimizing Root Architecture

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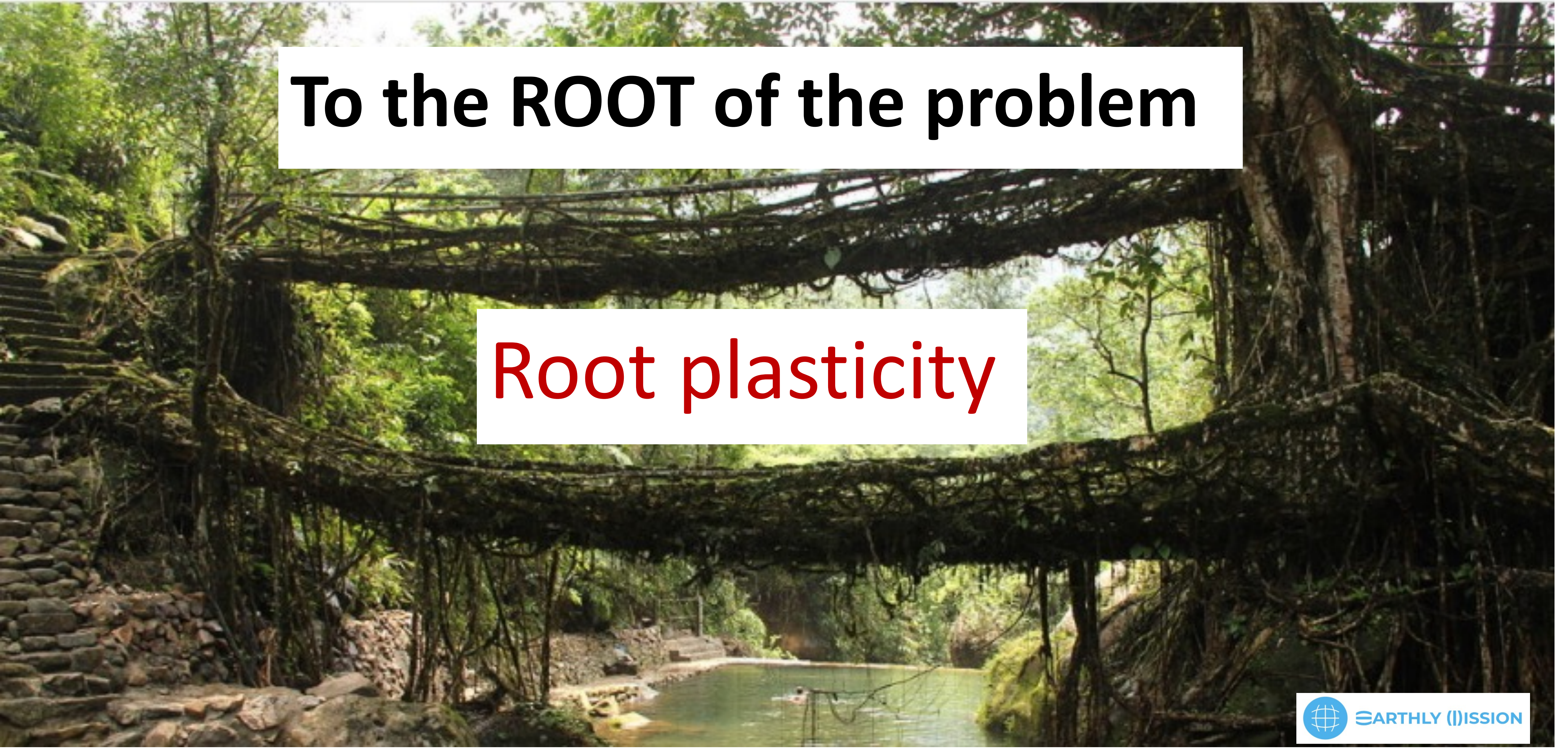
