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RHIZOSPHERE SPATIOTEMPORAL ORGANISATION
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Root Hairs bridge the gap between roots and soil water

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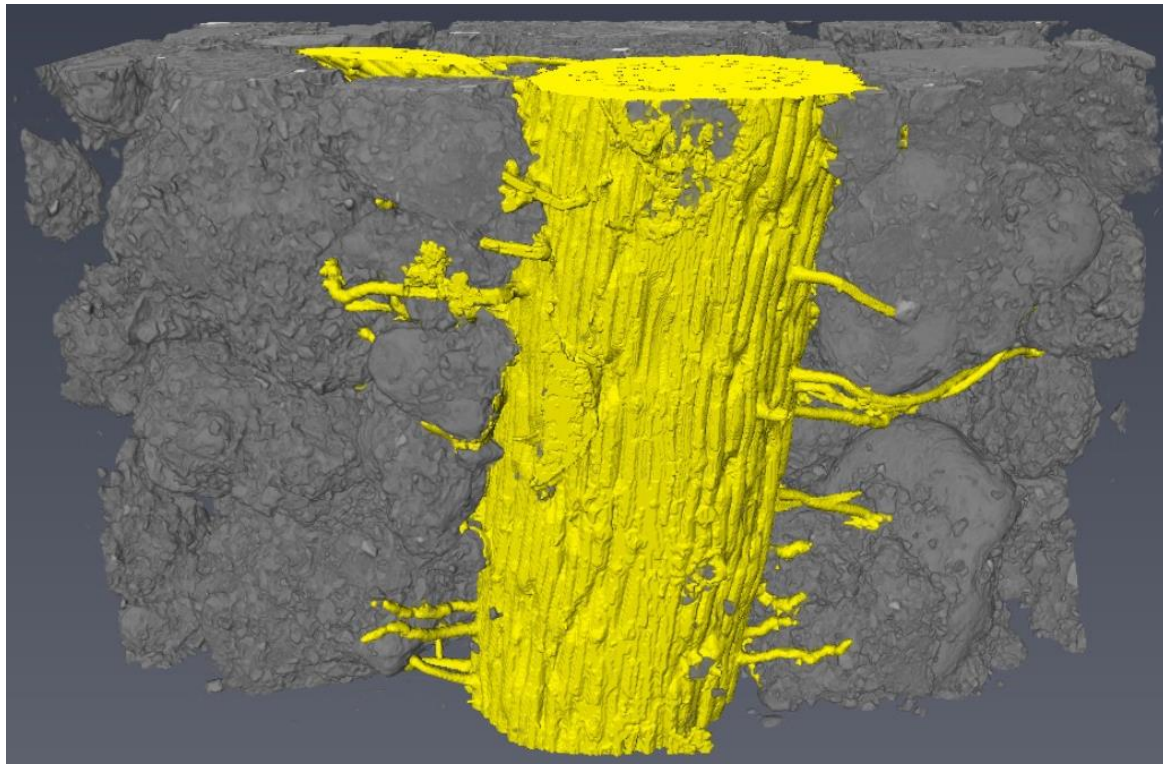

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Motivation

White & Kirkegaard, Plant Cell & Environment 2010

- The important role of root hairs in the uptake of immobile elements (e.g. phosphorous) is well accepted.
- Experimental evidences on root hairs enabling to sustain high transpiration rates in drying soil prove their significance for root water uptake (Carminati et al. 2017).
- These advantages are attributed to parameters such as the increase of root surface area and root-soil contact area

BUT:

- What‘s the scale of these factors?

→ There‘s still a lack of quantification of measures that potentially help us to understand important processes in the rhizosphere.

Objective

White & Kirkegaard, Plant Cell & Environment 2010

- Based on noninvasive high resolution synchrotron X-Ray CT images, the following parameters are investigated:
  - Relation between the increase of root surface area and root-soil contact area
  - Decrease of distances between soil matrix and root-soil contact
- Further research questions:
  - Is there any spatial pattern in
    - root hair branching?
    - root hair survival?

