Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

European Space Agency

The Plastic Plant

Root Architectural Responses to Limited and Altered Nutrient Availability

Bahar Aciksöz
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THE FUNCTION OF A CROP…

…STARTS WITH ITS ROOTS.

AGENDA:

- The experiment
- The results
- Conclusions & open questions

ROOT PLASTICITY: THE EXPERIMENT

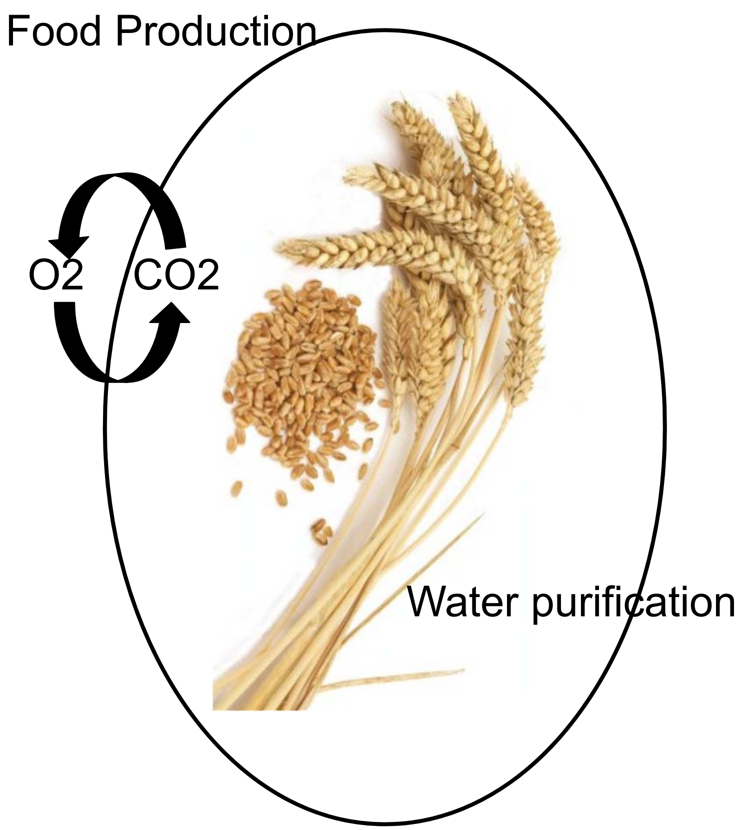
ROOT PARAMETERS

- Total root length
- Root volume
- Area covered by roots
- Projected area
- Root diameter
- Number of tips

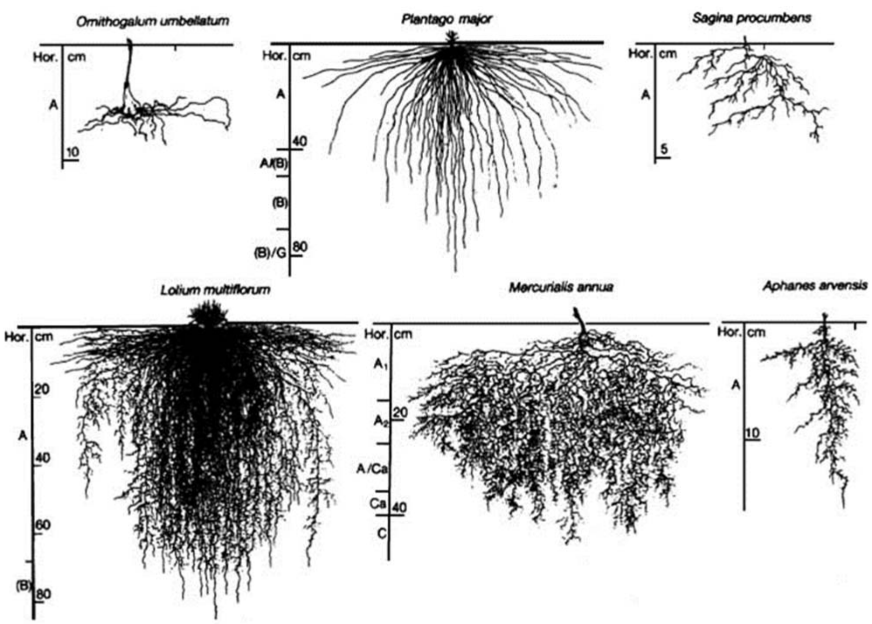
Micro Ecological Life Support System Alternative

- Operating closed ecosystems including higher plant compartments requires good understanding and prediction of plant behaviour particularly under nutrient constraints.
- Plant phenotyping (root morphological changes and shoot nutritional status to nutrient deficiencies) in the system to be vital to ensure reproducible and reliable system function.

Closed Ecological Life Support Systems



Root System Architecture (RSA)
Phenotyping the Hidden Half of Plants – Why?



Kutschera (1960)