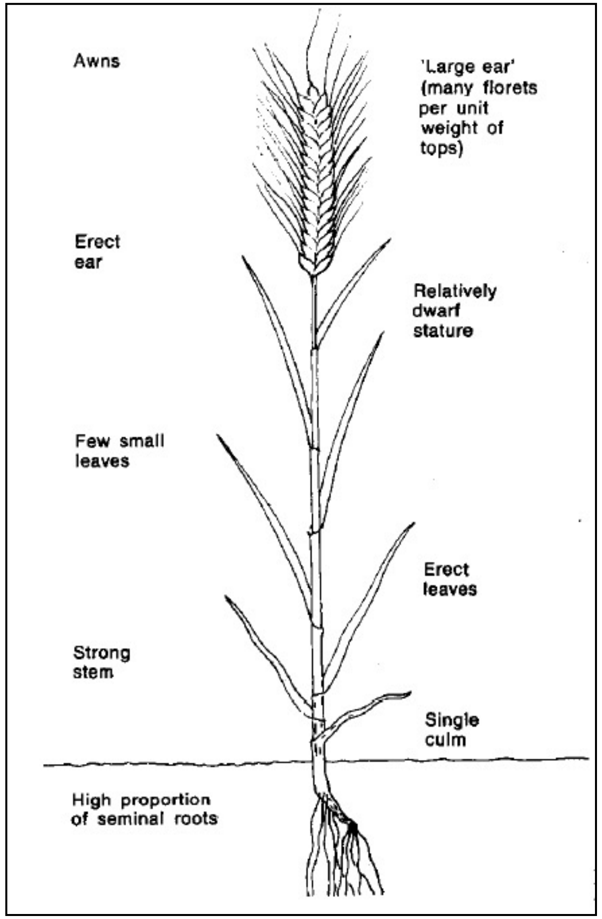
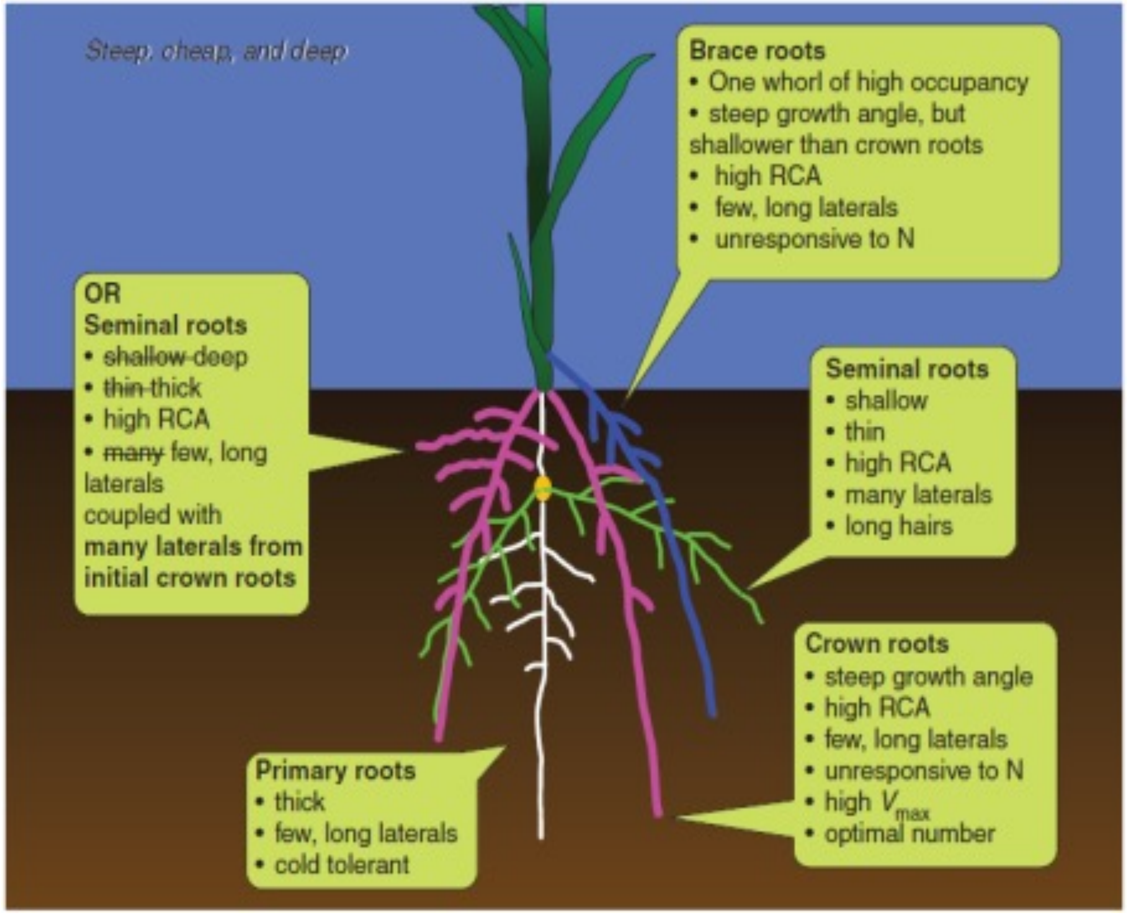