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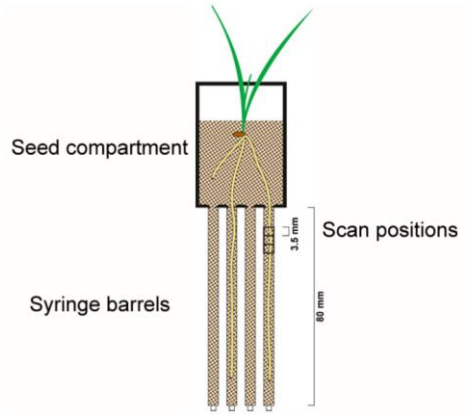
Experimental Setup

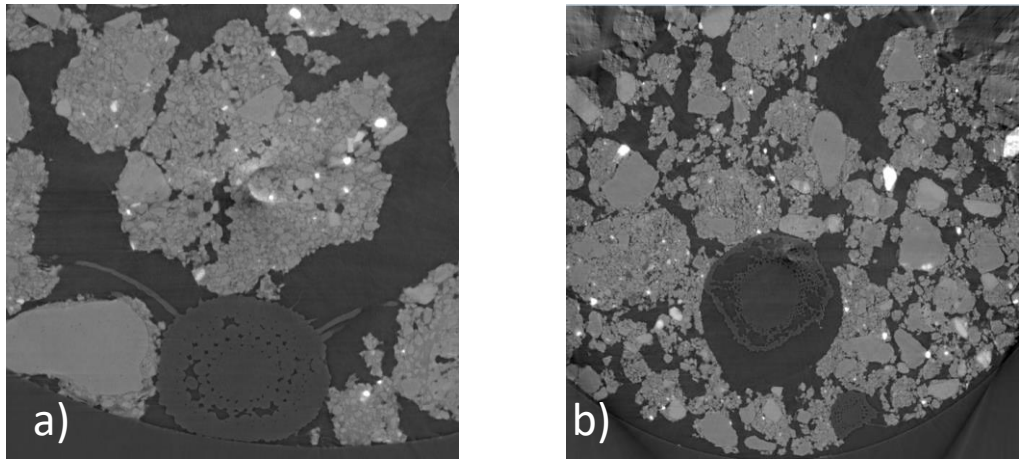
- Two contrasting maize genotypes (with and without root hairs) were grown in seedling holders containing seven syringe barrels per holder
- Synchrotron X-ray CT scans of the syringe barrels were conducted after eight days of growing and at three different positions per sample



Koebernick et al. New Phytologist 2017

Data & Image Analysis

- After image reconstruction, the different materials (roots (+hairs), soil and air) were segmented
- In total five subsamples of three independent plants were selected
  - Main criterion: roots had to be turgid; no visible root shrinkage within the whole stack



CT scan comparison of two different samples: a) The root is turgid and hairs growing through macropores are clearly visible. b) The root is shrinking and losing contact to the soil matrix resulting in major gaps between root and soil.

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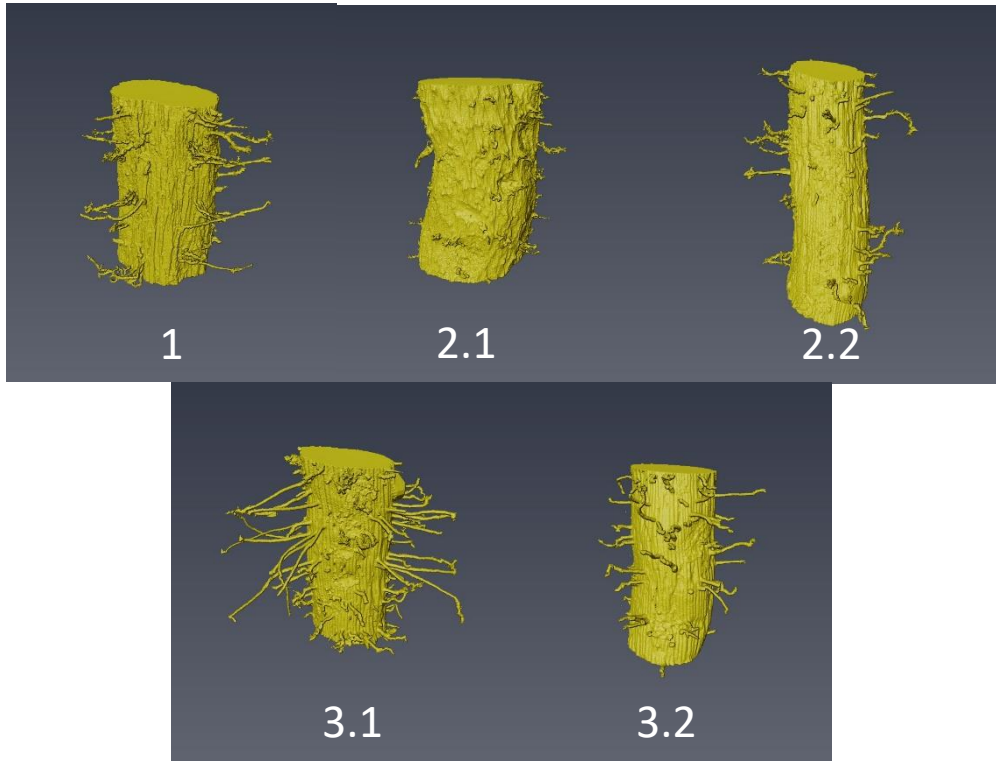
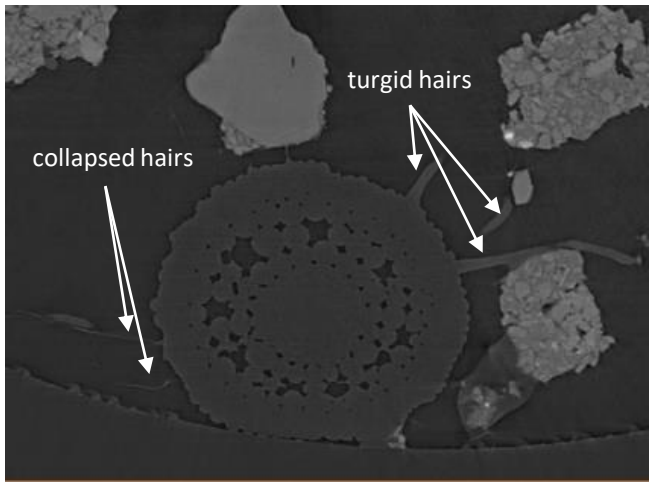
Samples

