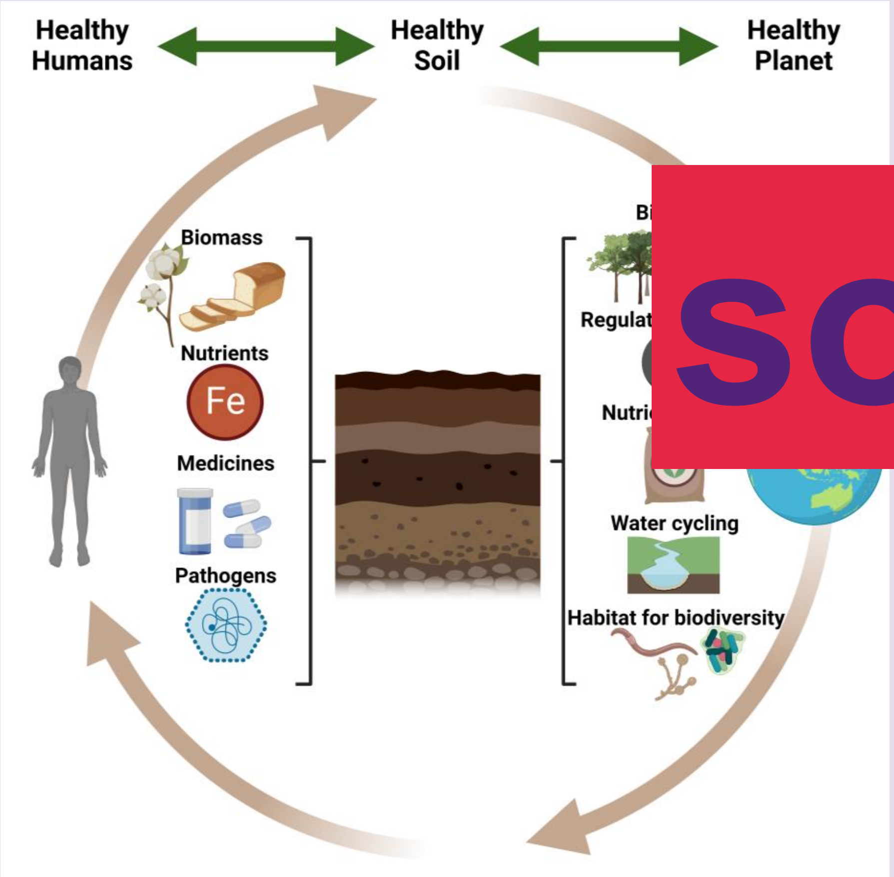
THE UNIVERSITY OF QUEENSLAND AUSTRALIA

Synchrotron techniques for global environmental and agricultural challenges

Dr Brigid McKenna – The University of Queensland

The 5th Asia-Oceania Forum for Synchrotron Radiation Research

The significance of soil



- **Soil is a critical, non-renewable**

soil ≠ dirt

- **Soils are a master variable in regulating critical Earth-system processes**
- **Soils are central to human and planetary health**

Kopittke, P. M., Minasny, B., Pendall, E., Rumpel, C., & McKenna, B. A. (2024). Healthy soil for healthy humans and a healthy planet. *Critical Reviews in Environmental Science and Technology*, *54*(3), 210-221.

Soils contribution to planetary boundaries

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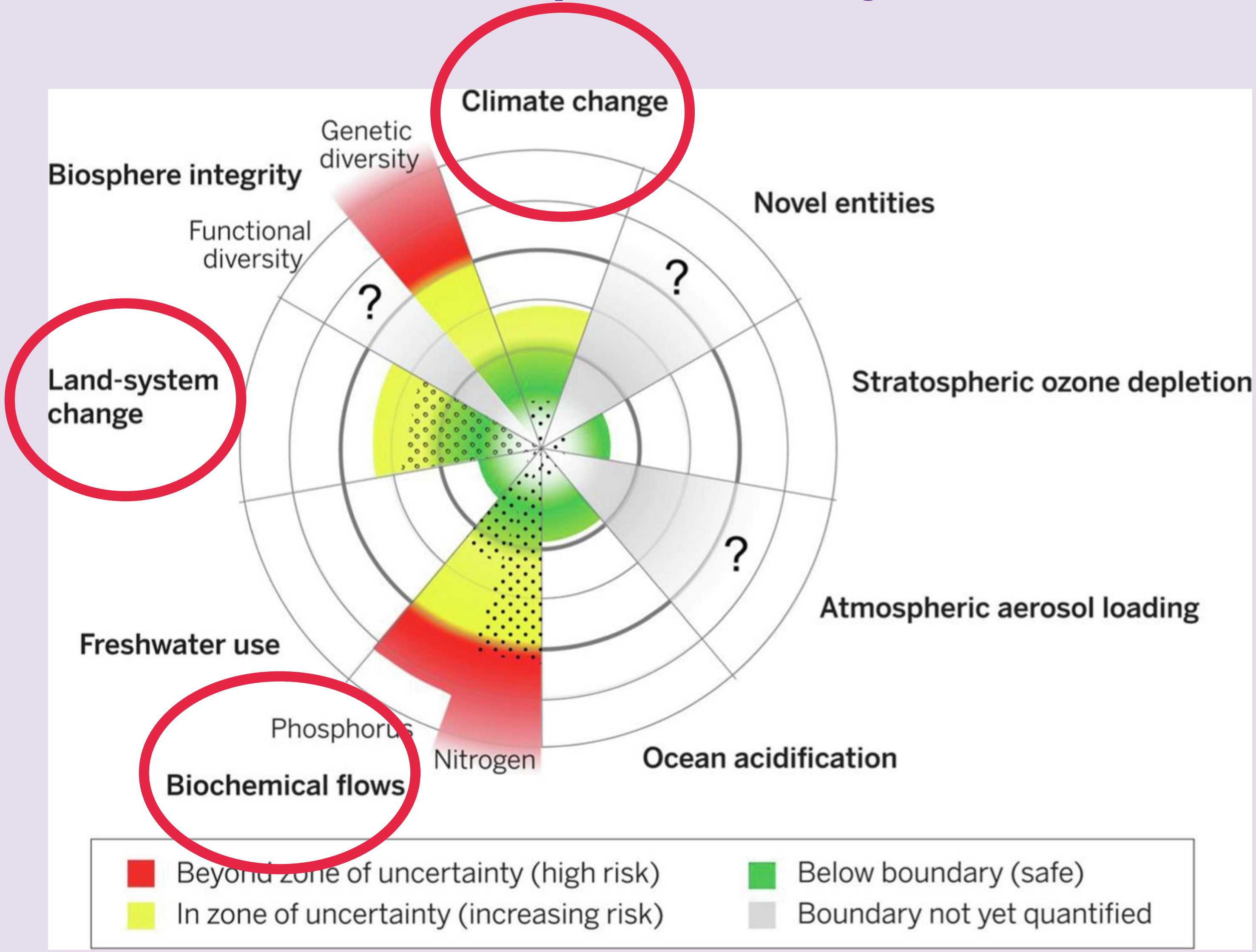
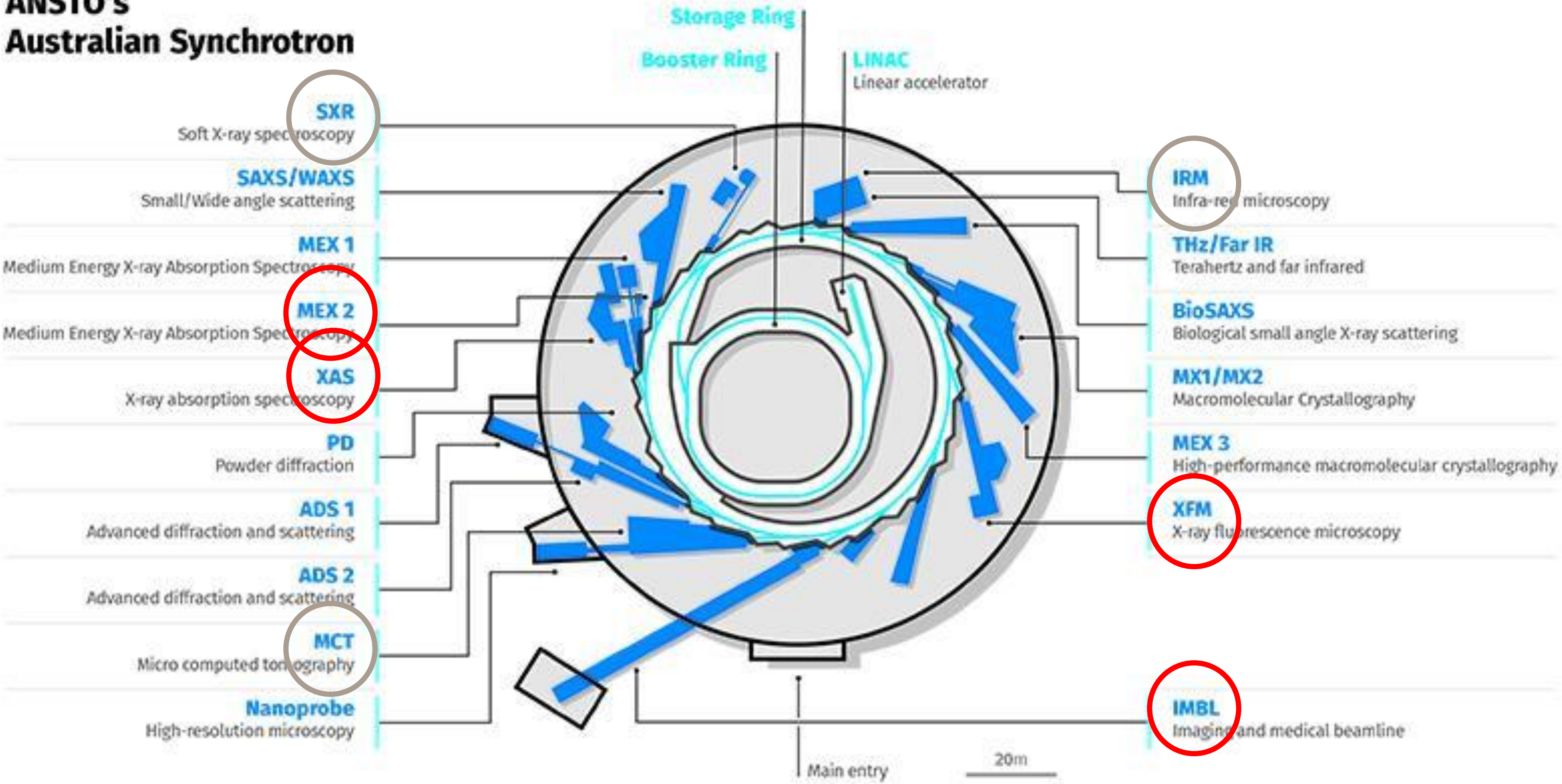


Kopittke, P. M., Menzies, N. W., Dalal, R. C., McKenna, B. A., Husted, S., Wang, P., & Lombi, E. (2021). The role of soil in defining planetary boundaries and the safe operating space for humanity. *Environment International*, *146*, 106245.