To the ROOT of the problem
Root plasticity
EARTHLY (I)ISSION

Crop ideotypes and roots



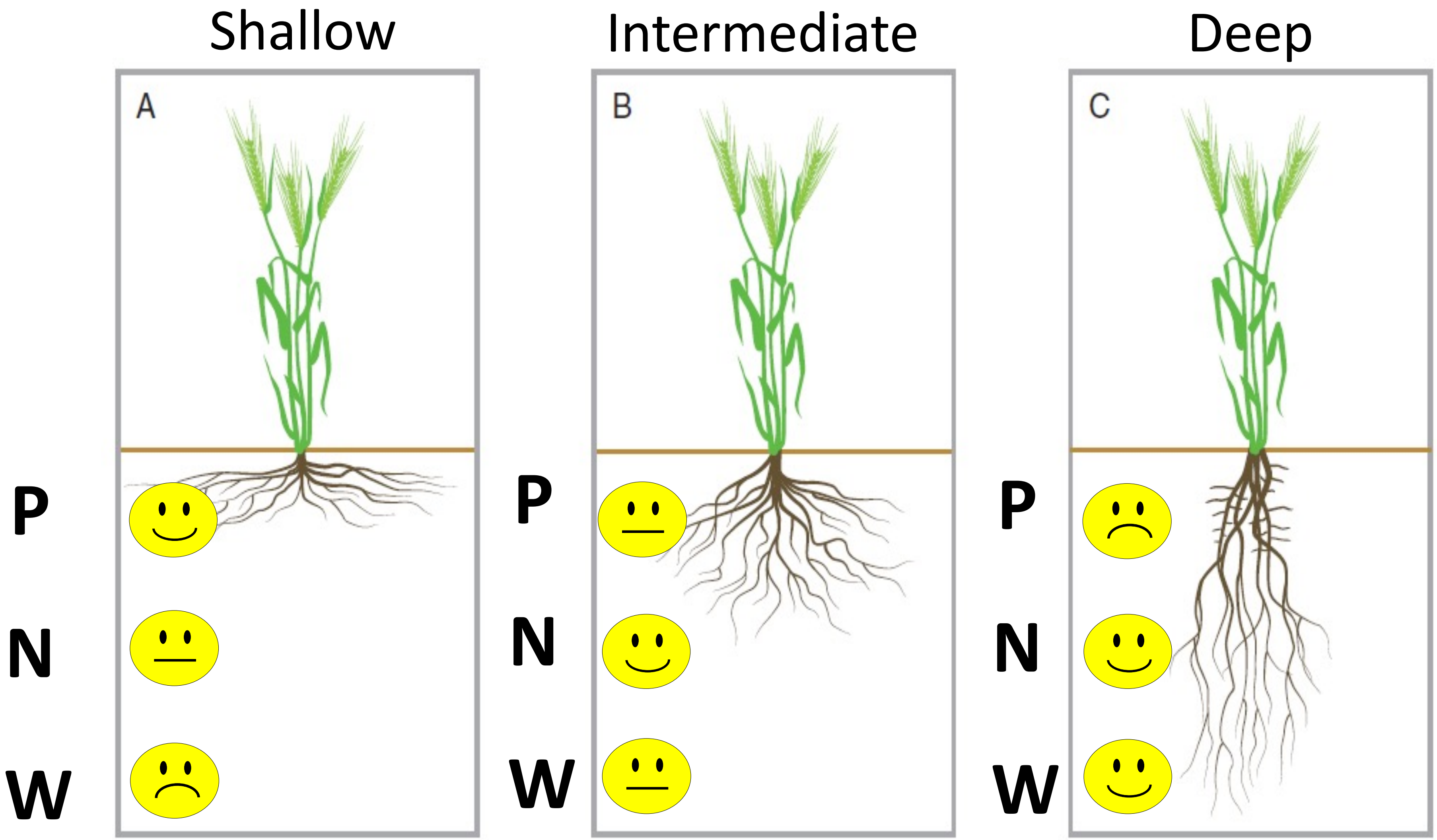


Donald CM (1968). The breeding of crop ideotypes. Euphytica

Lynch J (2013). Steep, cheap and deep, an ideotype for maize roots. Ann Bot

Lynch J (2018). Rightsizing root phenotypes for drought resistance. JXB

Root system architecture ideotypes

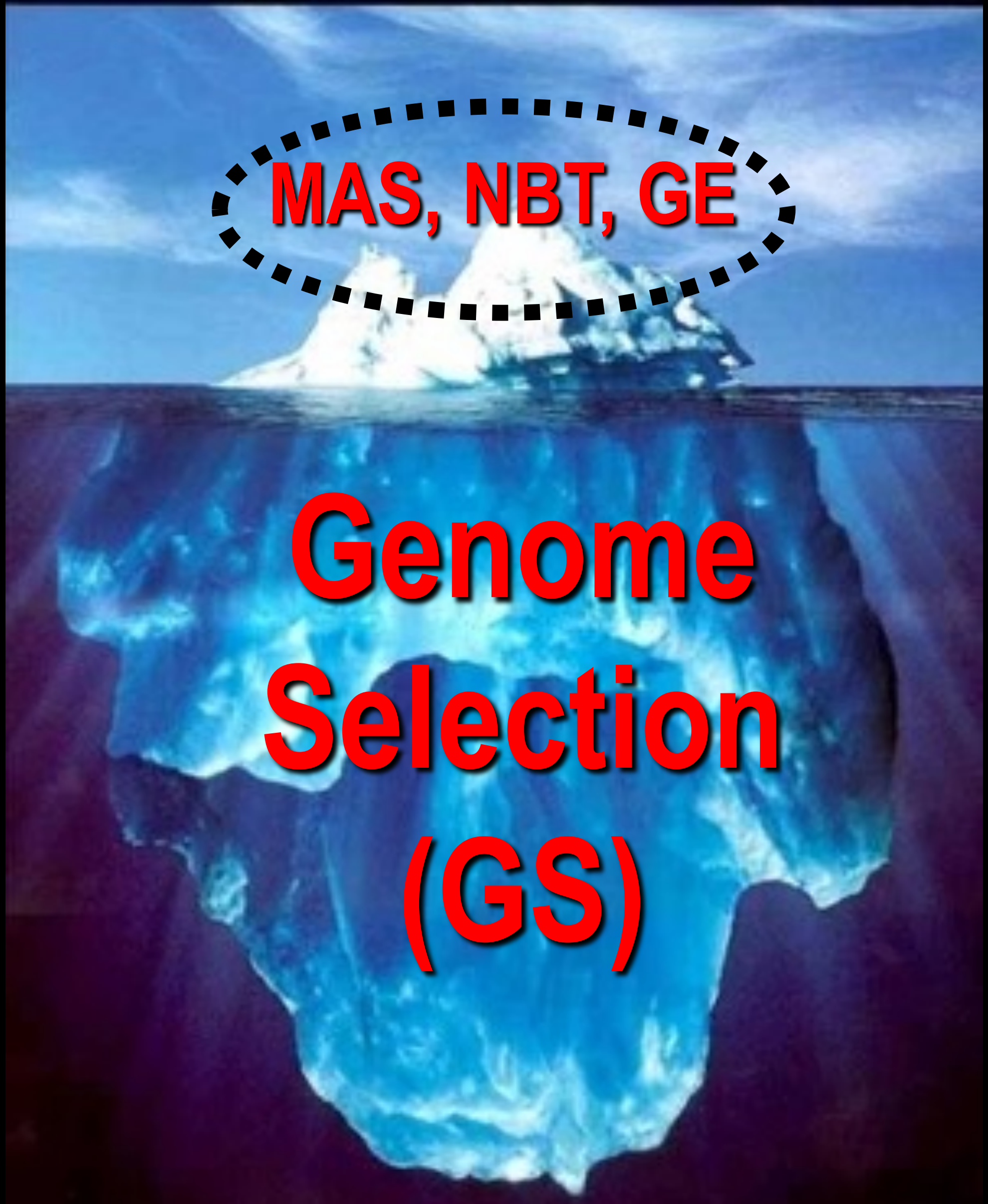


Modified from White *et al.* (2013) Annals of Botany

The crop QTLome iceberg

Major
QTL

Major
QTL



Salvi S., Tuberosa R. (2015). COPB 32, 179-185

Minor
QTL

Minor
QTL

Status quo of research in root system architecture - 1

- Our understanding of the genes that shape root system architecture (RSA) was mainly acquired from studies on *Arabidopsis* mutants.
- In field-grown plants, variability in root traits is controlled by quantitative trait loci (QTL) and their interactions with the environment and management practices (G x E x M).
- In most crops, ample genotypic variability has been documented for root traits and their plasticity under different environmental conditions.
- Leveraging the genetic variability of the root QTLome requires a deep understanding of the genetic make-up of RSA and root anatomy traits, their ontogeny and functions.

Tetraploid wheat native variation

Global Durum wheat Panel

1,018 elite entries

LD decay 4.2-7.2 Mbp

Mazzucottelli E et al. (2020)

Tetraploid wheat Global Collection

1,854 entries

LD decay 0.2-4.5 Mbp

Maccaferri M et al. (2019)

Co-ordinated phenotyping for:

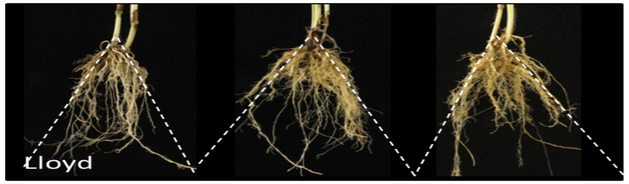
QTLome & allele mining

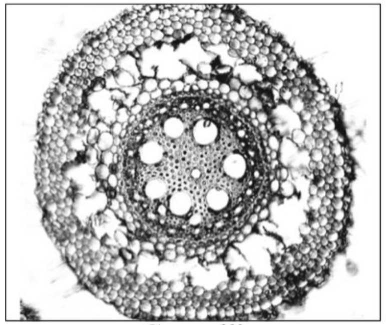
Functional genomics

Gene networks

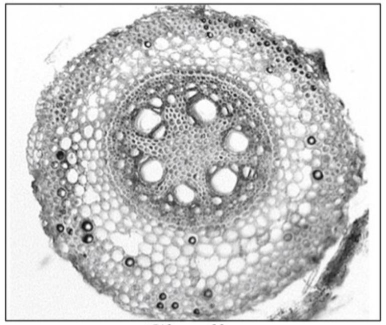
Multi-omics

Cloning

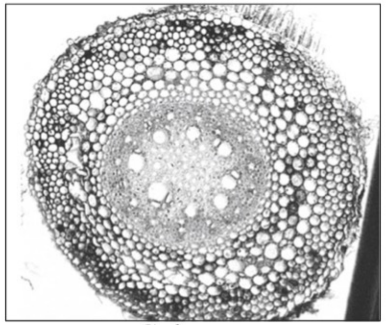