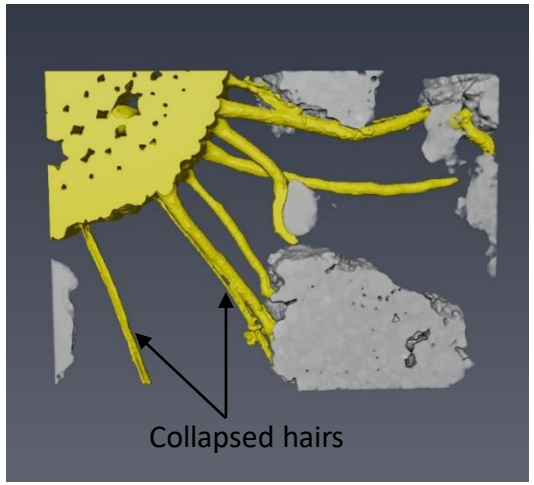


3D rendering of the selected subsamples of three independent plants. The segmented hairs are those that were turgid and most likely active in absorbing water and nutrients.

Comment

- Not only turgid root hairs but also many collapsed hairs are visible in the CT images
- Depending on the environmental conditions (Jungk, 2001), their life span is about few days (Fusseder, 1987)
- We consider matric potential as one factor influencing their life time
- Since our samples had to be largely dry (for contrast reasons) many hairs had already collapsed