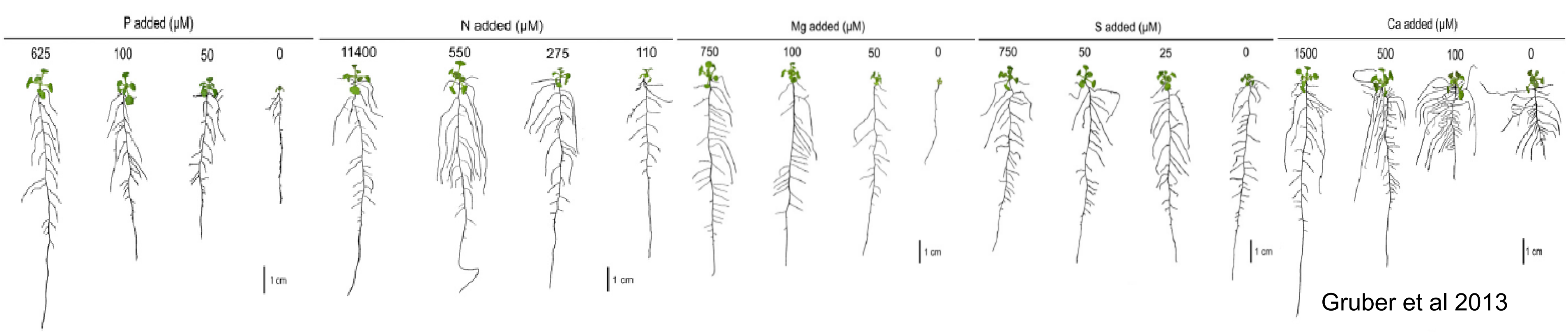
- Root system architecture (RSA) refers to the spatial arrangement and distribution of the roots
- RSA can strongly affect yield
- Branching patterns allows to promote nutrient acquisition
- An important aspect of below-ground crop physiology is its root foraging performance, which is inherently related to RSA
- **However, root phenotyping is a challenging task, mainly because of the hidden nature of the plant organ**

Root Architecture Response of Wheat to single and altered nutrient deficiencies

Root system architecture is plastic and influenced by the environment

The aims of this research:

- Reproducibly quantification of growth and architecture of roots
- Nutrient specific responses of wheat root morphology
- Elucidating dynamic establishment of roots in space and time
- Interaction of root responses with aboveground plant part
- Improving the physical modeling of root growth architecture



Gruber et al 2013

Non-invasive phenotyping of roots

continous

Low supply

High supply

Low supply High supply

discontinued

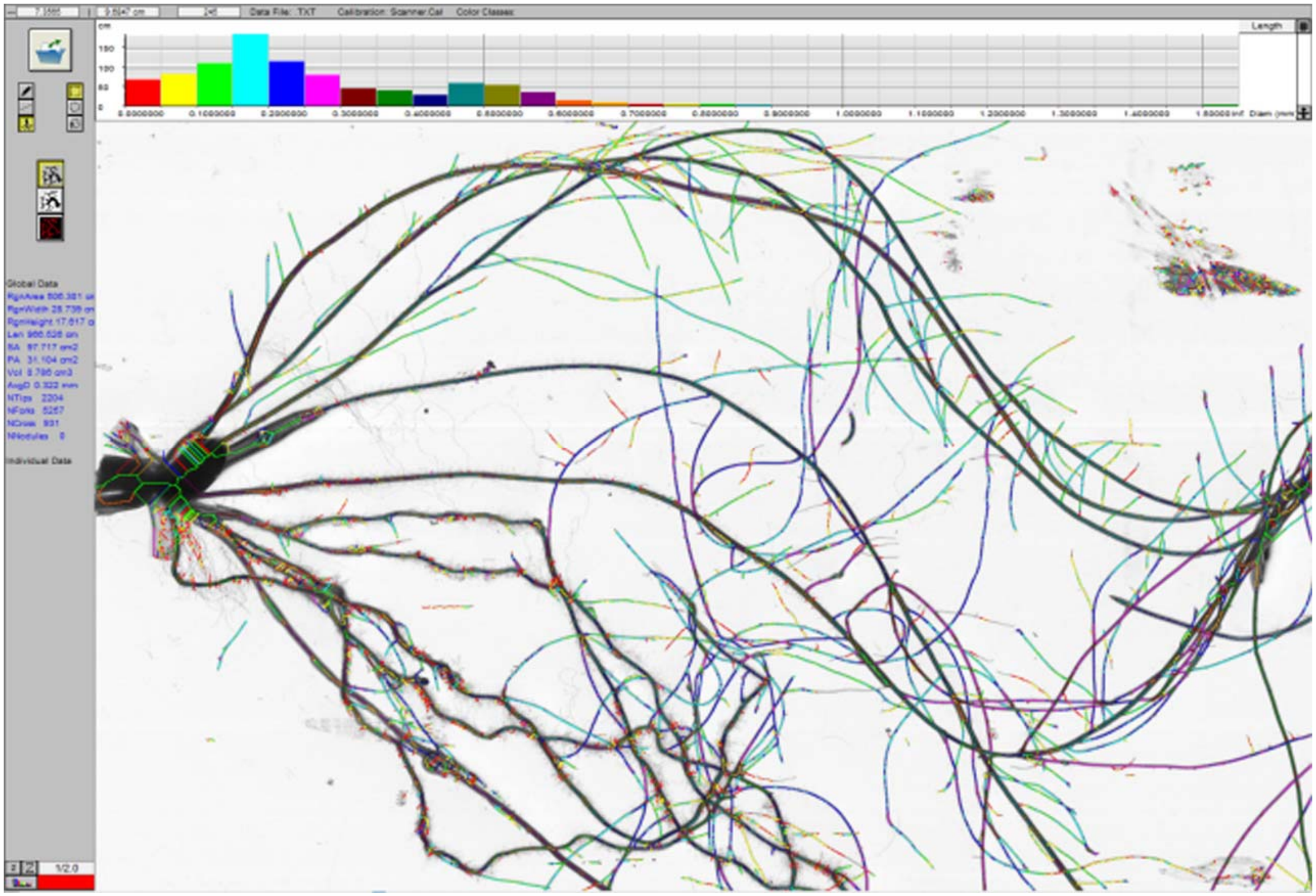
High supply Low supply

discontinued

- Hydroponic experiments with bread wheat were conducted
- Single nutrient deficiencies for 8 different macro-micro elements
- (Potassium, Nitrogen, Phosphorus, Calcium, Magnesium, Sulphur, Iron, Zinc)