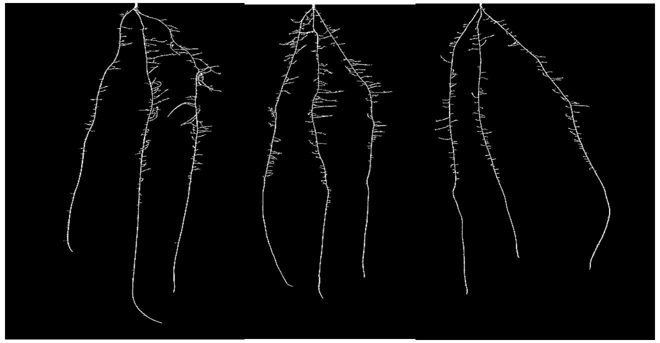
Cappelli



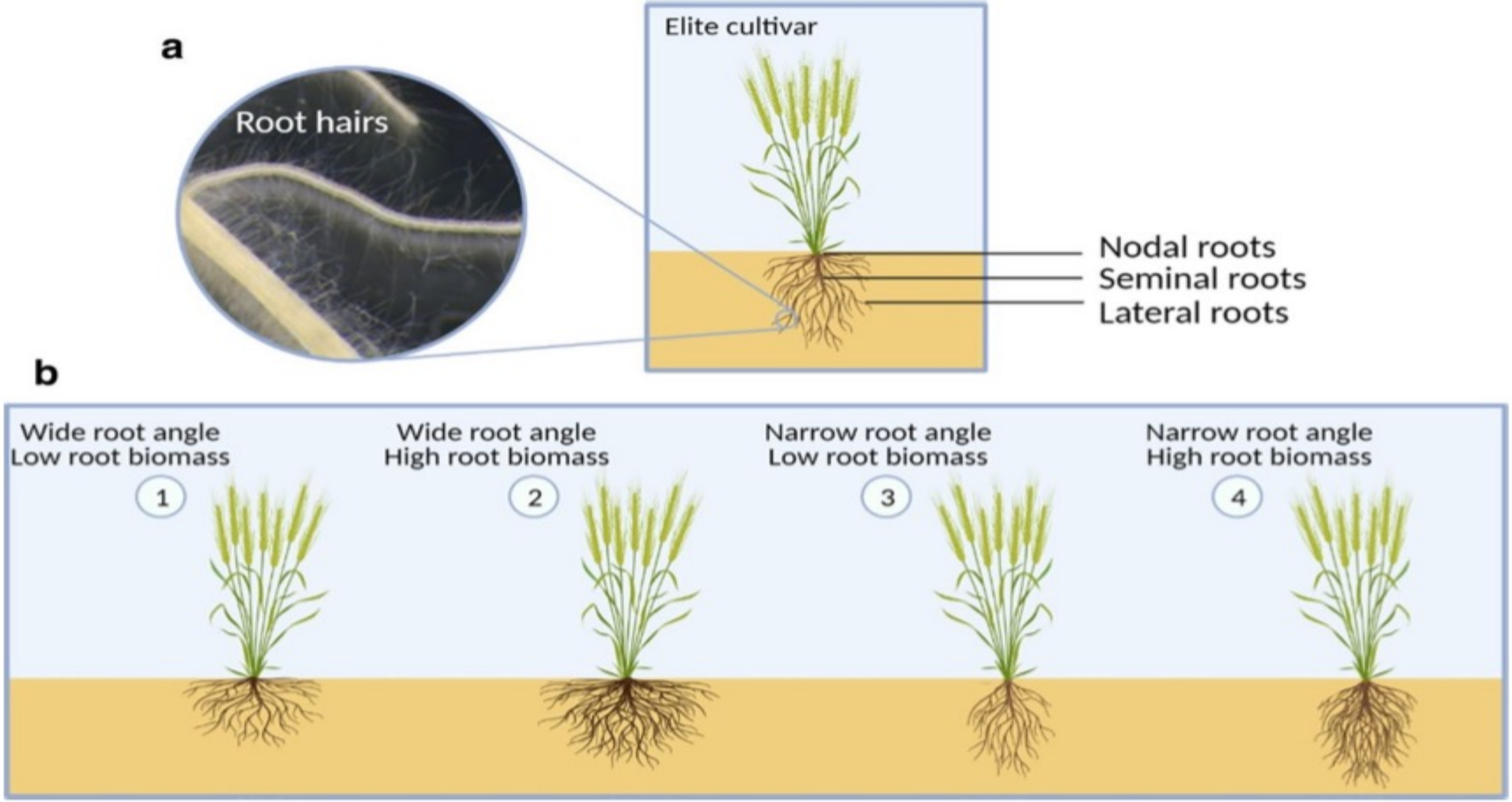
Claudio



Colosseo



Different root ideotypes that can be generated by combining different genetic loci controlling root angle and root biomass.