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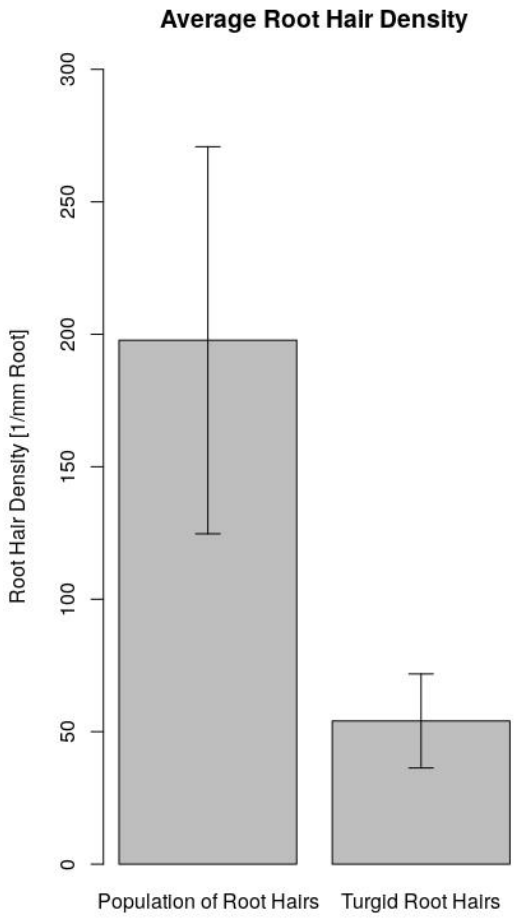
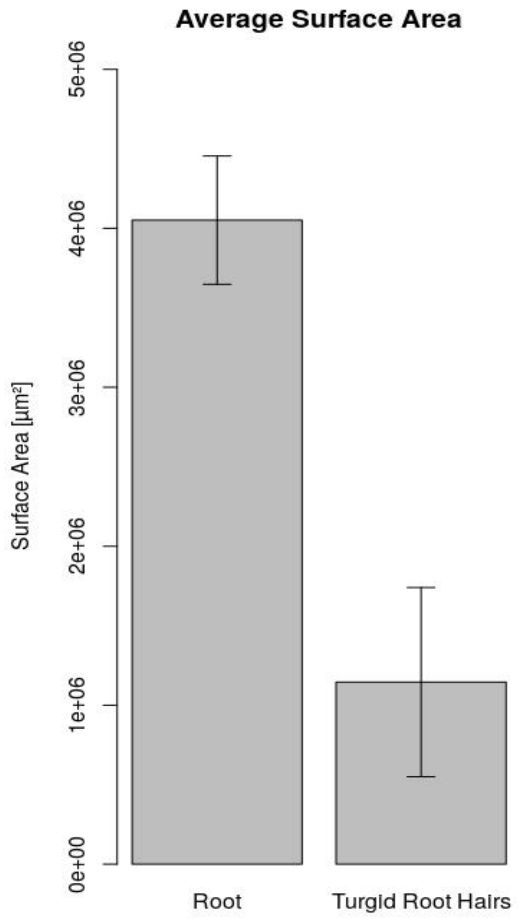
Results



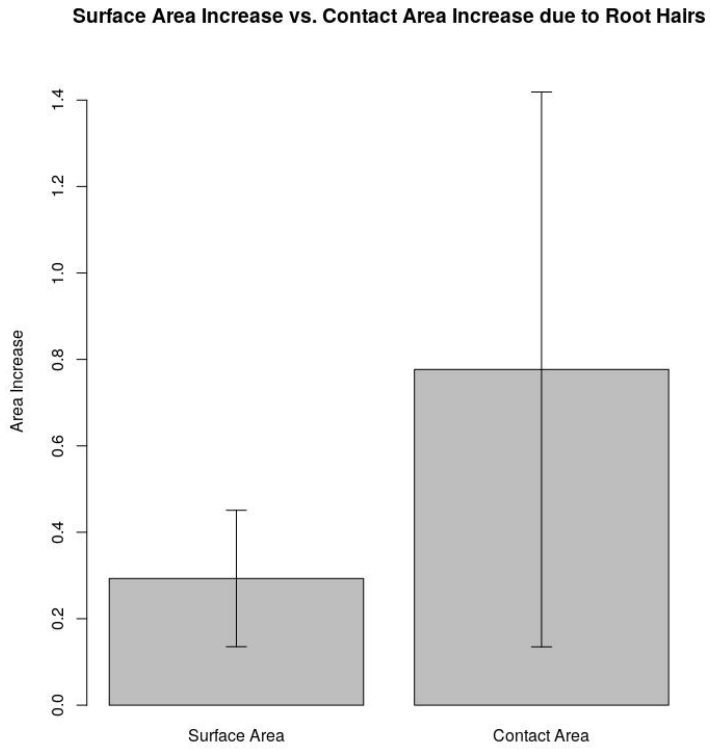


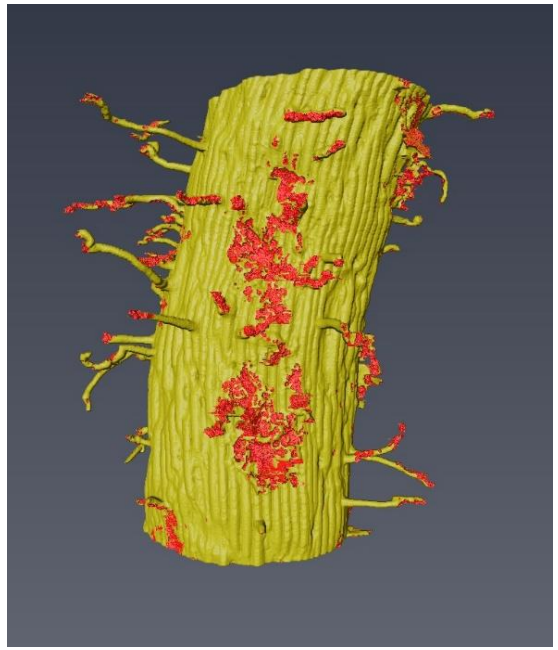
- Population of root hairs: turgid + collapsed hairs