ANSTO's Australian Synchrotron



Global challenges

Challenge 1

Improving fertiliser use efficiency

Challenge 2

Soil constraints to plant growth

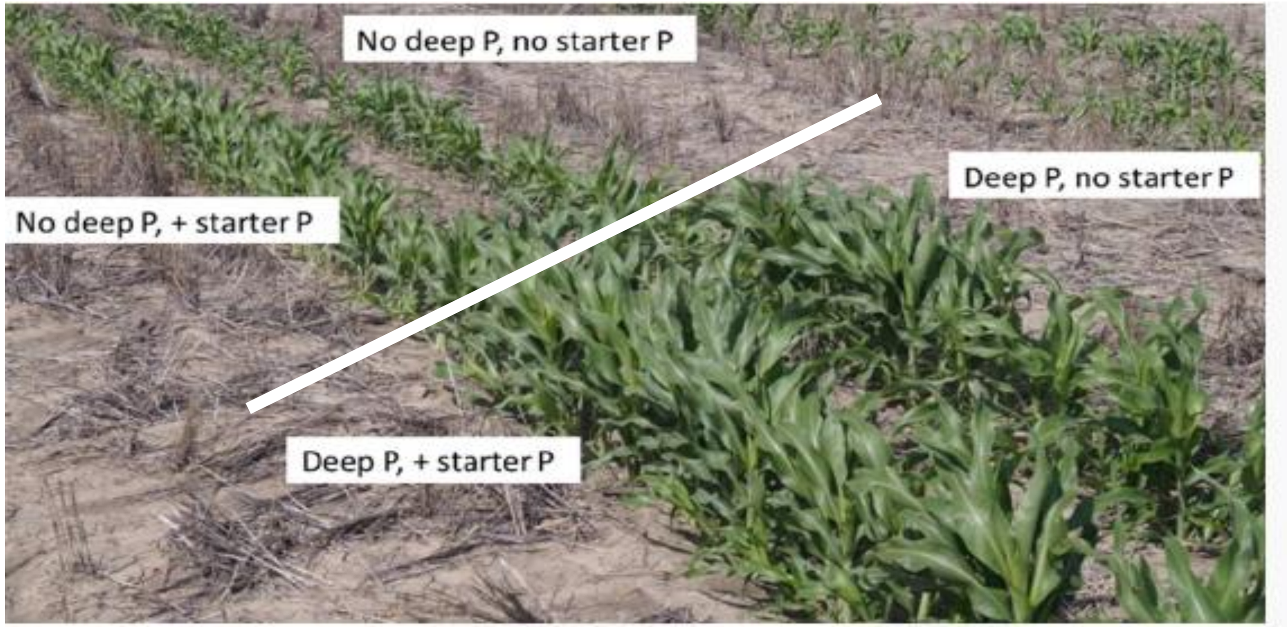
Challenge 3

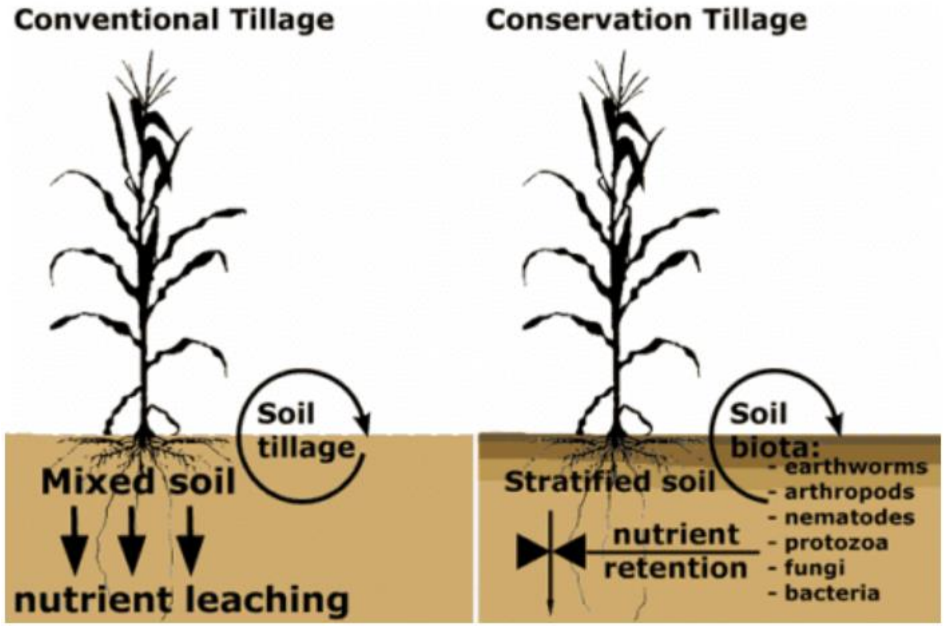
Enhancing human nutrition

Challenge 1

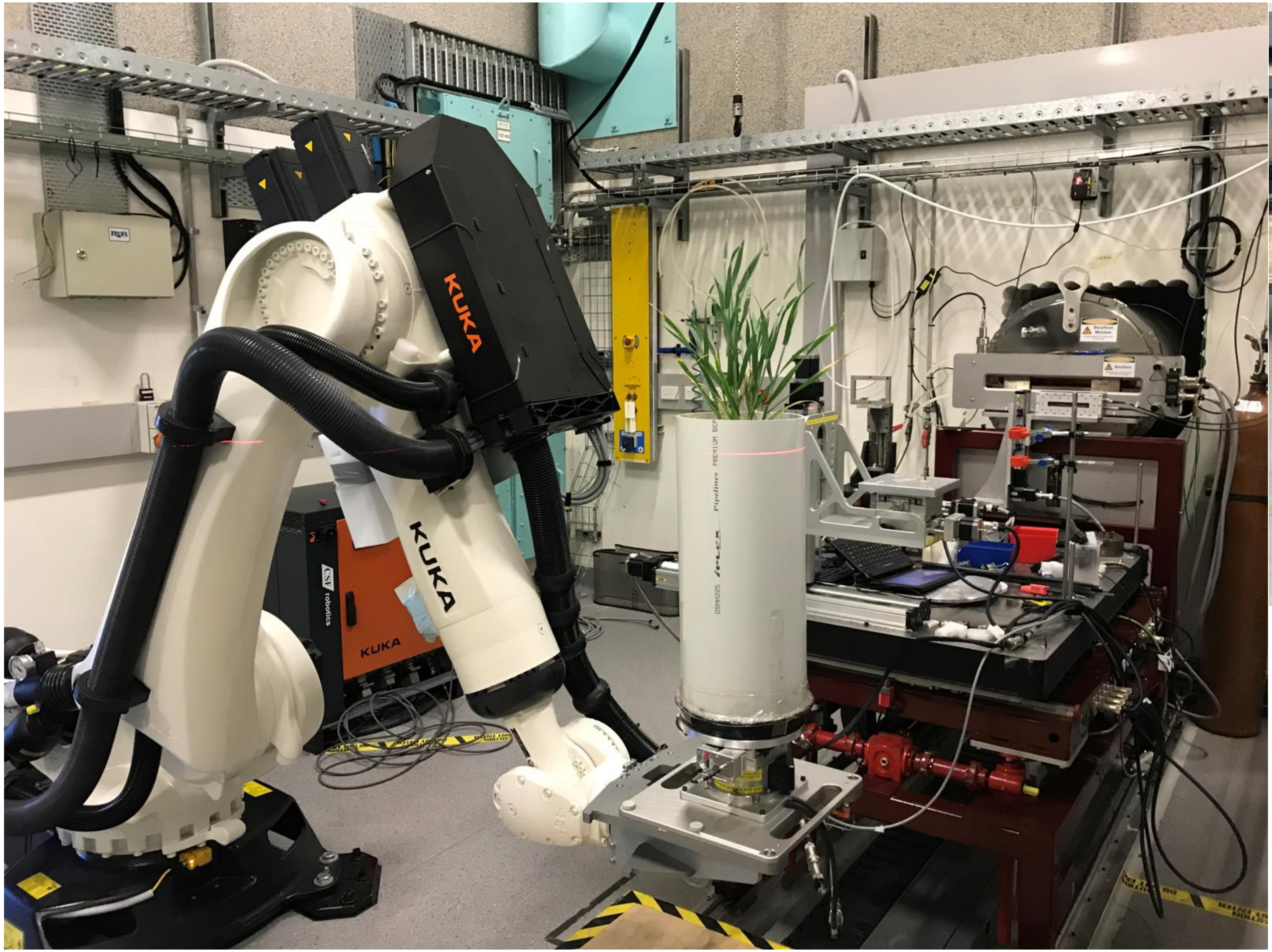
Improving fertiliser use efficiency – P

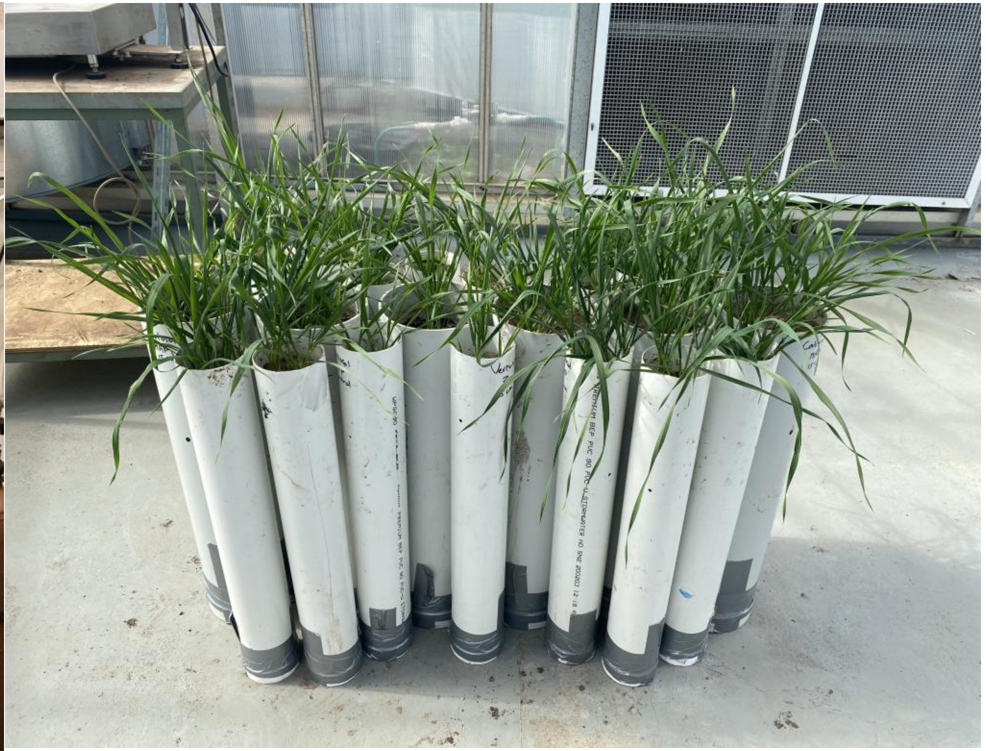
- **Phosphorus use efficiency only 5-25%**
- **P resources are finite and subject to geopolitically instability**
- **P geochemical cycle well beyond planetary boundaries**
- **Bulk chemistry has been the dominant source of knowledge – but this misses much of the mechanistic details**
- **Can we go from small scale measurements to large scale and laterally resolved analyses**





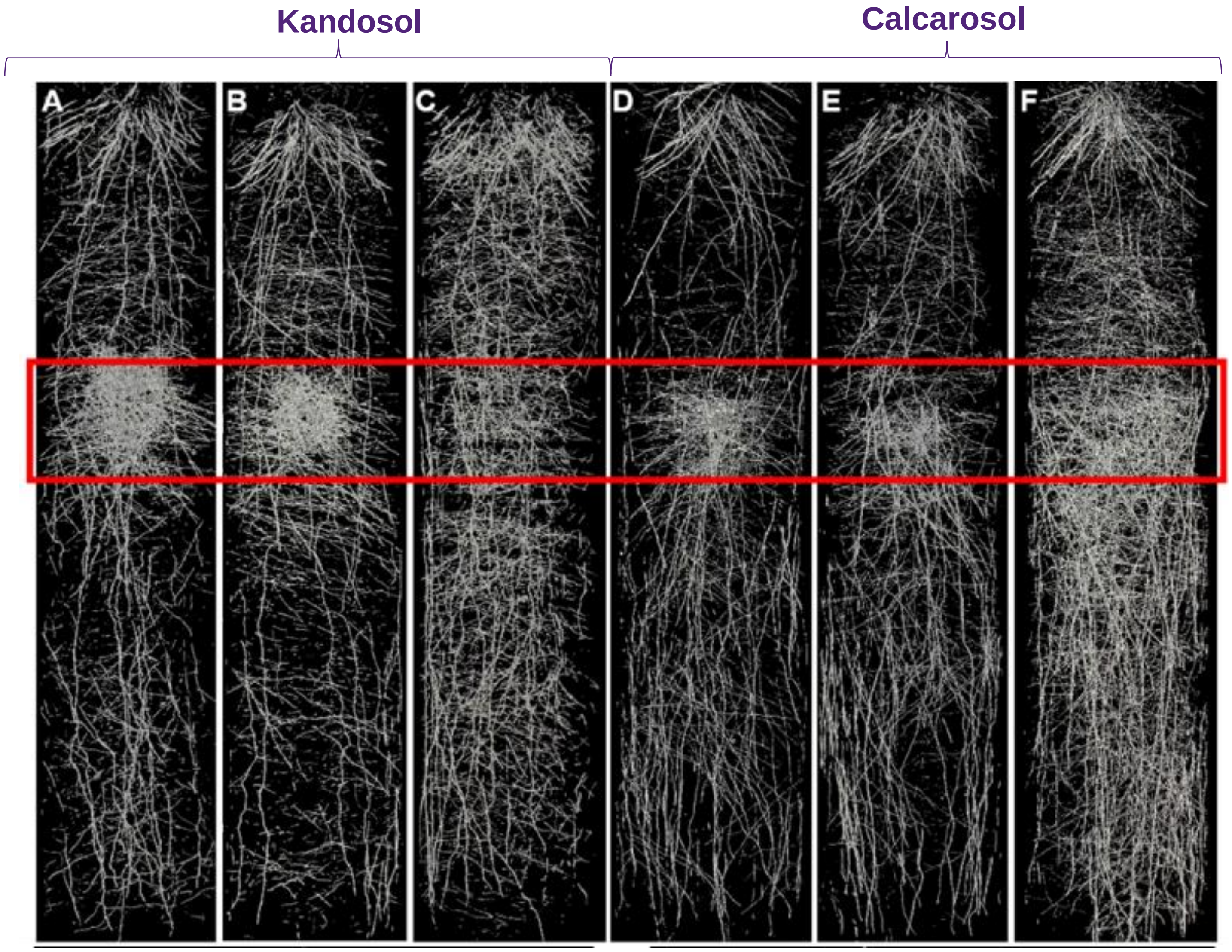
X-ray tomography of intact soil cores – IMBL