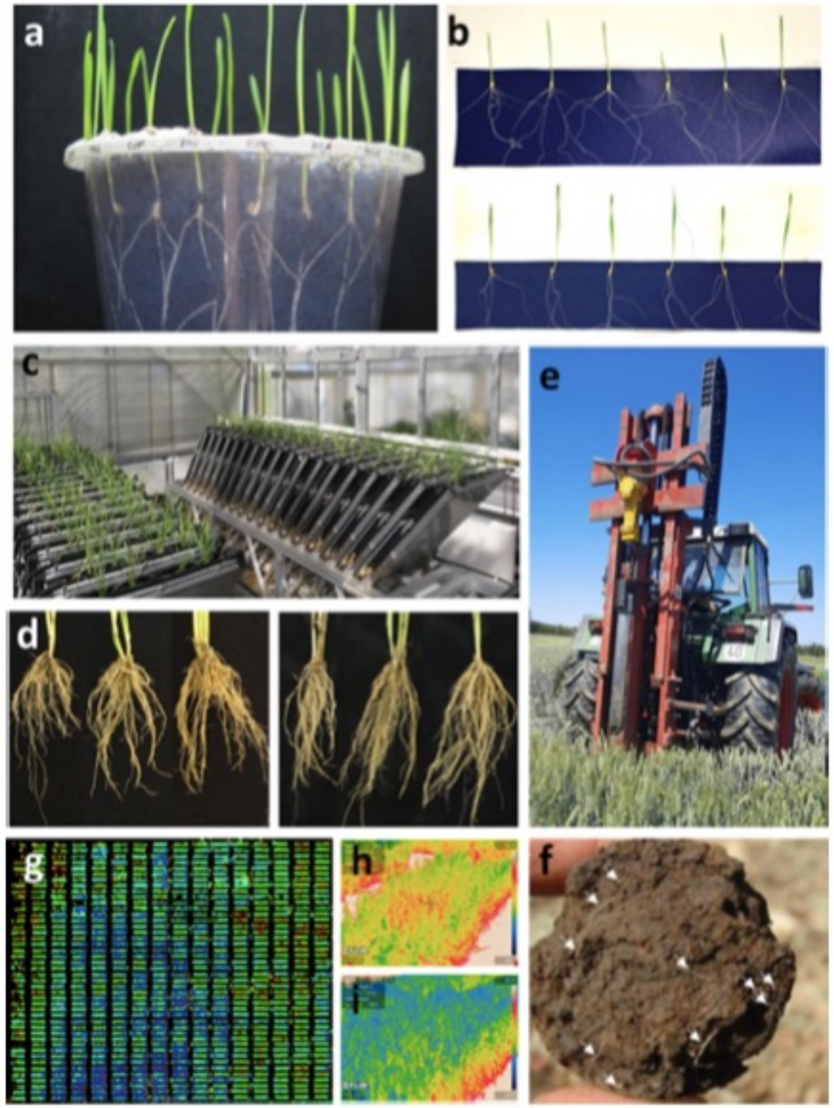


Ober et al. (2021). Wheat root systems as a breeding target for climate resilience. TAG, 1-18

Future challenges to be addressed with high priority -1

High-throughput phenotyping of root traits in

- Controlled conditions: aeroponics, semi-hydroponics, hydroponics, soil mesocosms, “novel” artificial substrates.
- Experimental fields with rain shelters and/or Free-Air Carbon dioxide Enrichment (FACE) facility
- Field conditions: canopy temperature, robots, soil cores, root anatomy using LAT (Strock et al, 2019) JXB 70, 5327-5342).
- Large rhizotrons: ‘Deep Frontiers’ project https://projects.au.dk/deepfrontier/