Avg. Root Length	1.4mm ± 0.1mm
Avg. Hair Length per mm Root	14.9mm ± 7mm
Avg. Hair Radius	7.6µm ± 0.8µm
Estimated Matric Potential of the samples	below -460kPa
Avg. Porosity	0.51 ±0.04

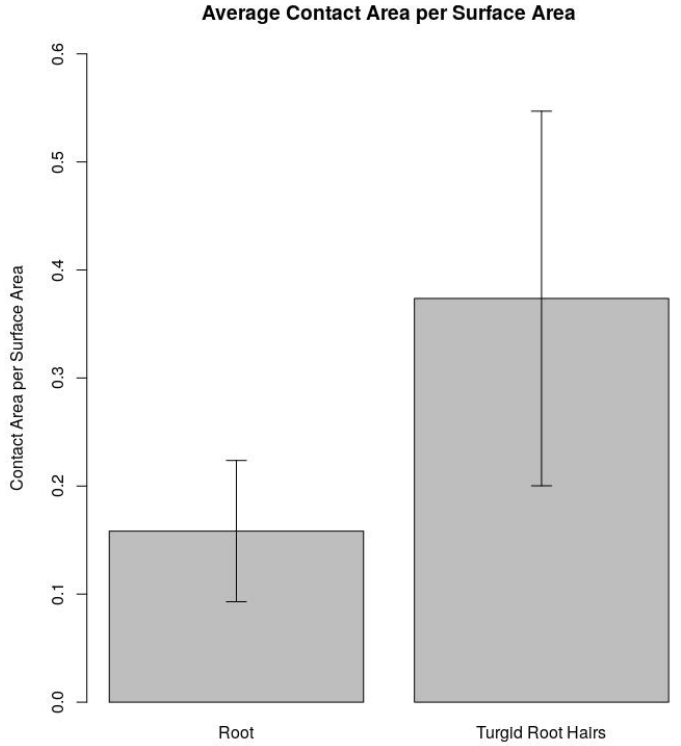
Matric Potential, Porosity and Root Hair Measurements (related to turgid hairs).

Results: Surface Area & Contact Area





3D rendered root with soil contacts depicted in red



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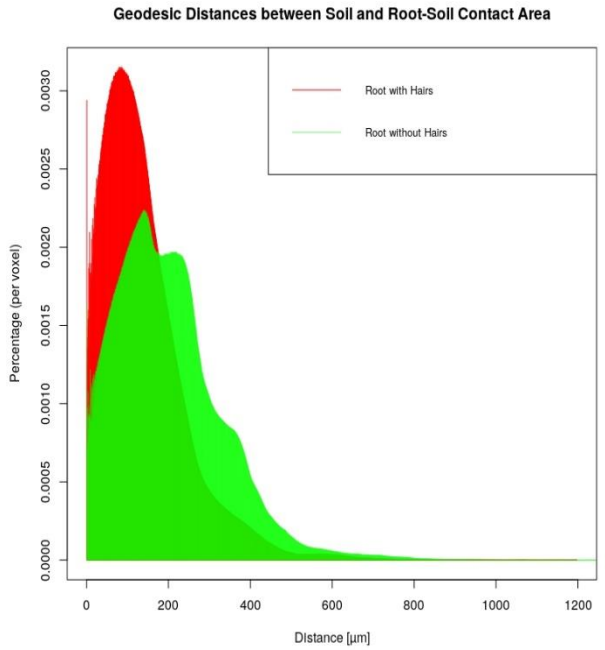
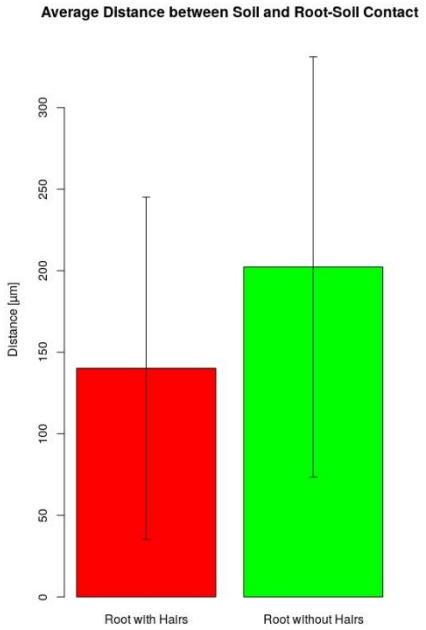
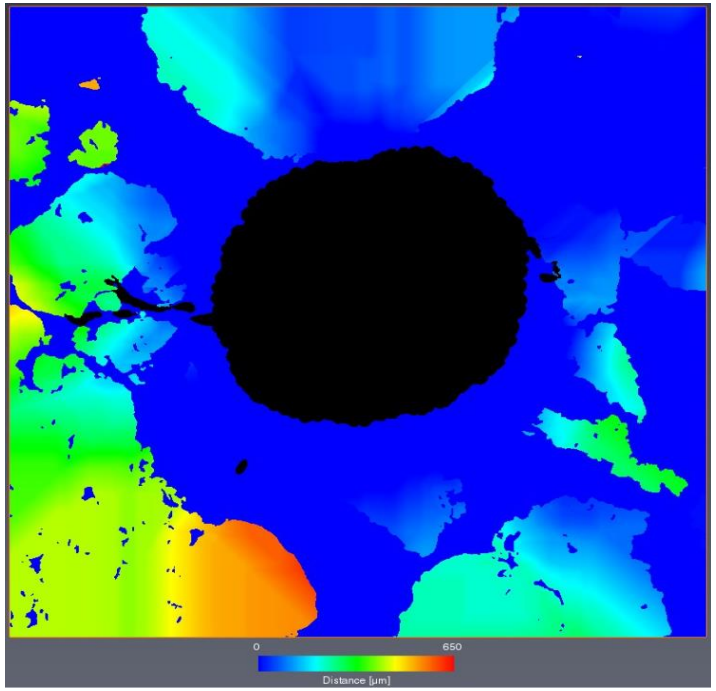
Results: Distance Data Soil – Root