- Estimating root measurements combined with different colors in 30 number of per root diameter classes
- Range of wheat root diameter is > 0.05 mm up to < 1.5 mm

Non-invasive phenotyping of roots: WinRhizo

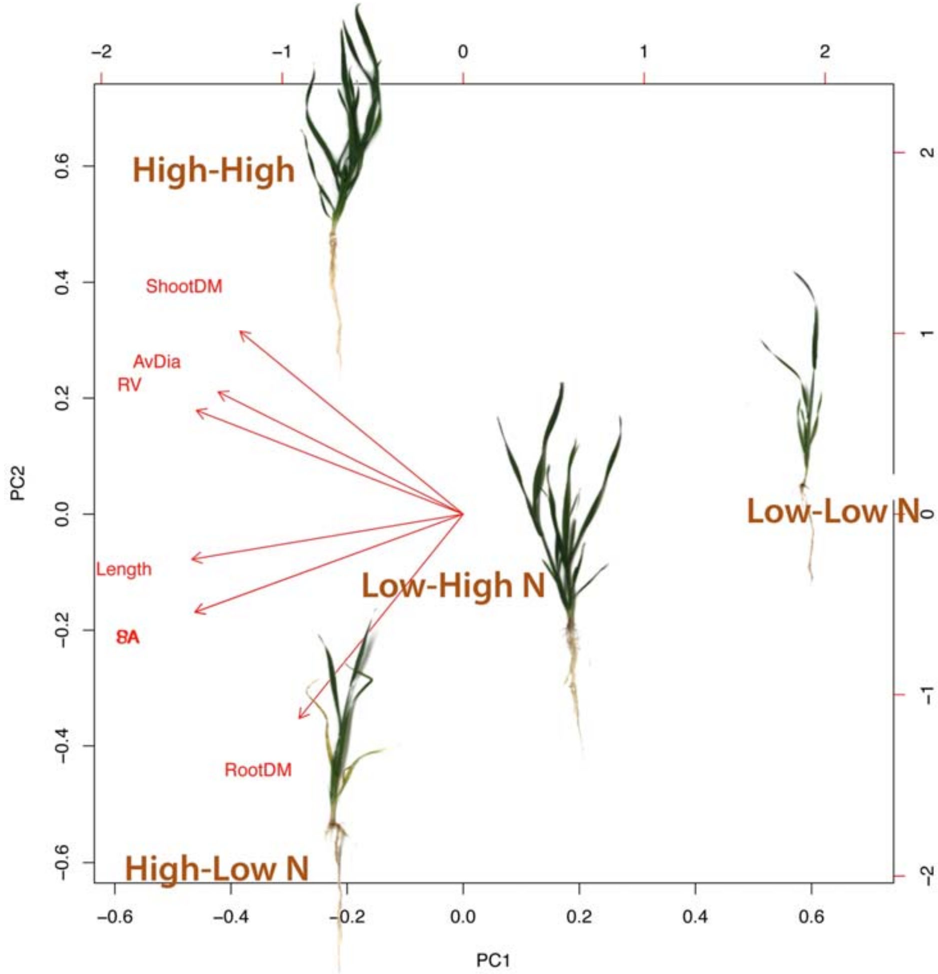


RESULTS

A Principal Component Analysis (PCA) was undertaken on independent root traits.

PCA based on RSA plasticity of deficiency and altered conditions

Nitrogen



N Low-High: Thinner root system

- Increased root length, decreased shoot, root vol. Impairment in early growth

N High-Low: Thicker root system

- Increased root volume, decreased shoot, enhanced root DM and surface area, indication of growth stimulation (Lopez and Bucio 2003)

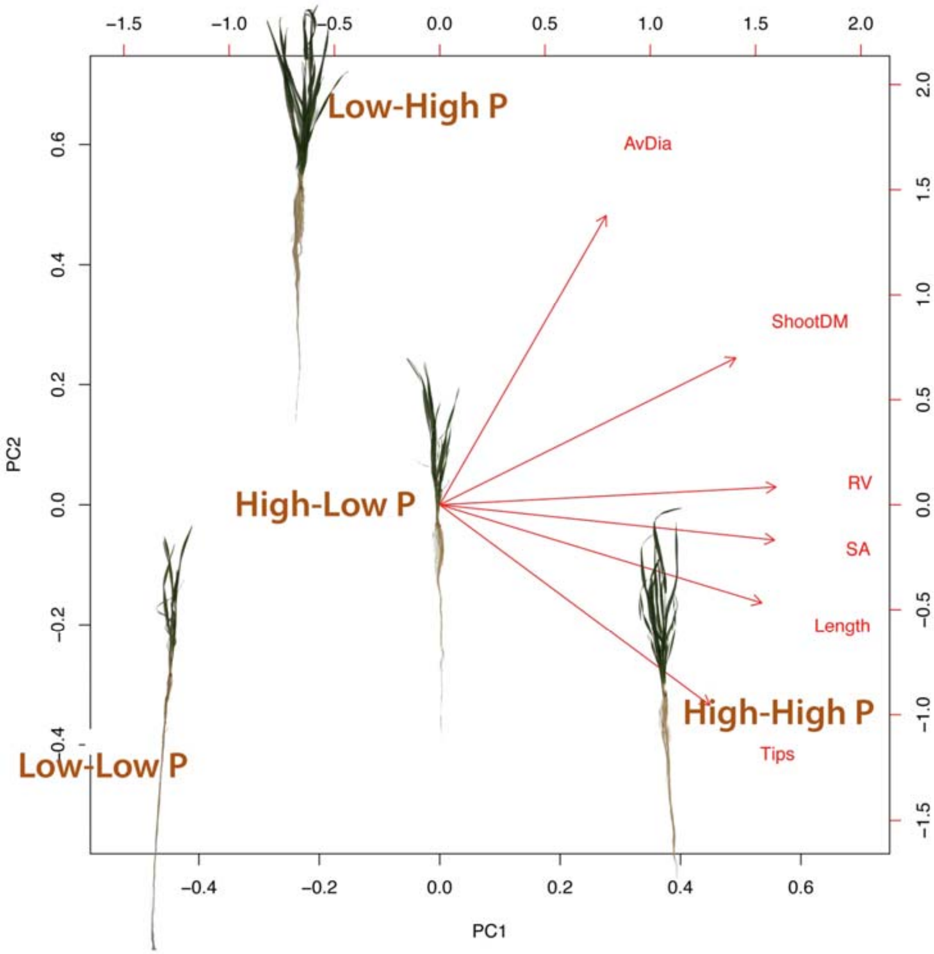
N Low: gave distinct results among all treatments