X-ray tomography of intact soil cores – IMBL

9cm Ø, 35cm length, 34µm voxel, 3.5h/column

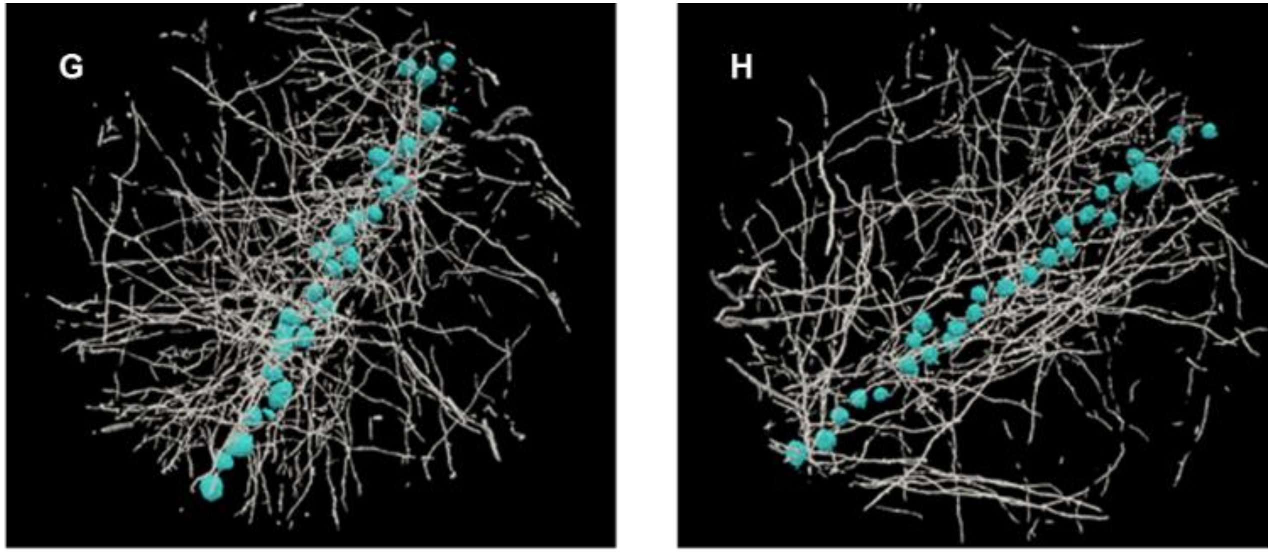


Banded P fertiliser at 15 cm depth

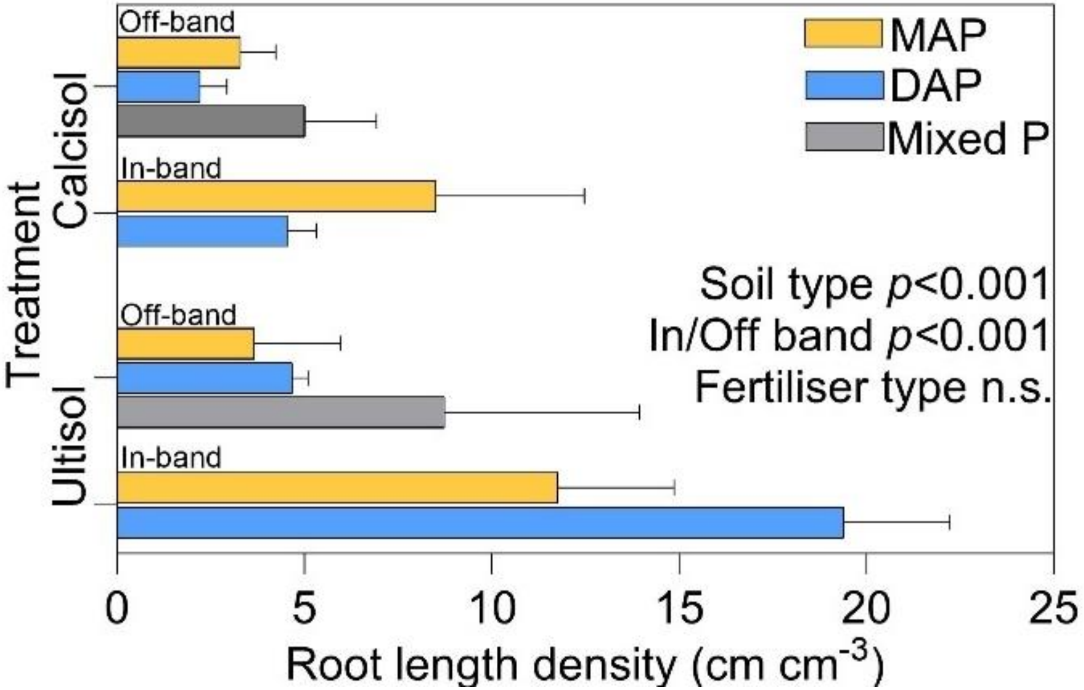
X-ray tomography of intact soil cores – IMBL

X-ray tomography of intact soil cores – IMBL

P-induced root proliferation



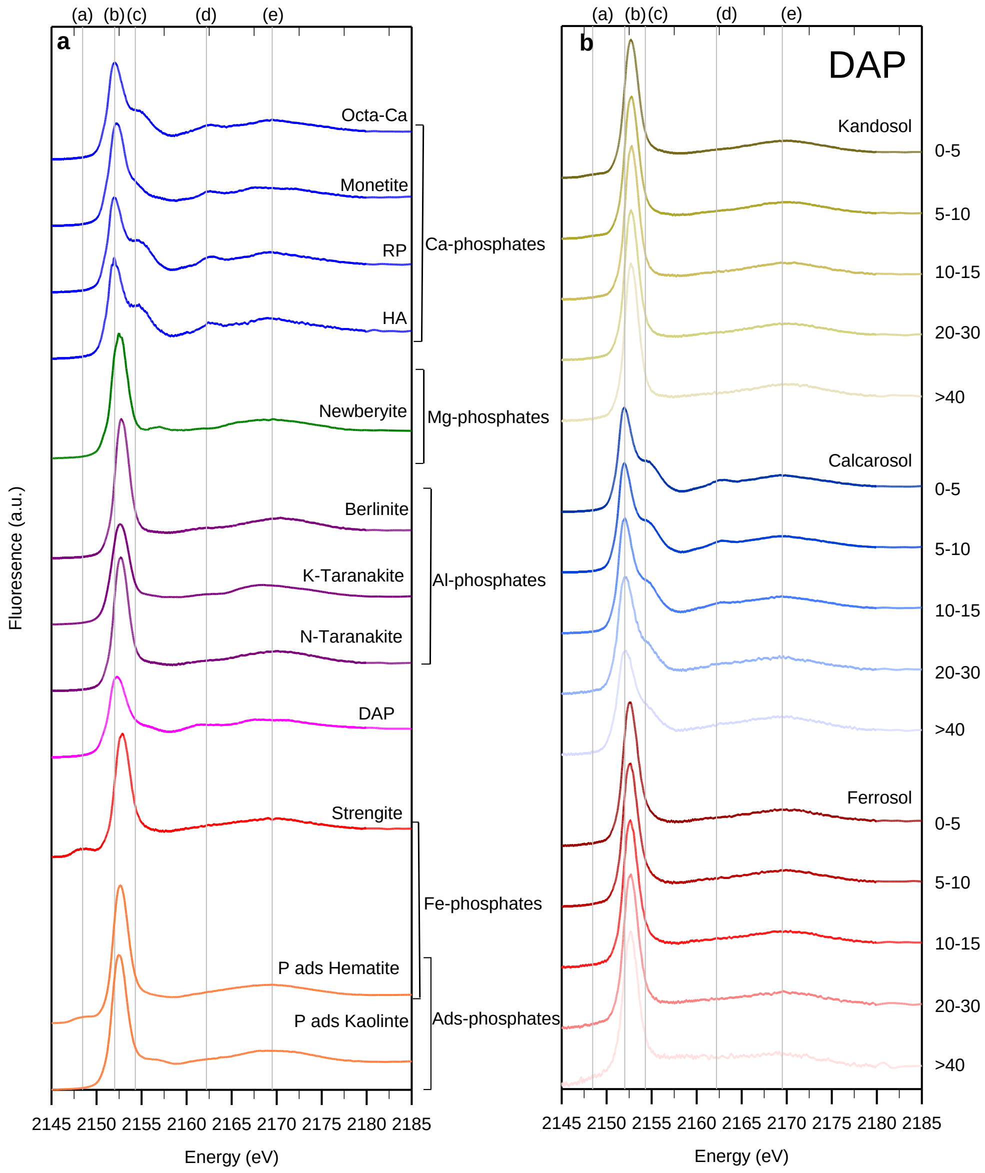
Roots develop even near fertiliser granules despite the high salinity



Roots proliferation is more intense in the Ultisol than in the Calcisol

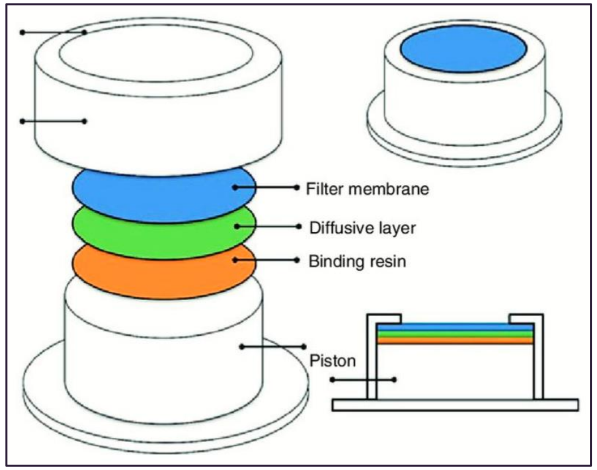
X-ray absorption spectroscopy – MEX2

P speciation with distance from a fertiliser band



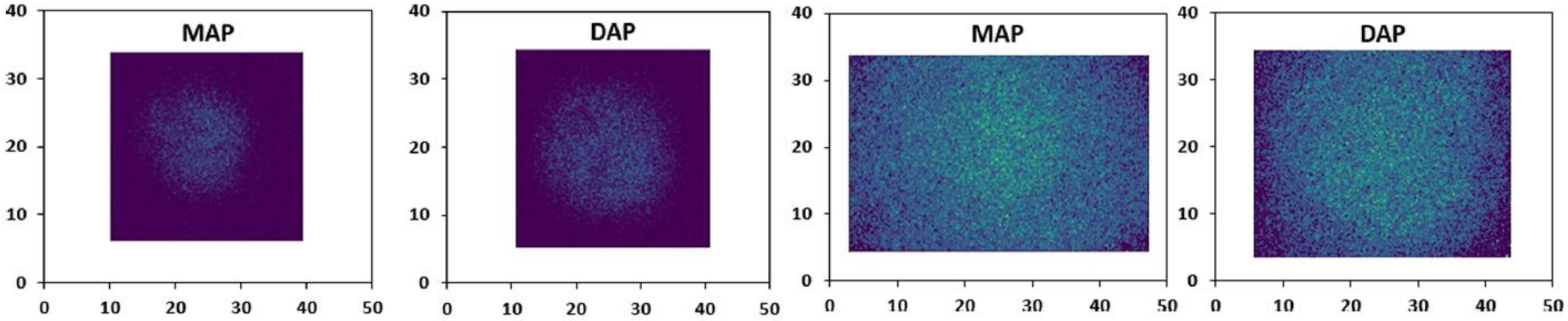
X-ray fluorescence microscopy – XFM

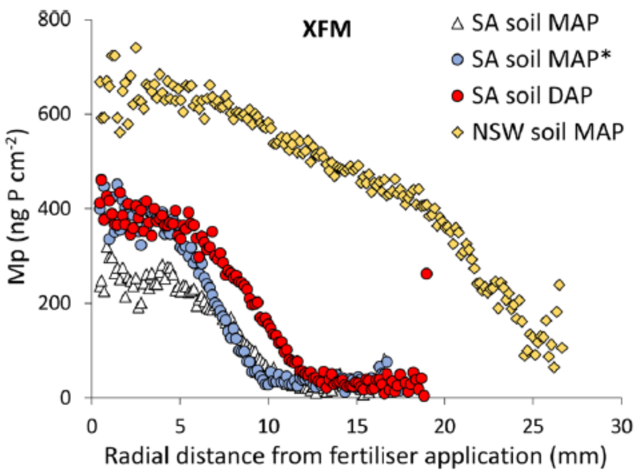
P bioavailability gradients from a fertiliser band