Comparing distances between soil and root surface shows a leftshift of the data due to hairs (only turgid hairs taken into account).



Difference of the geodesic distance maps with and without root hairs. For a better visualisation root and hairs are added in black.

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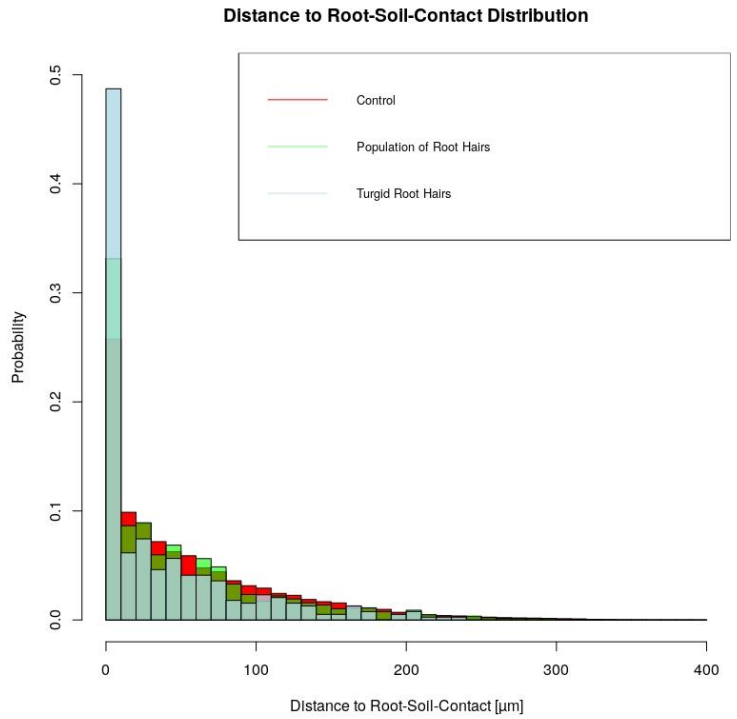
Results: Branching Pattern of Hairs



Distance measurements of hair branching points to root-soil contacts.
Population of hairs means the summary of collapsed and turgid hairs. For the control data (red), the distances between epidermis voxels and root-soil contacts are calculated.