PC1 plus PC2 explained 93% of observed traits

Importance of components:	PC1	PC2	PC3	PC4
Standard deviation	2.2541	1.2088	0.67664	7.44E-16
Proportion of Variance	0.7258	0.2087	0.06541	0.00E+00
Cumulative Proportion	0.7258	0.9346	1	1.00E+00

PCA based on RSA plasticity of deficiency and altered conditions

Phosphorus



P Low-High: Thicker root system

- Increasing the P content did not differ in total length but increased diameter and volume resulting a thicker main axis

P High-Low: Thinner root system

- # tips increased (branching), root-to-shoot DM increased while root volume decreased

P Low: gave distinct results among all treatments

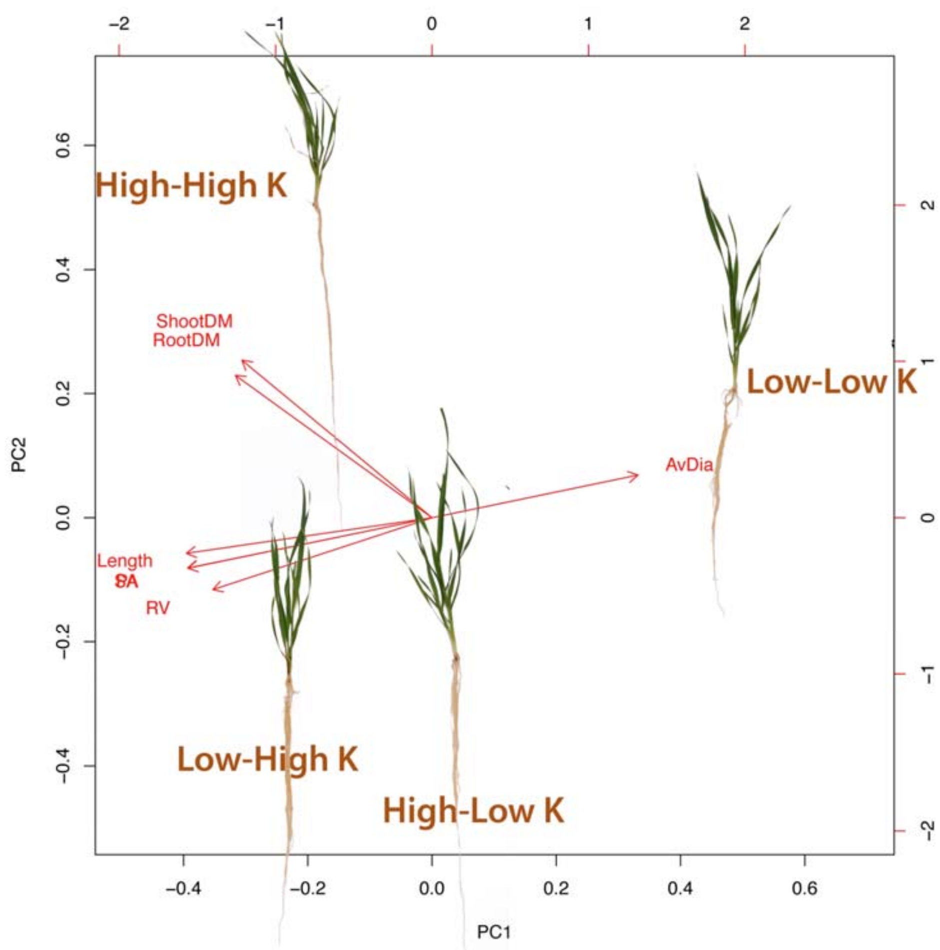
PC1 plus PC2 explained 98% of observed traits

Importance of components:

	PC1	PC2	PC3	PC4
Standard deviation	2.1349	1.1778	0.23446	3.36E-16
Proportion of Variance	0.7596	0.2312	0.00916	0.00E+00
Cumulative Proportion	0.7596	0.9908	1	1.00E+00

PCA based on RSA plasticity of deficiency and altered conditions

Potassium



While shoot and root biomass gave highest in high K treatment; root length, volume and surface gave similar results in altered conditions.

Average diameter and root length, volume were correlated negatively.

K Low: An increased diameter is more important for enhanced capture of immobile than mobile ions.