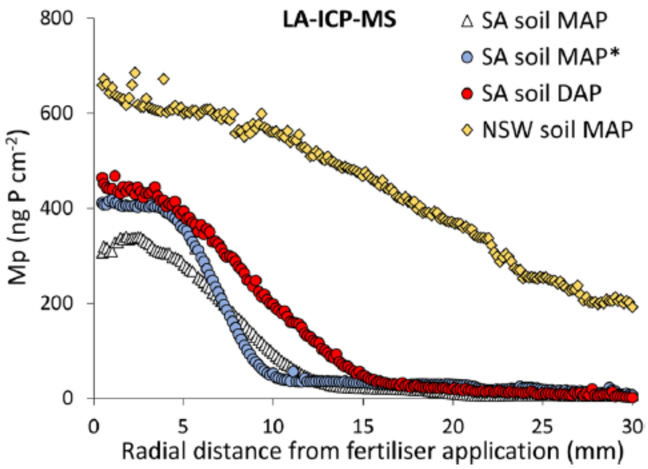


Diffusive gradients in thin-films (DGT) devices are used to quantify and visualise potentially available nutrients in the environment

Calcarosol | **Kandosol**



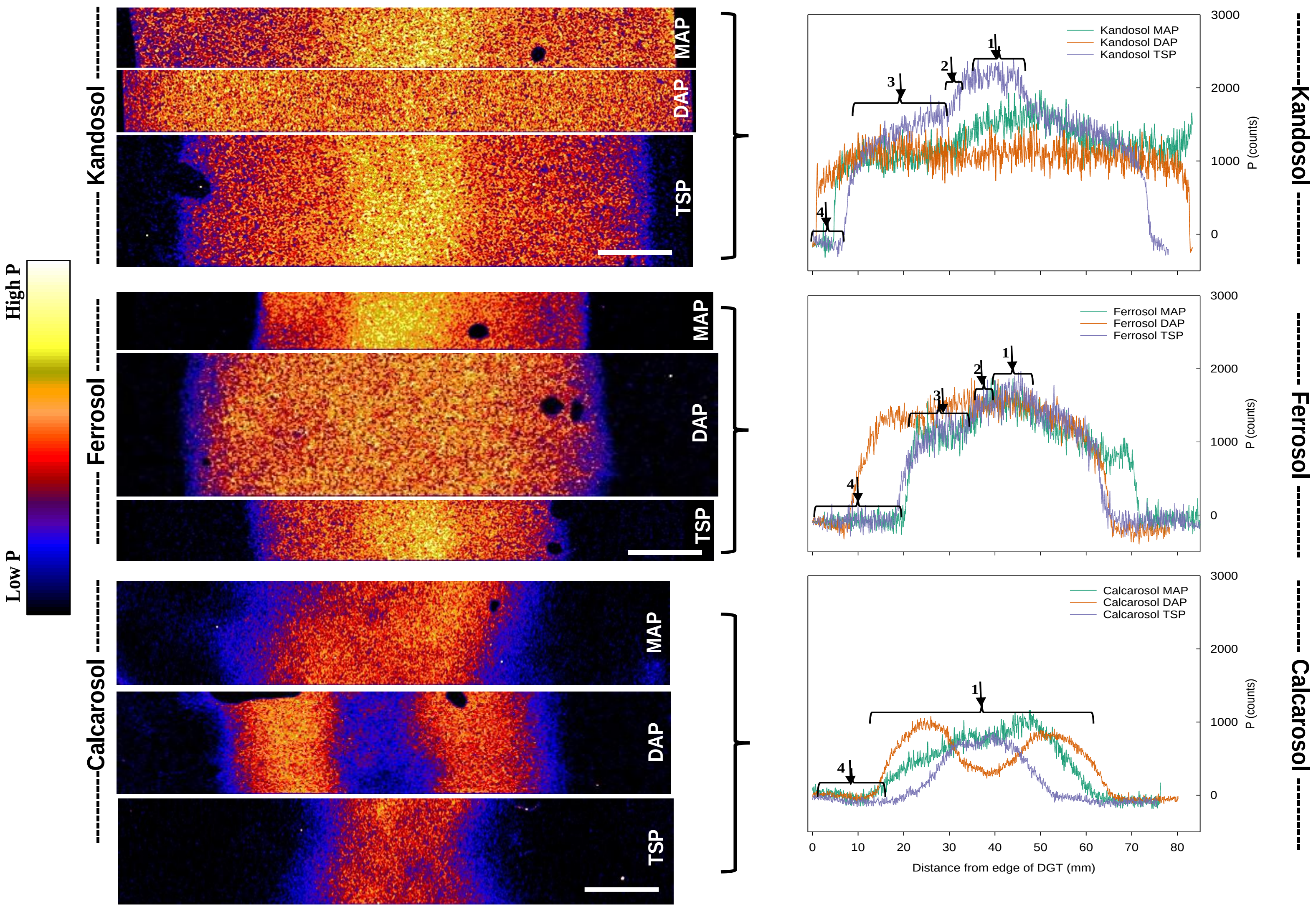




Moens, C., Lombi, E., Howard, D. L., Wagner, S., Payne, J. L., Kopittke, P. M., & Doolette, C. L. (2023). Mapping phosphorus availability in soil at a large scale and high resolution using novel diffusive gradients in thin films designed for X-ray fluorescence microscopy. *Environmental science & technology*, *58*(1), 440-448.

X-ray fluorescence microscopy – benchtop XFM

P bioavailability gradients from a fertiliser band



Challenge 2

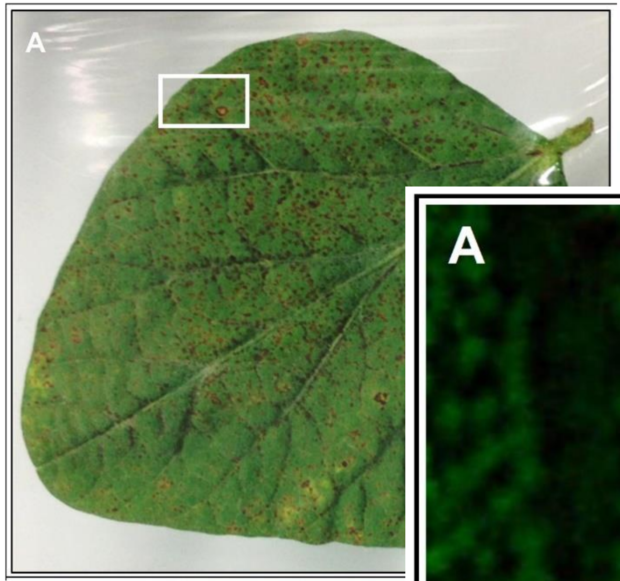
Soil constraints to plant growth – Mn in acid soils

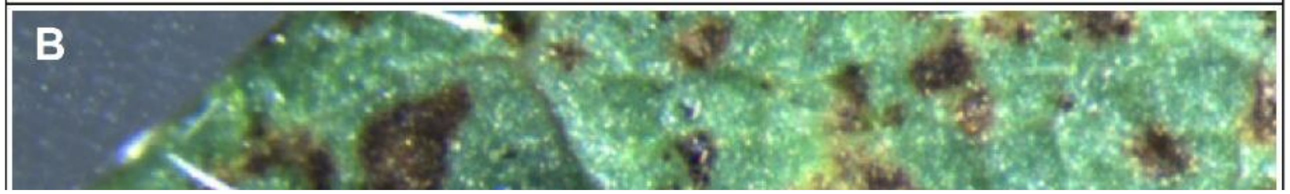
- **75% of Australian soils have one or more constraints such as high pH, nutrient deficiencies, acidity, salinity/sodicity, and compaction**
- **Increased yields required to feed the planet - 70% more food globally between 2005-2050 as a result of population growth and shifting diets**

