The Plastic Plant

Root Architectural Responses to Limited and Altered Nutrient Availability
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.
Root System Architecture (RSA)  
Phenotyping the Hidden Half of Plants – Why?

- 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

Kutschera (1960)
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

- 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
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

<table>
<thead>
<tr>
<th>Importance of components:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
</tr>
<tr>
<td>Proportion of Variance</td>
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<tr>
<td>Cumulative Proportion</td>
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</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Importance of Components</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard deviation</td>
<td>2.3461</td>
<td>0.9659</td>
<td>0.7502</td>
<td>2.80E-16</td>
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<tr>
<td>Proportion of Variance</td>
<td>0.7863</td>
<td>0.1333</td>
<td>0.0804</td>
<td>0.00E+00</td>
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<tr>
<td>Cumulative Proportion</td>
<td>0.7863</td>
<td>0.9196</td>
<td>1</td>
<td>1.00E+00</td>
</tr>
</tbody>
</table>
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:

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<tr>
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<tbody>
<tr>
<td>Standard deviation</td>
<td>2.5372</td>
<td>0.73916</td>
<td>0.12703</td>
<td>2.86E-16</td>
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<tr>
<td>Proportion of Variance</td>
<td>0.9196</td>
<td>0.07805</td>
<td>0.00231</td>
<td>0.00E+00</td>
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<tr>
<td>Cumulative Proportion</td>
<td>0.9196</td>
<td>0.99769</td>
<td>1</td>
<td>1.00E+00</td>
</tr>
</tbody>
</table>
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:

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<tr>
<td>Standard deviation</td>
<td>1.7642</td>
<td>0.8846</td>
<td>0.32405</td>
<td>1.52E-16</td>
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<tr>
<td>Proportion of Variance</td>
<td>0.7781</td>
<td>0.1956</td>
<td>0.02625</td>
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<tr>
<td>Cumulative Proportion</td>
<td>0.7781</td>
<td>0.9738</td>
<td>1</td>
<td>1.00E+00</td>
</tr>
</tbody>
</table>
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.
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.

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<tr>
<td>Standard deviation</td>
<td>1.9471</td>
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<td>0.02899</td>
<td>9.25E-18</td>
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<tr>
<td>Proportion of Variance</td>
<td>0.9478</td>
<td>0.05195</td>
<td>0.00021</td>
<td>0.00E+00</td>
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<tr>
<td>Cumulative Proportion</td>
<td>0.9478</td>
<td>0.99979</td>
<td>1</td>
<td>1.00E+00</td>
</tr>
</tbody>
</table>
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

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<th>PC4</th>
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</thead>
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<tr>
<td>Standard deviation</td>
<td>1.72</td>
<td>1.0196</td>
<td>0.0202</td>
<td>2.30E-17</td>
</tr>
<tr>
<td>Proportion of Variance</td>
<td>0.74</td>
<td>0.2599</td>
<td>0.0001</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>Cumulative Proportion</td>
<td>0.74</td>
<td>0.9999</td>
<td>1</td>
<td>1.00E+00</td>
</tr>
</tbody>
</table>
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.
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?
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 😊
THANK YOU!