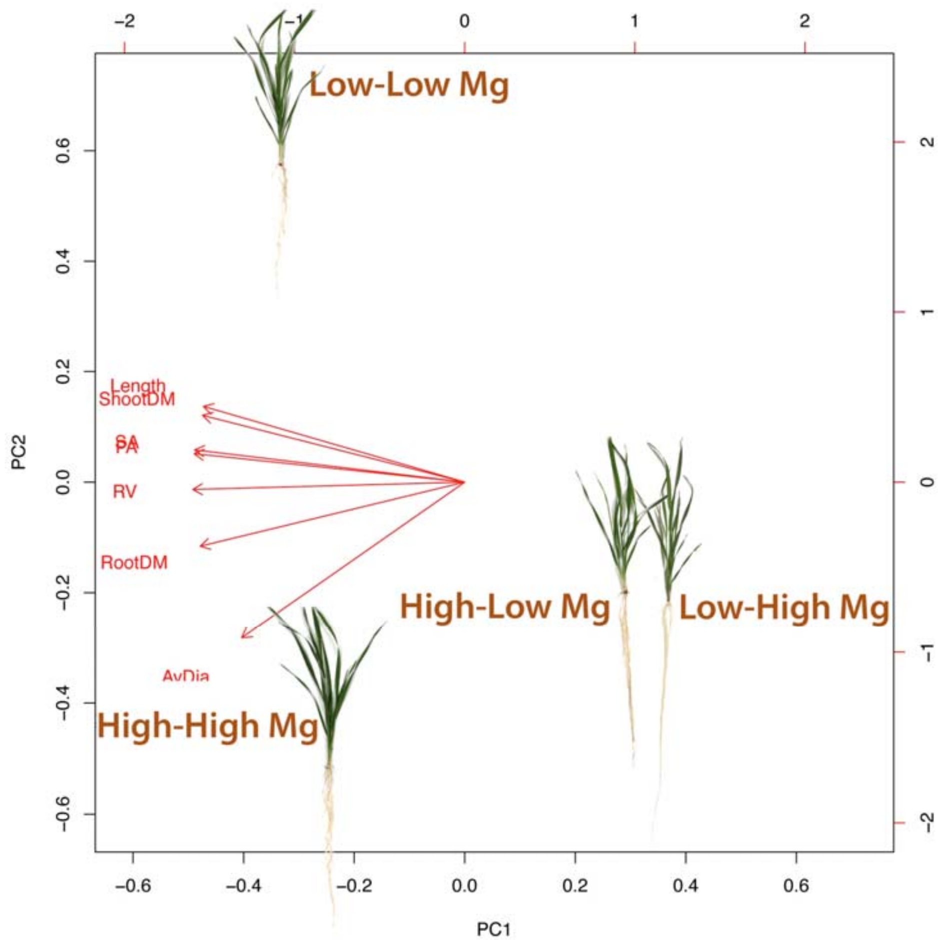
While altered conditions **K Low-High** and **K High-Low** correlated closely, the control groups: **K Low** and **K High** related against them

PC1 and PC2 explained 91% of the observed traits traits

Importance of Components	PC1	PC2	PC3	PC4
Standard deviation	2.3461	0.9659	0.7502	2.80E-16
Proportion of Variance	0.7863	0.1333	0.0804	0.00E+00
Cumulative Proportion	0.7863	0.9196	1	1.00E+00

PCA based on RSA plasticity of deficiency and altered conditions

Magnesium



While altered conditions **Mg Low-High** and **Mg High-Low** correlated closely, the control groups: **Mg Low** and **Mg High** related against them

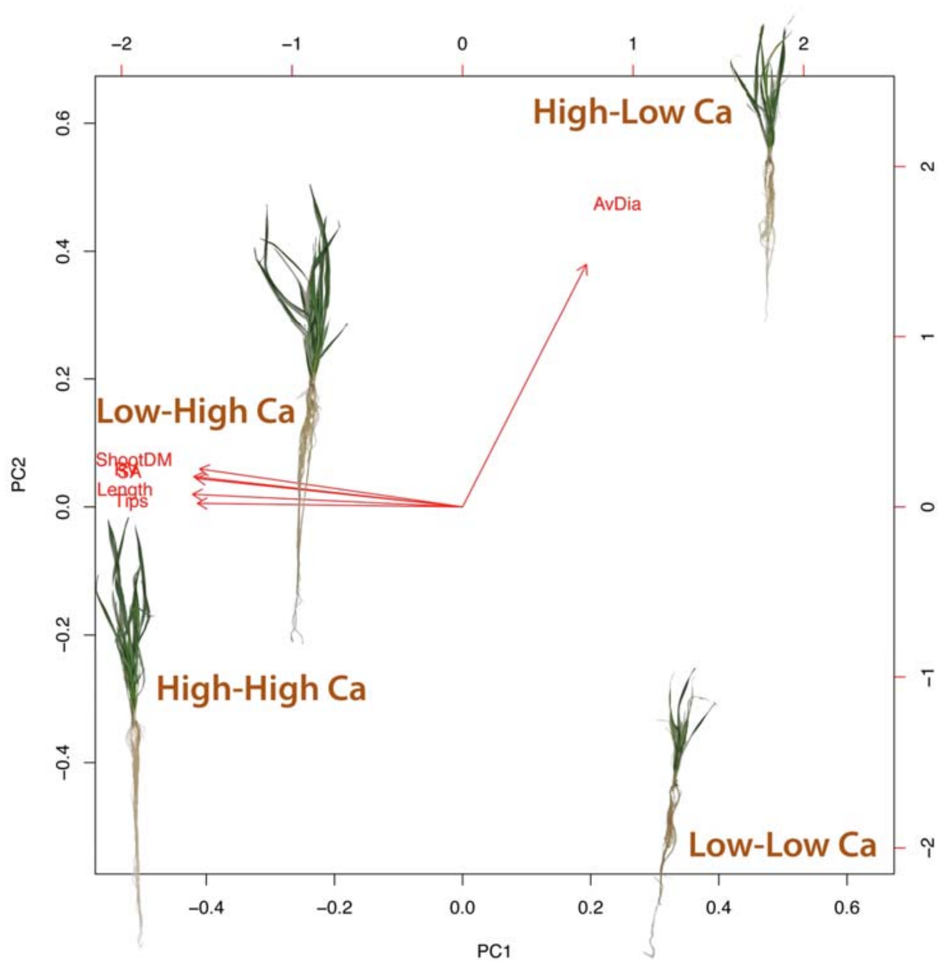
PC1 and PC2 explained 98% of the observed traits