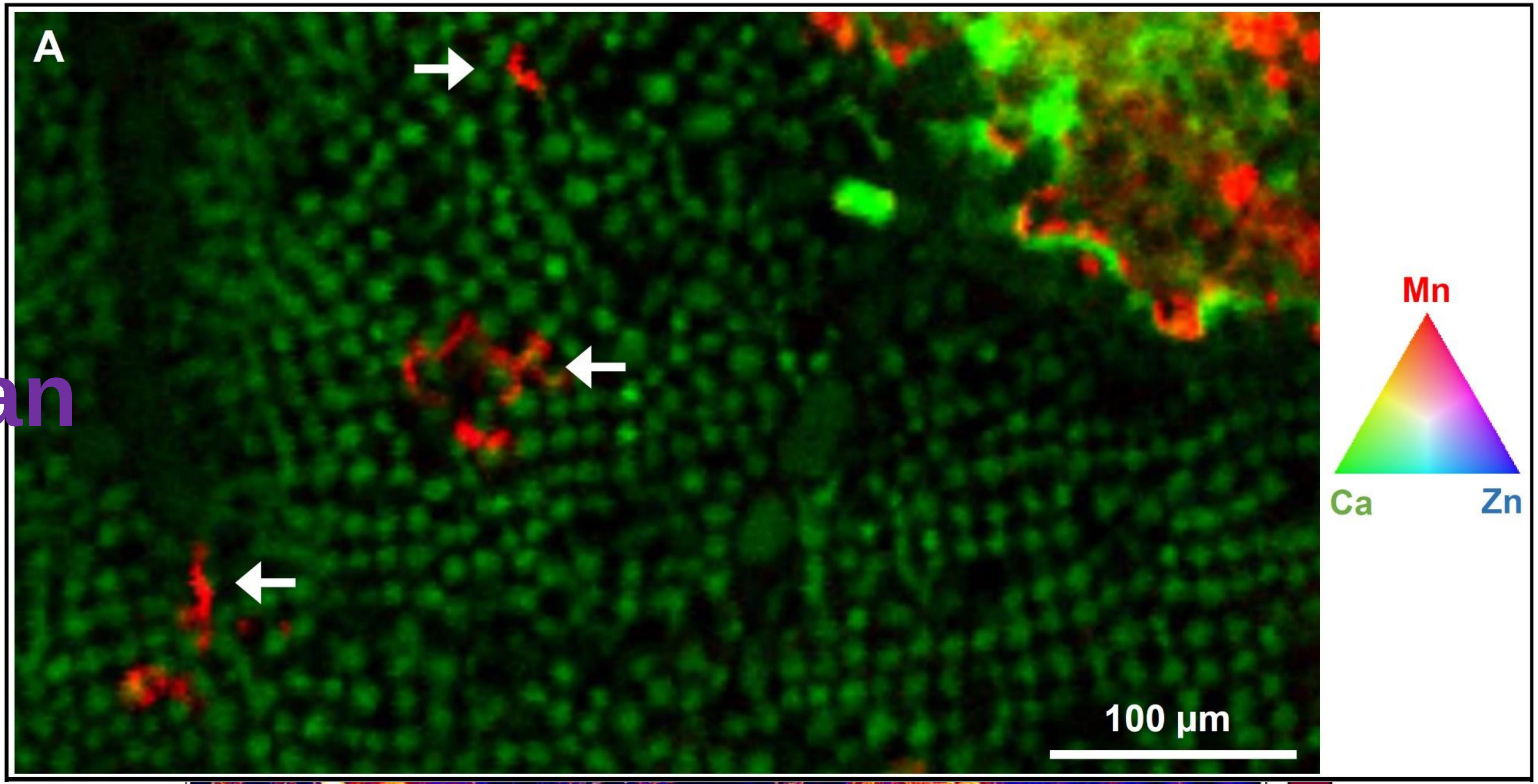
X-ray fluorescence microscopy – XFM

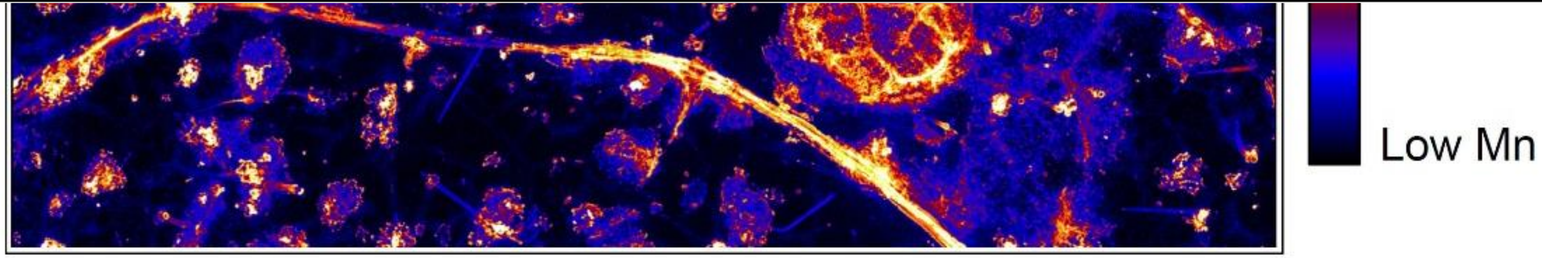
+

X-ray absorption spectroscopy – XAS









Soybean

ve soybean,
ns are due to
f Mn, initially in
ll wall

Blamey, F. P. C., Hernandez-Soriano, M. C., Cheng, M., Tang
Paterson, D. J., Lombi, E., ... & Kopittke, P. M. (2015). Synchr
techniques shed light on mechanisms of plant sensitivity and t
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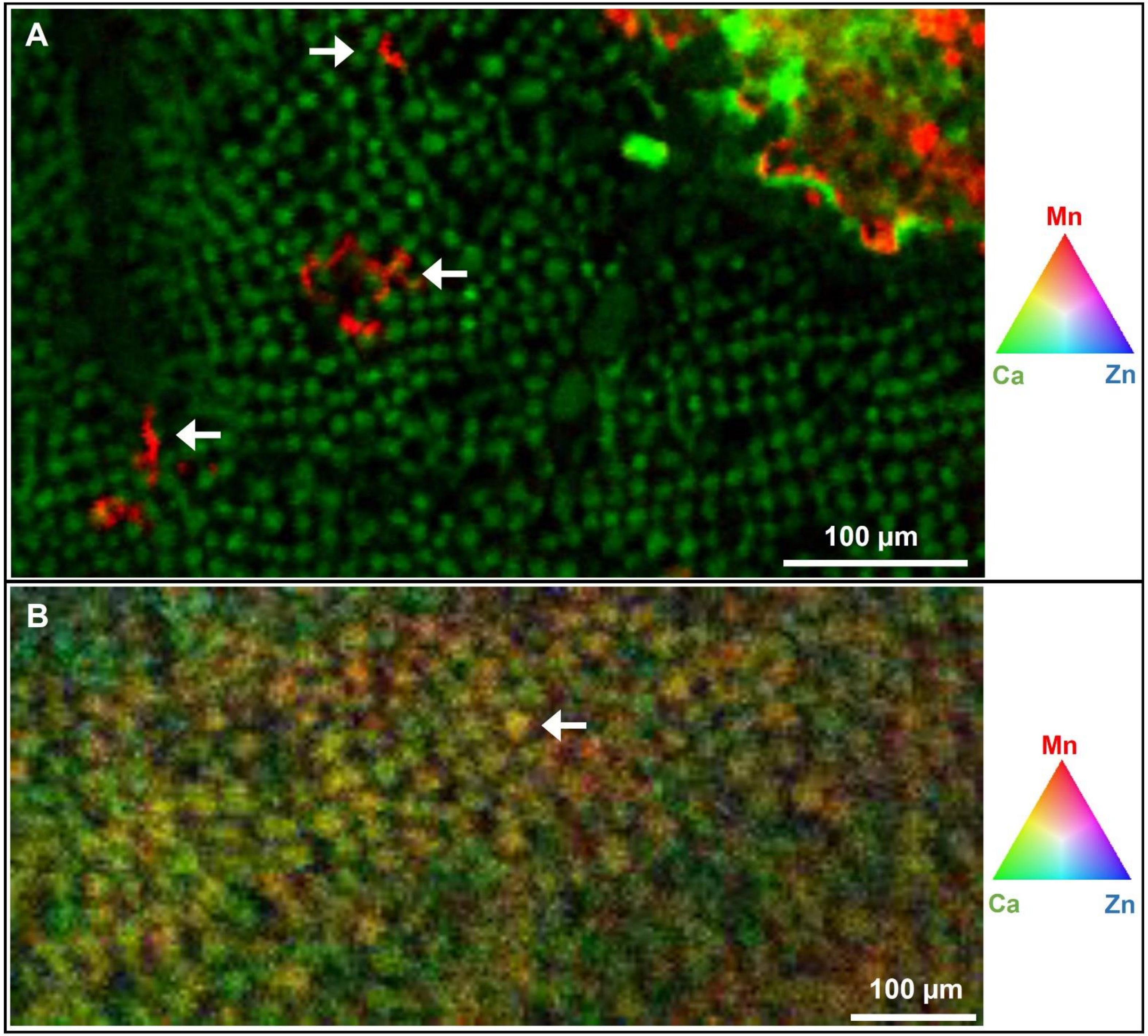
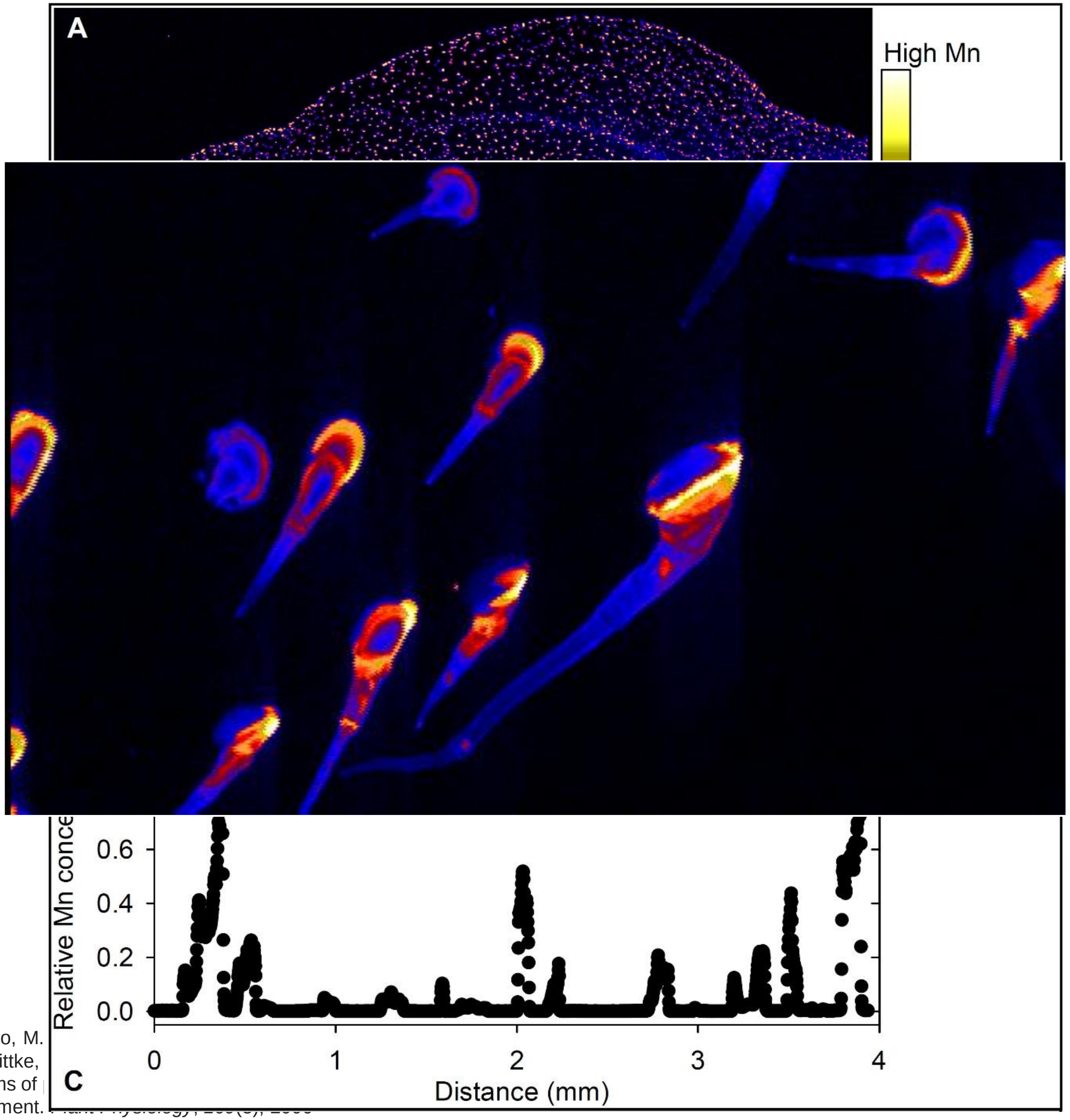
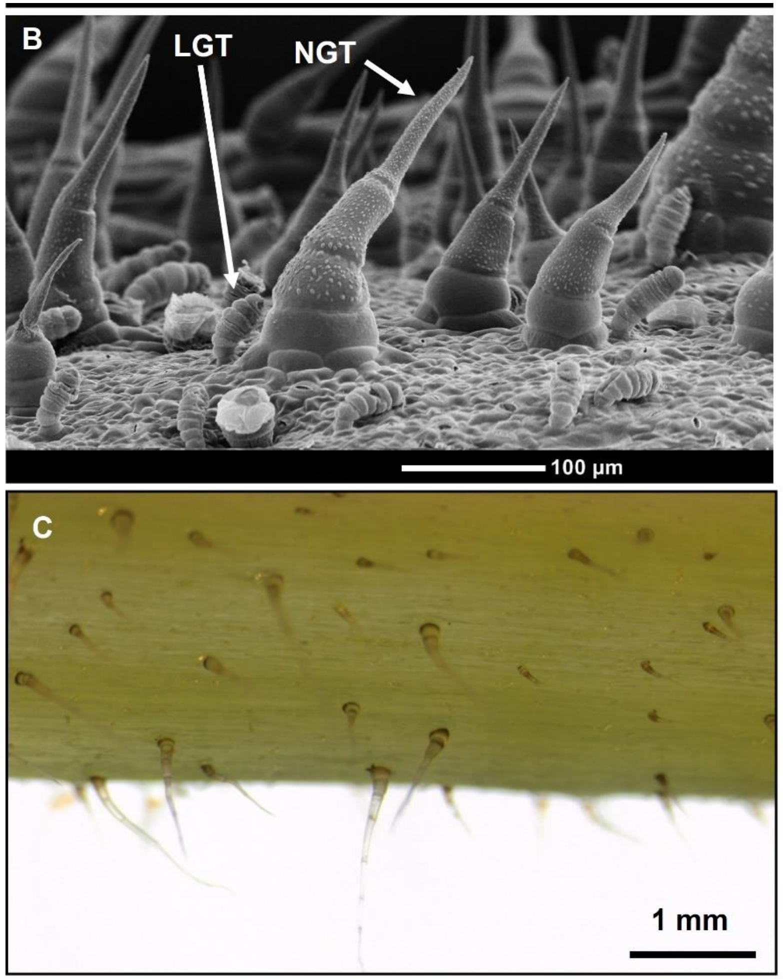


Lupin is tolerant because it is able to sequester Mn within the vacuole

Blamey, F. P. C., Herı
Paterson, D. J., Lomb
techniques shed light
high manganese in th
2020.