- The comparison of control (red) and population of hairs (green) shows a slightly higher probability (+7.5%) for hairs to branch within the first 10µm
- The probability of turgid hairs in that interval is even higher (0.5) which means that a relatively high percentage of hairs survives in these regions
- The hairs of the remaining intervals follow a random distribution

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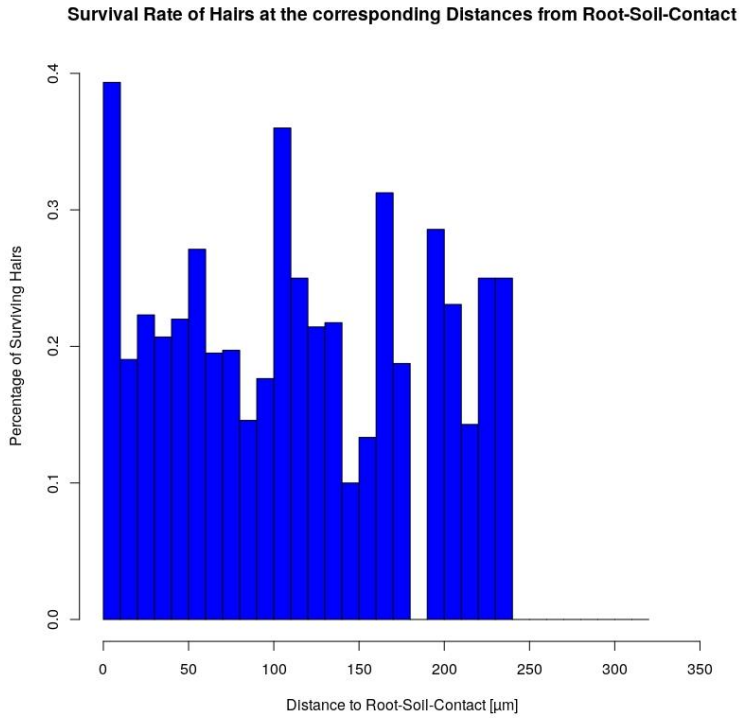
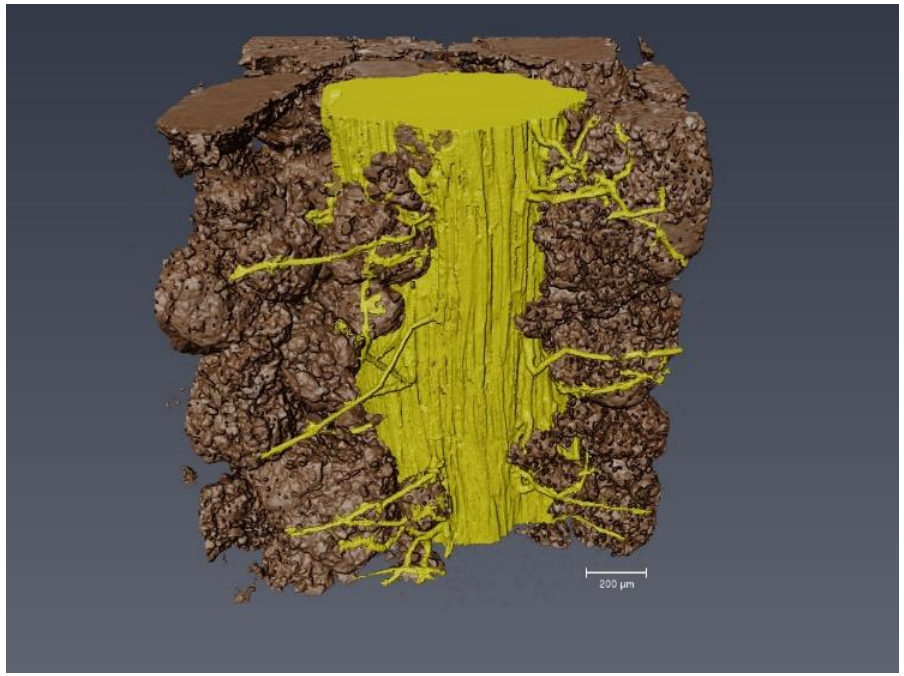
Results: Survival Pattern of Hairs



This survival map shows the surviving rate for hairs within each interval. Indeed, the highest rate is reached within the first 10µm but there are also other local maxima reaching almost the same value (e.g. 100-120µm).