Importance of components:

	PC1	PC2	PC3	PC4
Standard deviation	2.5372	0.73916	0.12703	2.86E-16
Proportion of Variance	0.9196	0.07805	0.00231	0.00E+00
Cumulative Proportion	0.9196	0.99769	1	1.00E+00

PCA based on RSA plasticity of deficiency and altered conditions

Calcium



Additional supply, **Ca Low-High** treatment gave similar results with **Ca High** treatment. Except average diameter, by decreasing Ca resulted shallower and thicker root system.

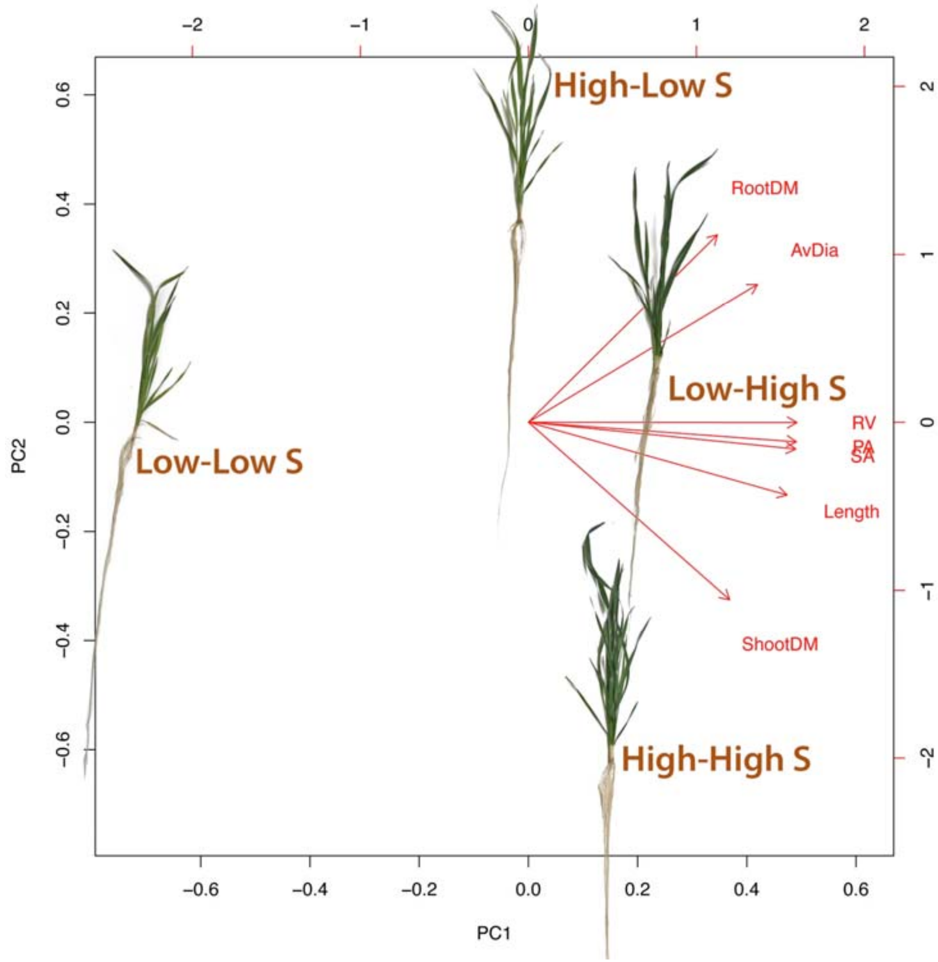
PC1 and PC2 explained 96% of the observed traits.

Importance of components:

	PC1	PC2	PC3	PC4
Standard deviation	1.7642	0.8846	0.32405	1.52E-16
Proportion of Variance	0.7781	0.1956	0.02625	0.00E+00
Cumulative Proportion	0.7781	0.9738	1	1.00E+00