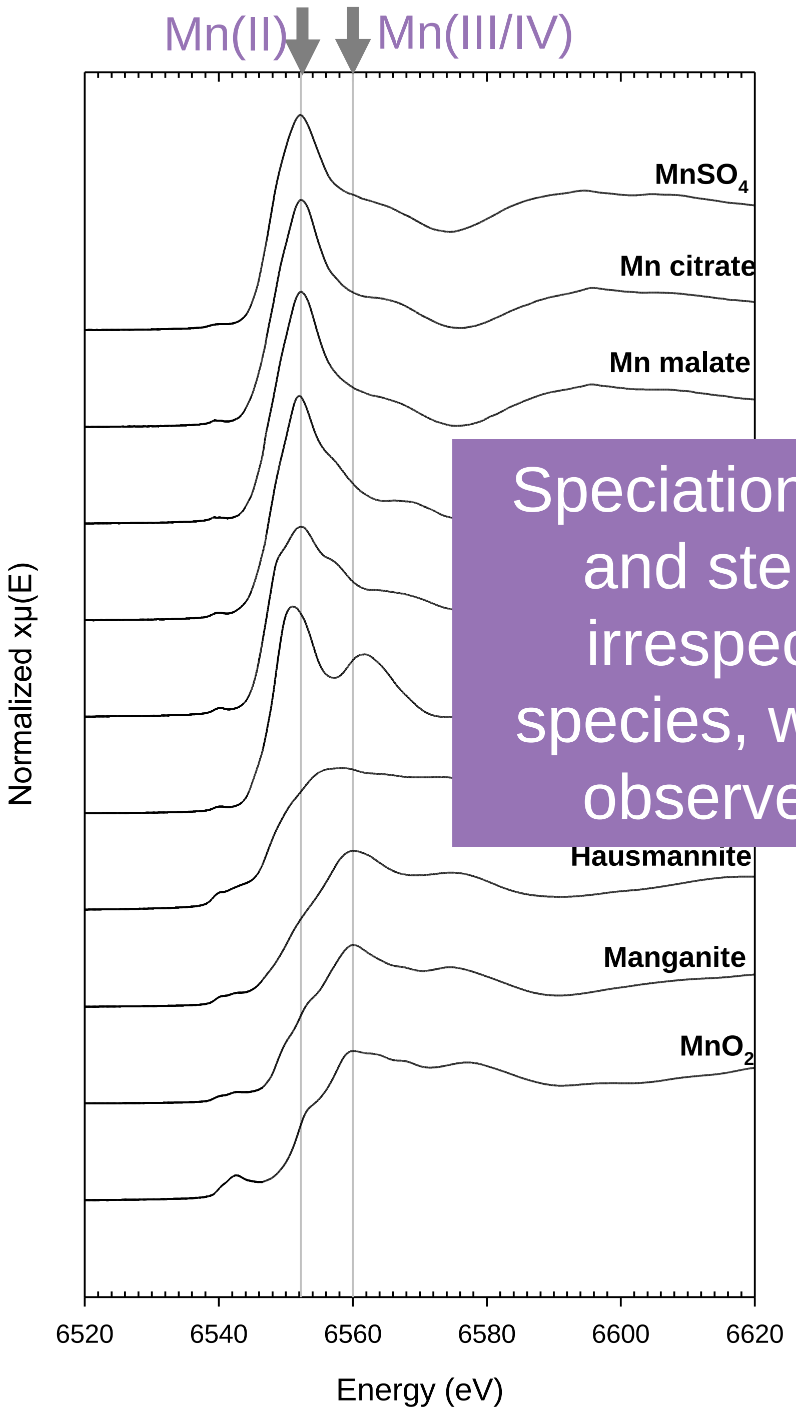
Sunflower



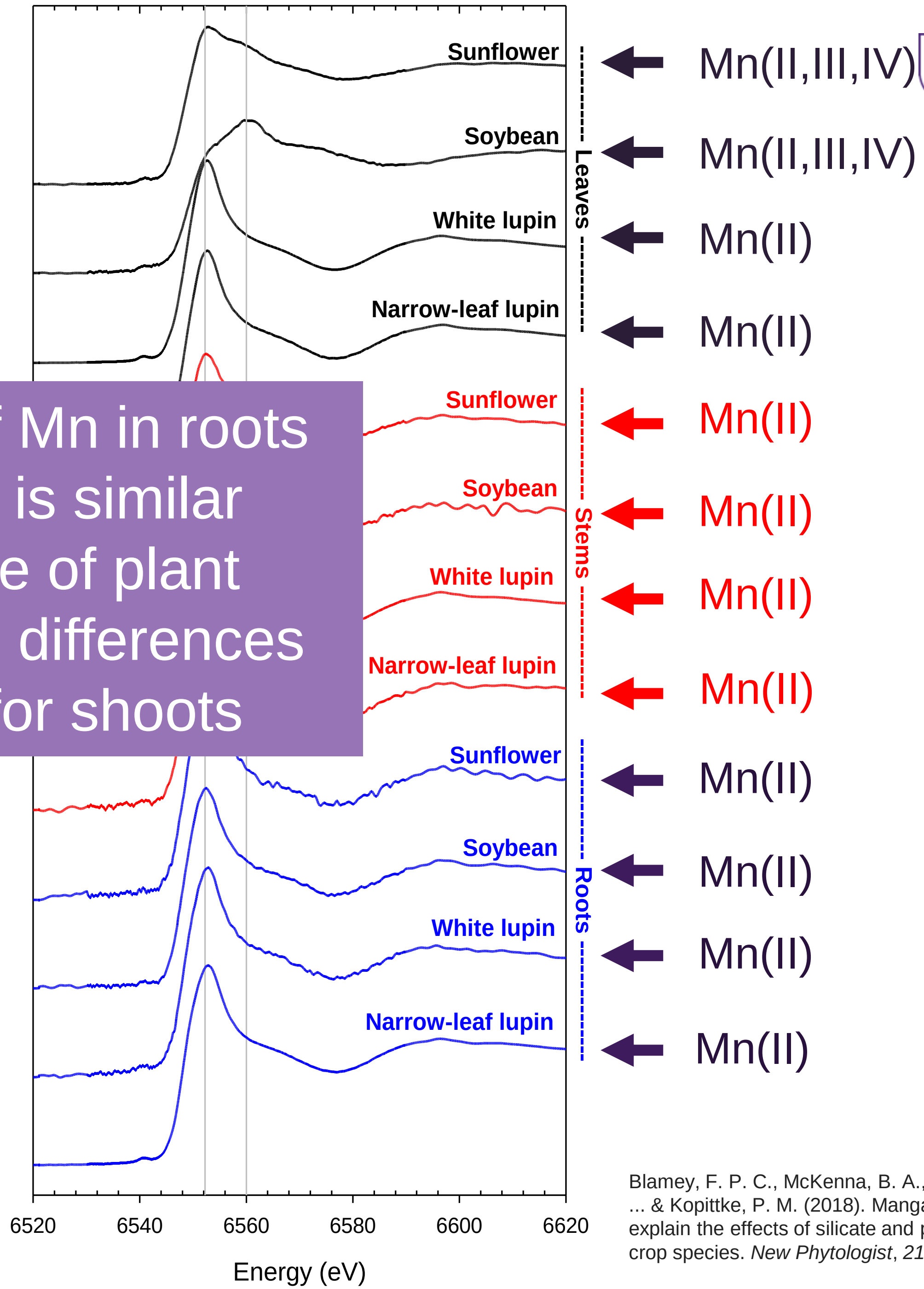


In Mn-tolerant sunflower, Mn is sequestered within trichomes

Blamey, F. P. C., Hernandez-Soriano, M.
Paterson, D. J., Lombi, E., ... & Kopittke,
techniques shed light on mechanisms of
high manganese in the root environment. Plant Physiology, 169(3), 1900
2020.



Speciation of Mn in roots and stems is similar irrespective of plant species, with differences observed for shoots



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Blamey, F. P. C., McKenna, B. A., Li, C., Cheng, M., Tang, C., Jiang, H., ... & Kopittke, P. M. (2018). Manganese distribution and speciation help to explain the effects of silicate and phosphate on manganese toxicity in four crop species. *New Phytologist*, *217*(3), 1146-1160.

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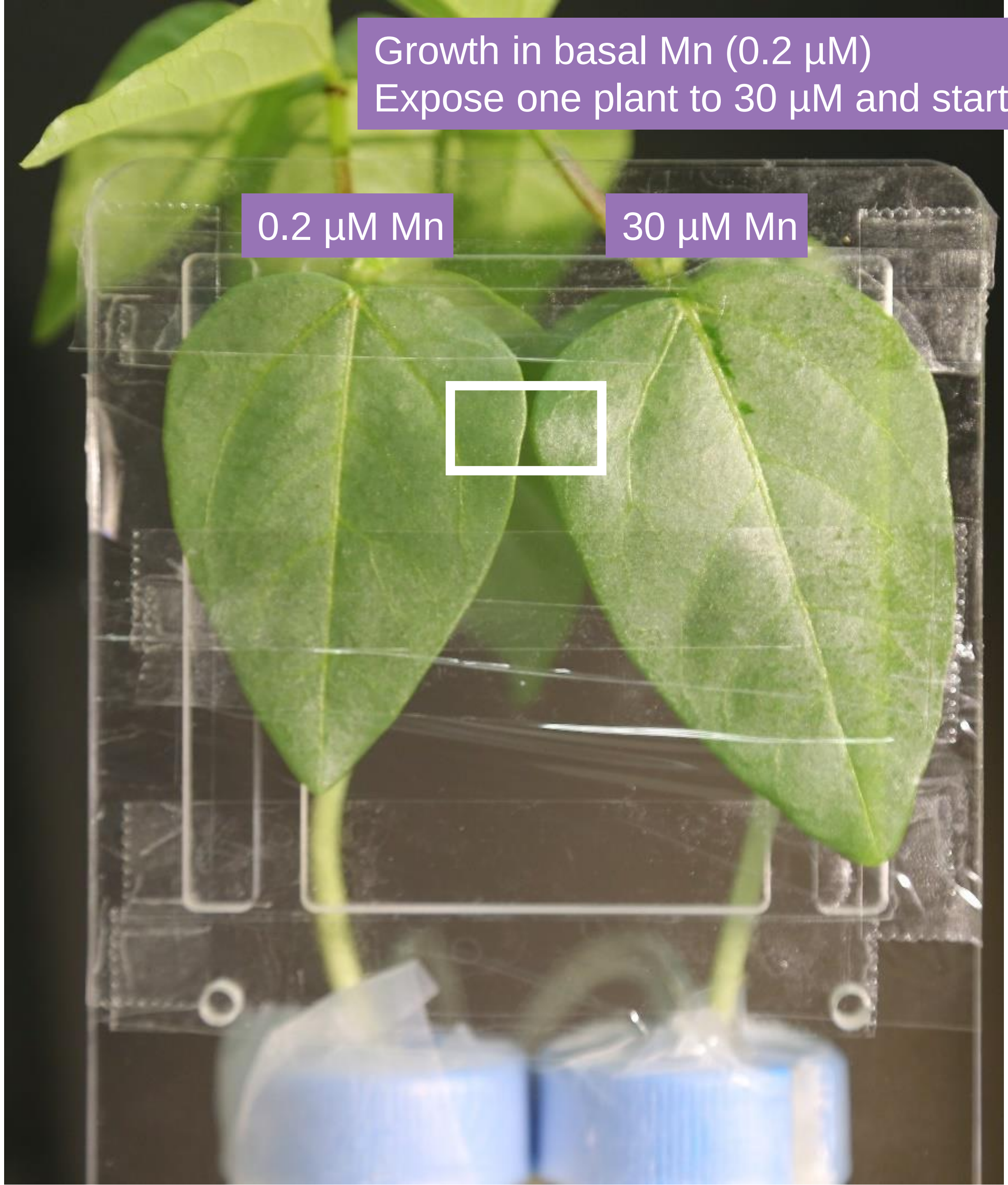
Soybean