3D rendered sample showing turgid hairs branching in the close vicinity of root-soil contacts

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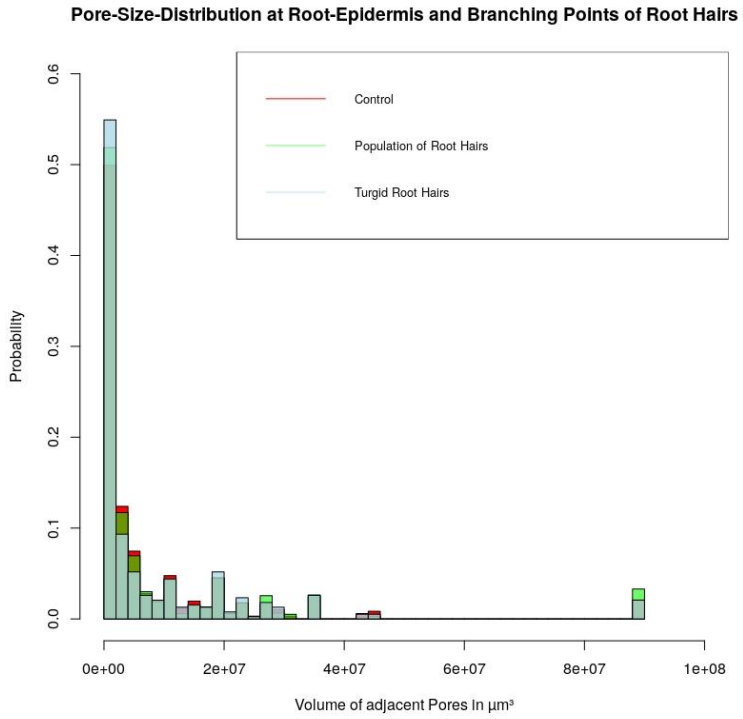
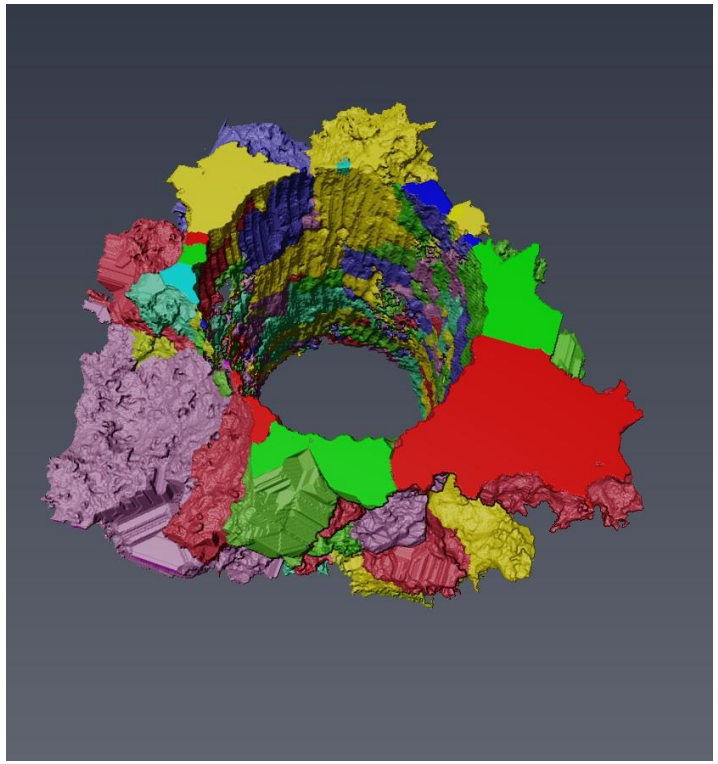


Measurements of pore sizes at hair branching points. The control data (red) contains the volume of all pores in contact to the roots and the corresponding percentage of root surface area they cover.
The comparison shows: regarding the pore size, root hairs branch and survive randomly.



Control Data: Labelled pores in direct contact to the root epidermis.

Conclusion

- At the given matric potential, turgid root hairs increase the surface area of a root by 30% (costs)
- They increase the contact area to soil by 80% (benefit)

- Due to hairs preferentially growing through macropores, the average distance from soil to root(-hair) surfaces decreases by 30%. The bigger the distance between root and soil particles (within a reasonable volume), the more pronounced is that effect.
  → Root hairs bridge the gap between roots and soil

- Branching patterns of hairs (pore sizes):
  - Random branching

- Branching patterns of hairs (distance to contact):
  - Only a small preference of branching points close to root-soil contacts could be observed
  - Since the rest of the probability distribution follows the control, hairs are considered to branch randomly

- Root hair survival pattern:
  - Considering drought stress, the most important hairs active in transport (for both nutrients and water) are the ones that survive significantly negative water potentials
  - Particularly hairs branching in direct contact to soil particles meet this criterion

Acknowledgements

RHIZOSPHERE SPATIOTEMPORAL ORGANISATION SPP 2089

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