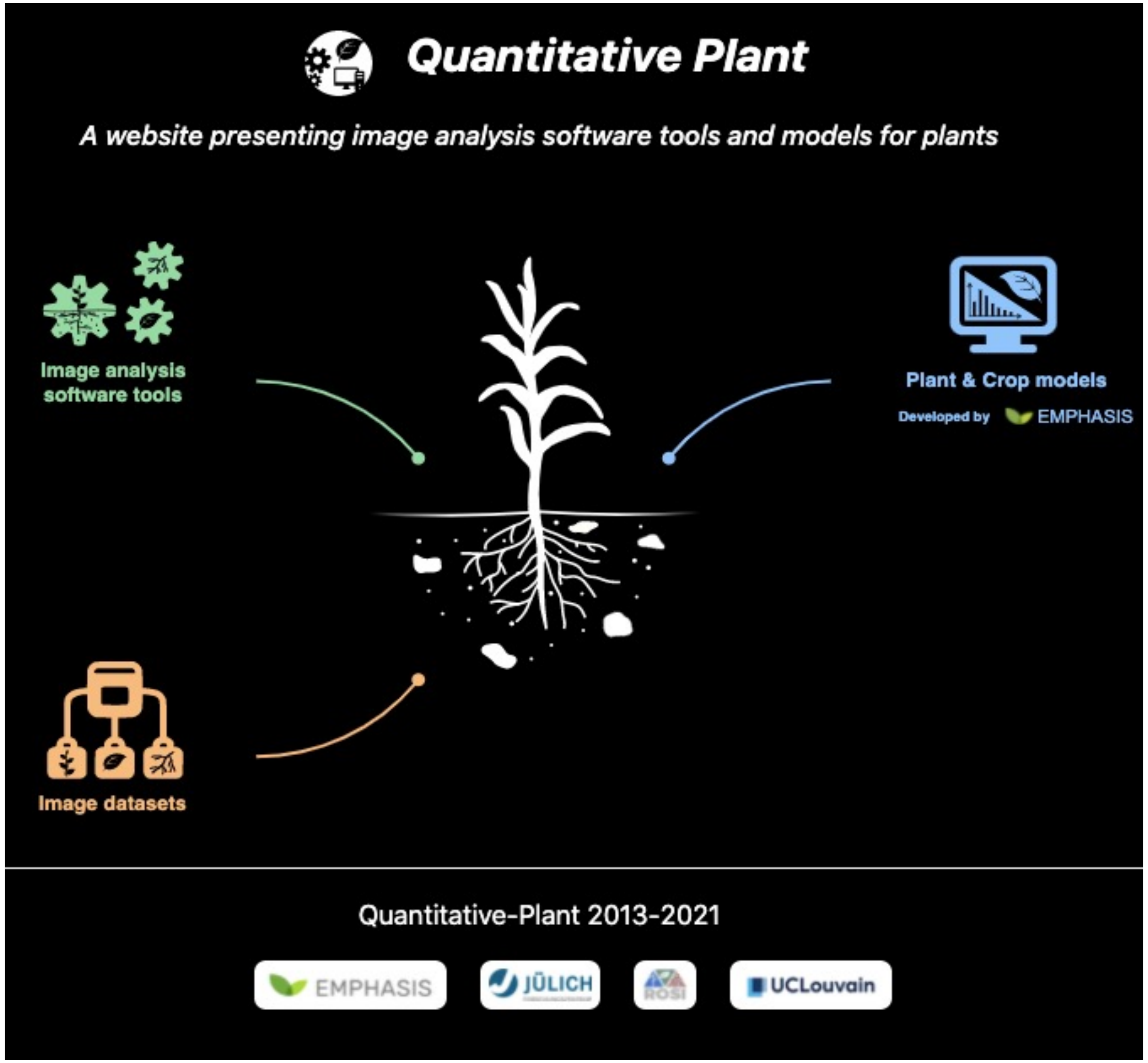


Ober et al. (2021). TAG, 1-18

Future challenges to be addressed with high priority - 2

Imaging

- Non-invasive imaging in 3/4D soil conditions (‘Hounsfield CT Facility’ in Nottingham)
- Automated image analysis based on artificial intelligence
- Development of user-friendly image analysis software



https://www.quantitative-plant.org/

Future challenges to be addressed with high priority - 3

Cloning of root mutants and major QTLs for RSA and root anatomy plasticity in response to:

- Flooding/excess water on early season root establishment and growth.
- Root rots in a context of dwindling seed treatment solutions, herbivory damages.
- Elevated atmospheric CO_2 concentration.
- Soil stresses (drought, Nitrogen, Pi, temperature, salinity, aluminum/pH).
- Soil compaction.

What are the most relevant unsolved questions (scientific questions, societal and economic challenges)?

- Lack of a systems biology appreciation of hormonal effects on RSA.
- Based on QTL effects, capacity to model root traits and root/shoot ratio to optimize crop’s performance in varying soil types, management and environments.
- Closer and more effective engagement with seed companies.
- Evaluate the effects of new RSA and root anatomy ideotypes on yield, quality and GHG emission of crops cultivated under conventional and organic farming.
- Evaluate the capacity of crops with different RSA or root anatomy to sequester C within soil (e.g., organic matter), and soil modifications related to roots and exudates.
- Evaluate yield and environmental footprint of crops with different RSA or root anatomy using networks of instrumented fields and models.

What needs to be done to solve the scientific questions and to meet the societal and economic challenges?

Societal and economic challenges

- Outreach activities and engagement to educate and inform the public about
- The biology of plant roots.
- Key role played by research on roots in agriculture.
- The unprecedented opportunities and advantages offered by biotechnology (e.g., MAS, NBT, editing) applied to modern breeding.