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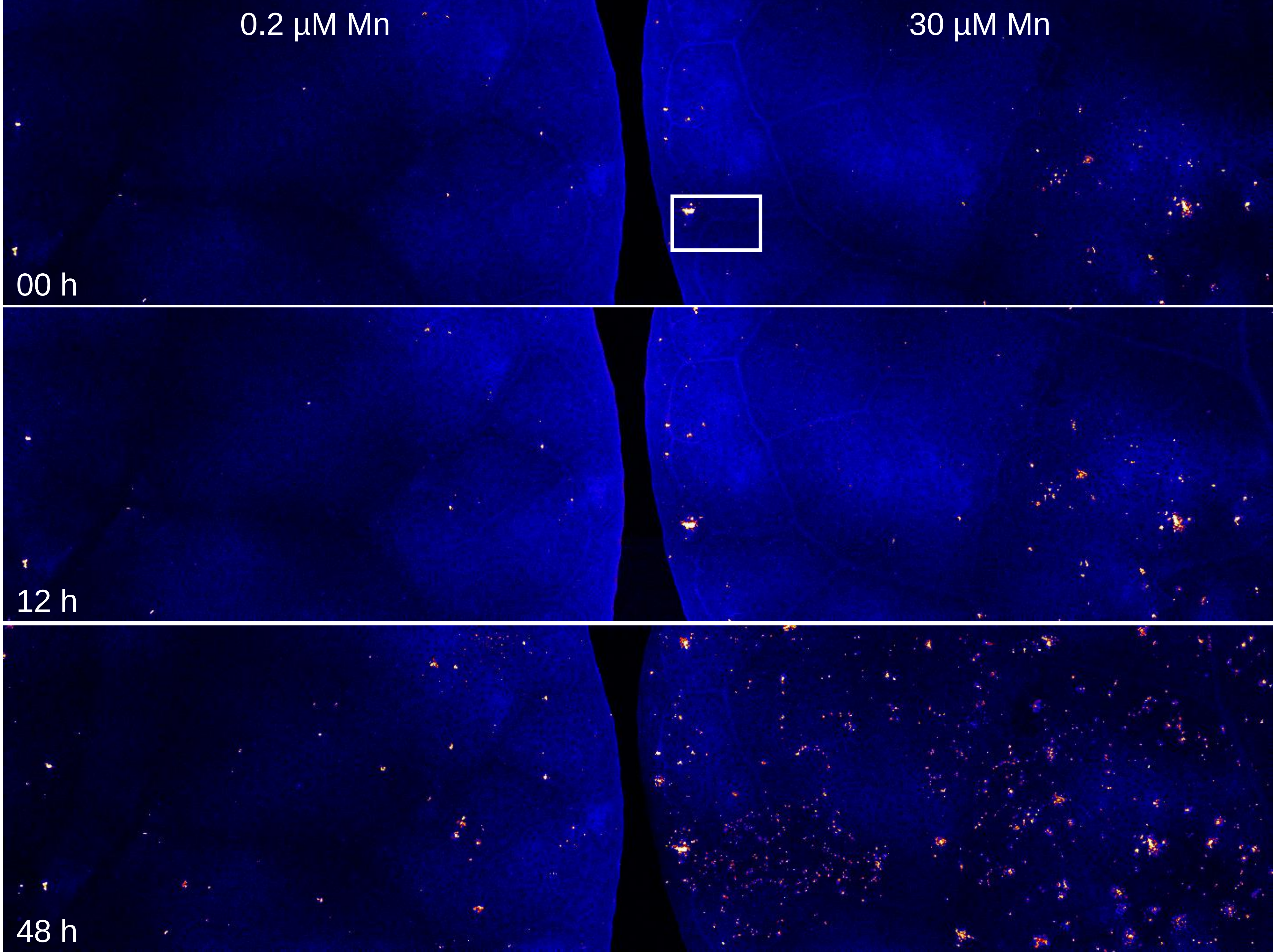
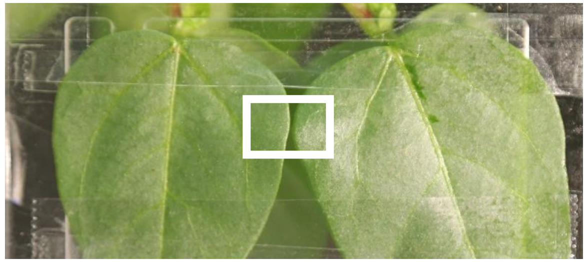
- This experiment represents the first time resolved, elemental mapping, in plants, *in vivo*





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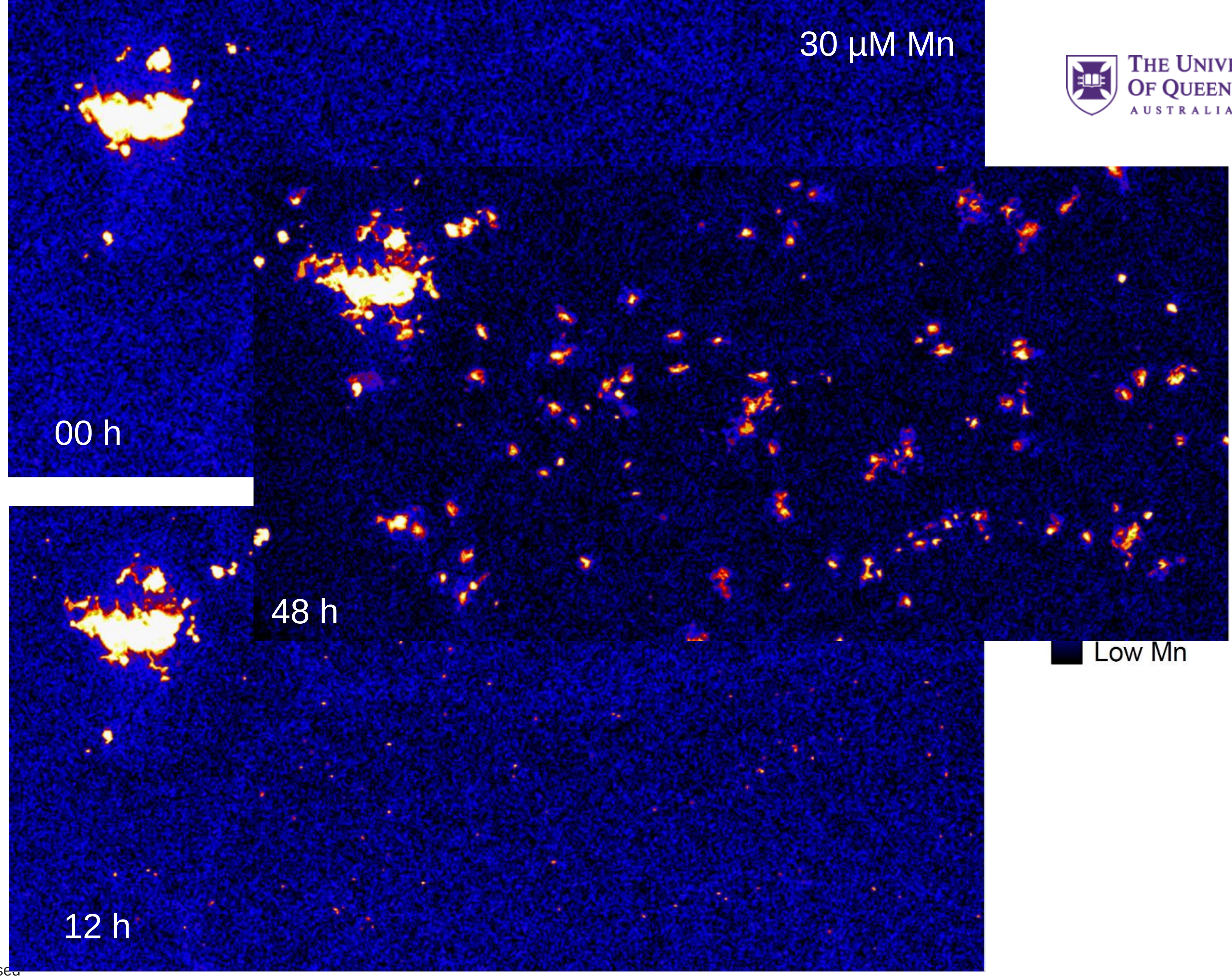
Soybean



Blamey, F. P. C., Hernandez-Soriano, M. C., Cheng, M., Tang, C., Paterson, D. J., Lombi, E., ... & Kopittke, P. M. (2015). Synchrotron-based techniques shed light on mechanisms of plant sensitivity and tolerance to high manganese in the root environment. *Plant Physiology*, *169*(3), 2006-2020.

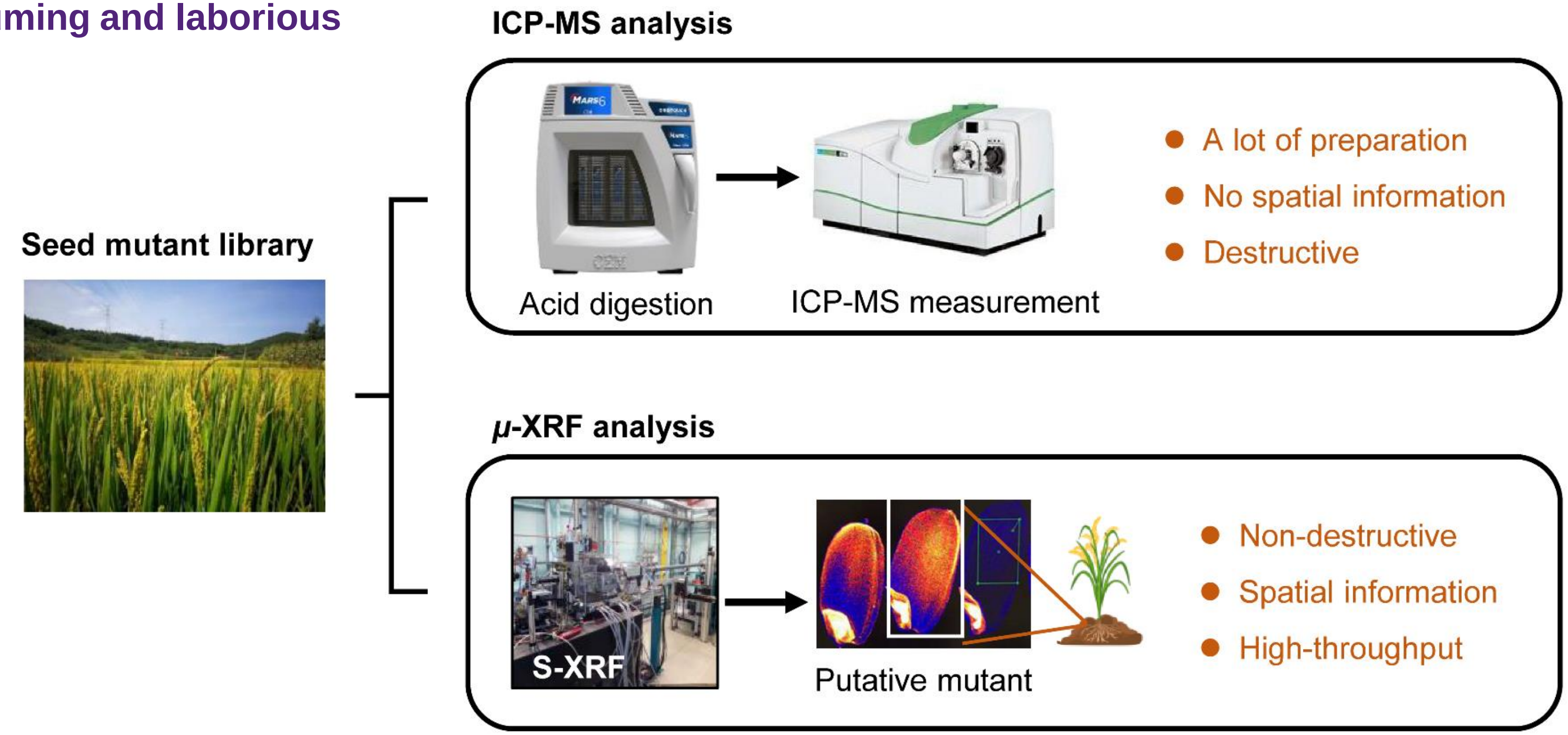
Challenge 3

Human nutrition

- micronutrient deficiency affects billions of people

- cereals are a poor source of micronutrients

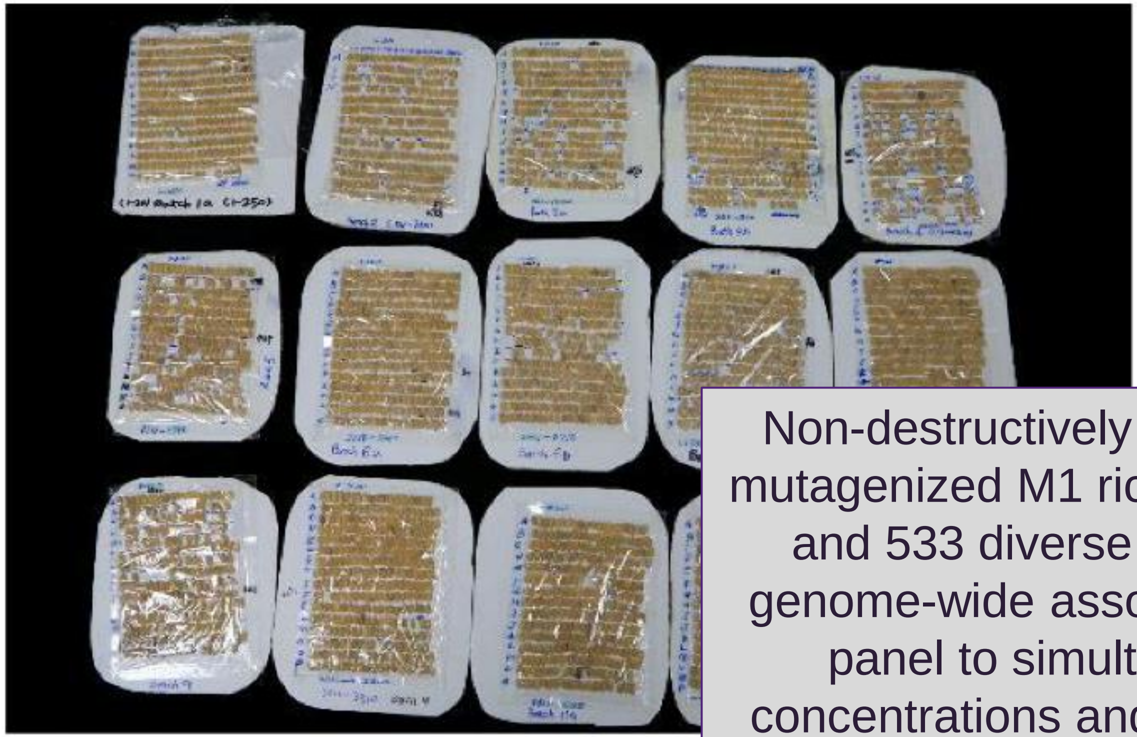
- screening plant libraries is time-consuming and laborious



Ren, Z.-W., Yang, M., McKenna, B.A., Lian, X.-M., Zhao, F.-J., Kopittke, P.M., Lombi, E., Wang, P., 2023. Fast X-ray fluorescence microscopy provides high-throughput phenotyping of element distribution in seeds. Plant Physiol 191, 1520-1534.