PCA based on RSA plasticity of deficiency and altered conditions

Sulphur



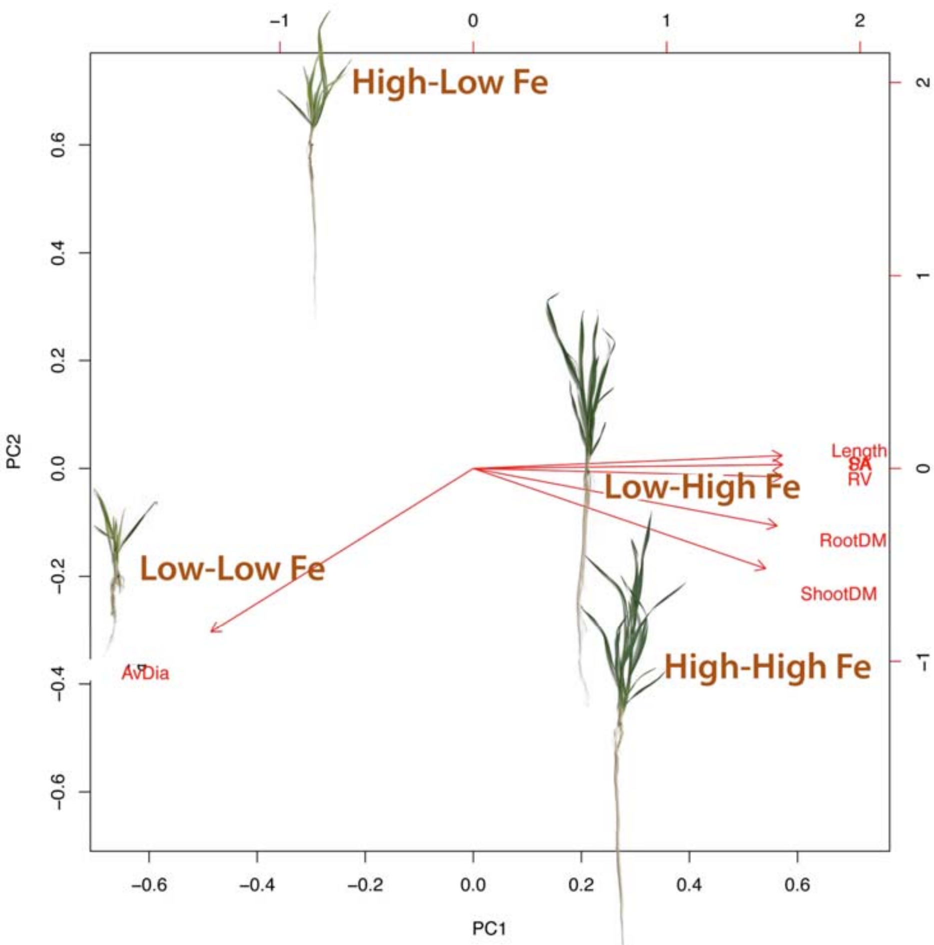
Withdrawal of supply **S Low** , **S High-Low** root DM and average diameter almost the same,while **S Low-High** and **S High** have similar results on length, volume and shoot DM.

Solely PC1 explained 90% of the observed traits.

Importance of components

	PC1	PC2	PC3	PC4
Standard deviation	1.9076	0.6008	0.01337	4.38E-16
Proportion of Variance	0.9097	0.09024	0.00004	0.00E+00
Cumulative Proportion	0.9097	0.99996	1	1.00E+00

PCA based on RSA plasticity of deficiency and altered conditions
Iron



Although Fe is a trace element, the deficiency conditions withdrawal caused restricted root length, volume and surface area.

Interestingly, **Fe Low** resulted thickest root system

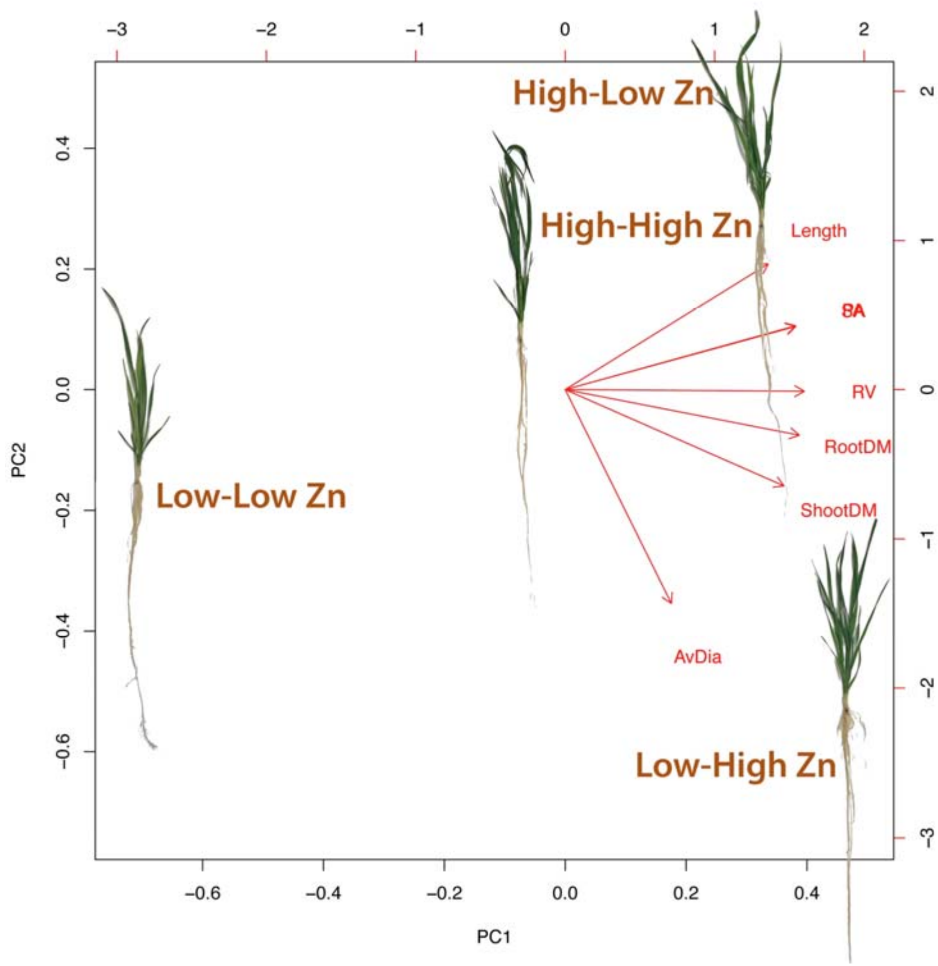
Solely PC1 explained 94% of the observed traits.