X-ray fluorescence microscopy – XFM

4,190 EMS-mutagenized M1 rice seeds



533 accessions rice seed

Non-destructively scanned 4,190 EMS-mutagenized M1 rice (*Oryza sativa*) seeds and 533 diverse rice accessions in a genome-wide association study (GWAS) panel to simultaneously measure concentrations and spatial distribution of elements in the embryo, endosperm, and aleurone layer

Ren, Z.-W., Yang, M., McKenna, B.A., Lian, X.-M., Zhao, F.-J., Kopittke, P.M., Lombi, E., Wang, P., 2023. Fast X-ray fluorescence microscopy provides high-throughput phenotyping of element distribution in seeds. Plant Physiol 191, 1520-1534.

X-ray fluorescence microscopy – XFM

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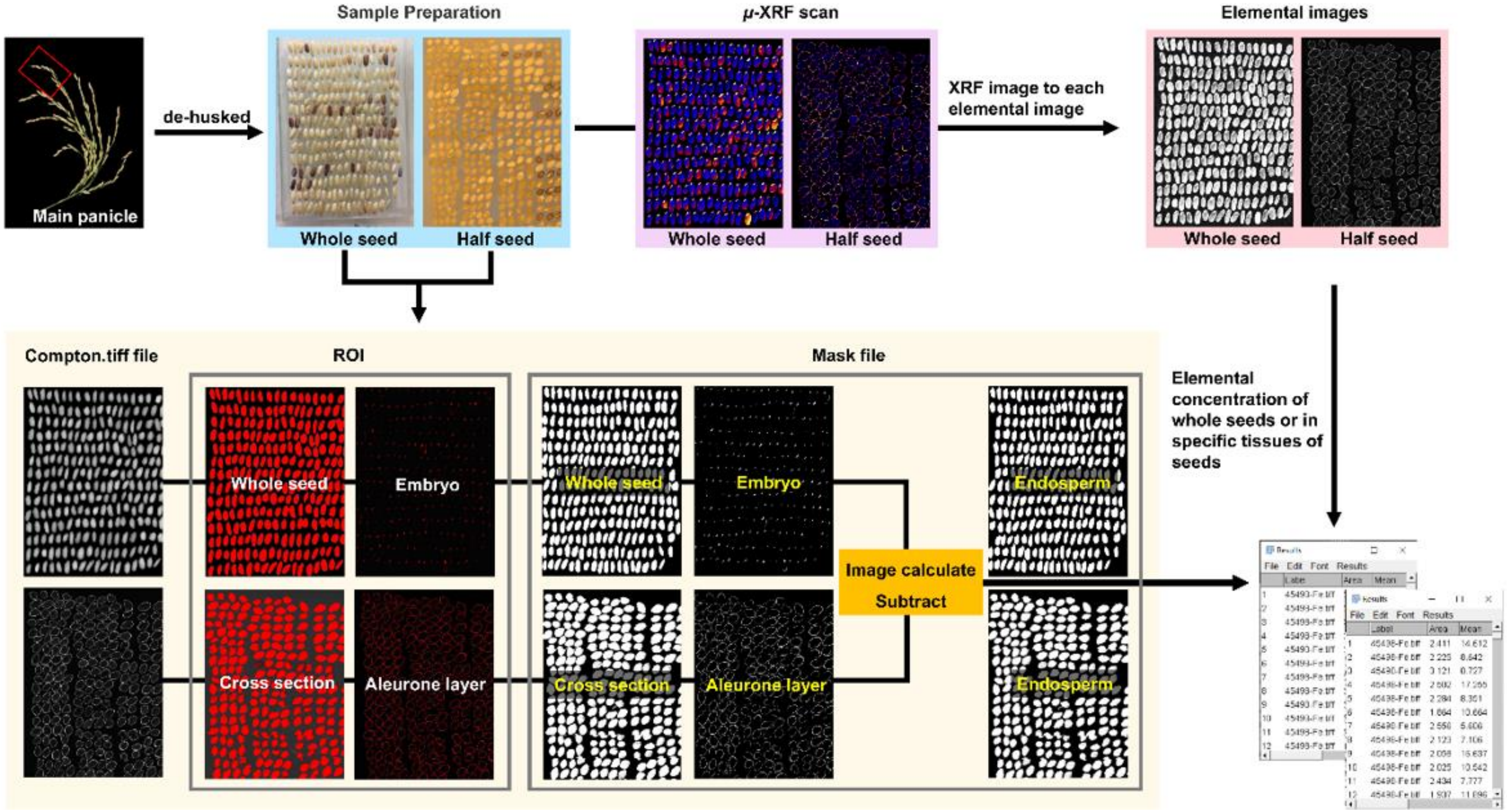
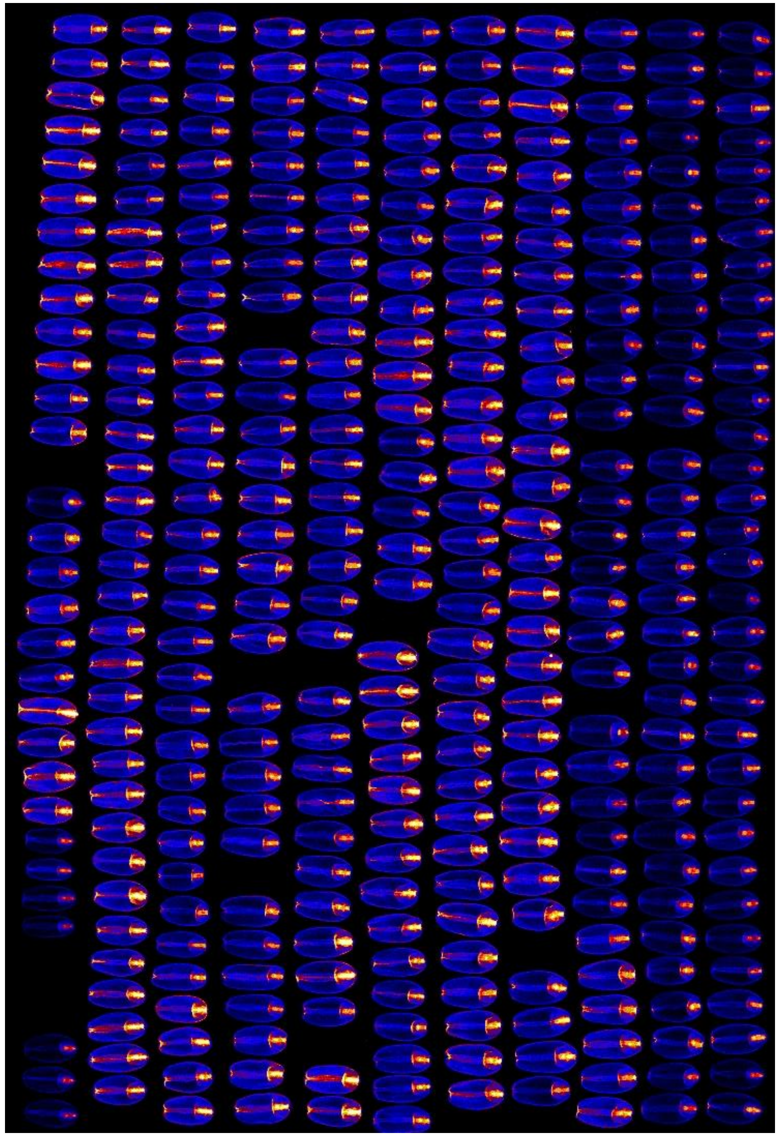
High-throughput phenotyping and elemental distribution in seeds



Ren, Z.-W., Yang, M., N
Lombi, E., Wang, P., 20
high-throughput phenotyping of element distribution in seeds. Plant Physiol 191, 1520-1534.

X-ray fluorescence microscopy – XFM

Zn



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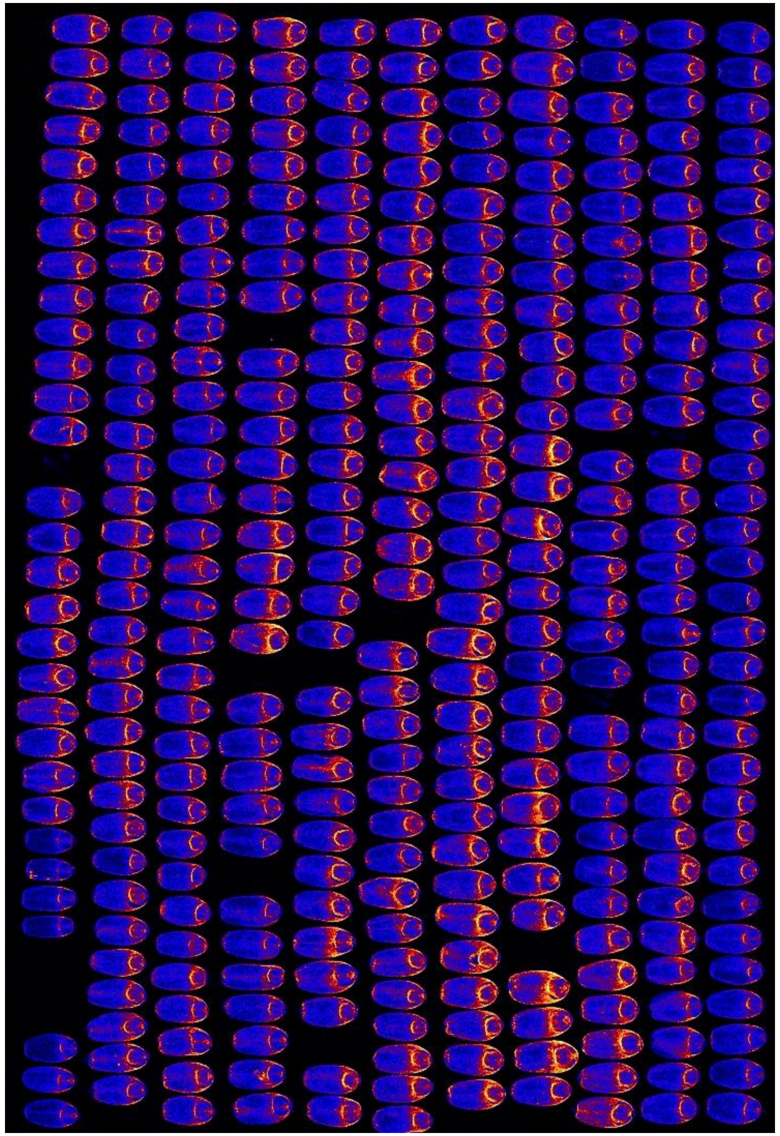
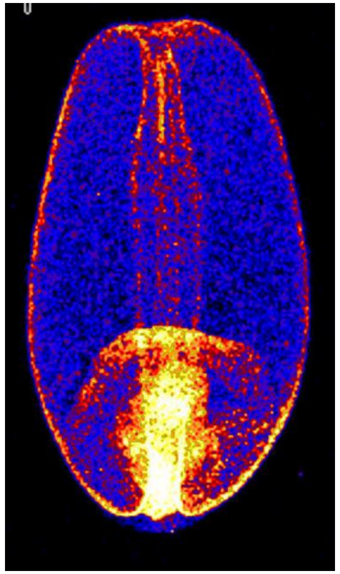


Zn



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Beamline Scientists: David Paterson, Martin de Jonge, Daryl Howard, Simon James, Jeremy Wykes, Peter Kappen, Anton Maksimenko, Daniel Hausermann

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