Importance of components:

	PC1	PC2	PC3	PC4
Standard deviation	1.9471	0.45587	0.02899	9.25E-18
Proportion of Variance	0.9478	0.05195	0.00021	0.00E+00
Cumulative Proportion	0.9478	0.99979	1	1.00E+00

PCA based on RSA plasticity of deficiency and altered conditions

Zinc



Zn High Low and **Zn High** gave similar results in total length, surface area, volume, root and shoot DM. (Zn is a semimobile element)

Zn Low-High: Thicker root system with increased diameter

PC1 and PC2 explained 99% of the observed traits

Importance of components:

	PC1	PC2	PC3	PC4
Standard deviation	1.72	1.0196	0.0202	2.30E-17
Proportion of Variance	0.74	0.2599	0.0001	0.00E+00
Cumulative Proportion	0.74	0.9999	1	1.00E+00

CONCLUSIONS

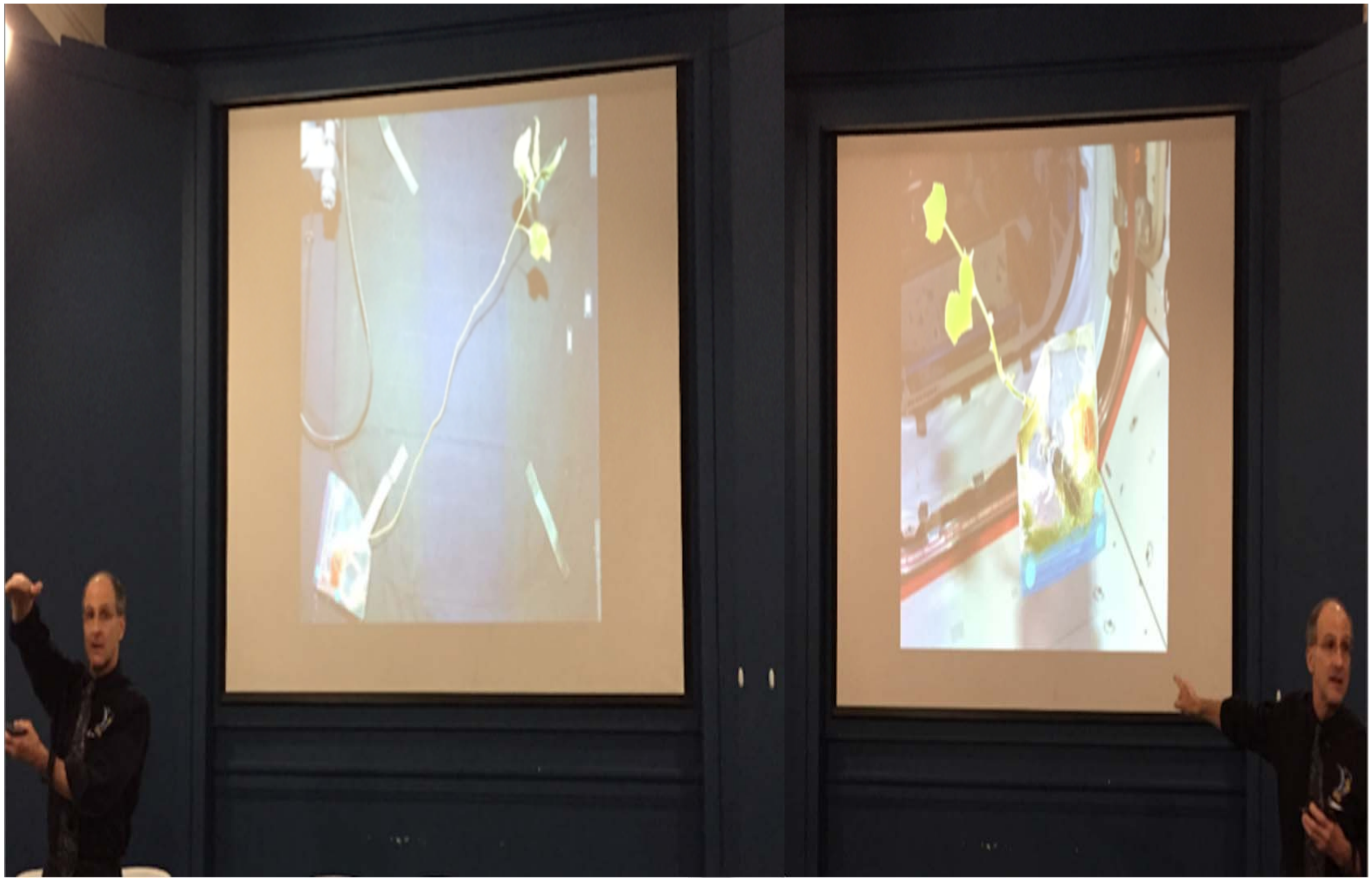
- Nutrient capture from the added was different of the scale of heterogeneity, suggesting that roots were sufficiently plastic in their response to track the scale of **continuous/discontinuous** and maintain performance.
- Root morphological and physiological responses are far from uniform across species, and even within species the size of the response depends on the **scale of heterogeneity**.
- Our future research focuses on the importance of root plasticity for **nutrient capture** rather than simply measuring the size of the response.
- Molecular research is also needed on the **signal pathways** involved in root proliferation responses.

CHALLENGES: ROOT ADAPTATIONS

Open questions

- Are there tradeoffs between efficiency and potential of resource acquisition?
- Is the aim of adapting crops in obstacle environments by root modification a realistic approach?
  - ➢ Reproducibility quantification of growth and architecture of roots
  - ➢ Elucidating dynamic establishment of roots in space and time
- What would be the optimal timing of fertilization for commercial and BLSS hydroponics?

Space for Inspiration Workshop, London 2016



Don Pettit, NASA astronaut and Space Gardener

The green plant you see in the bag, has been grown from zucchini seeds that he carried in his pocket up to International the Space Station without taking permission from the ground ☺

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THANK YOU!