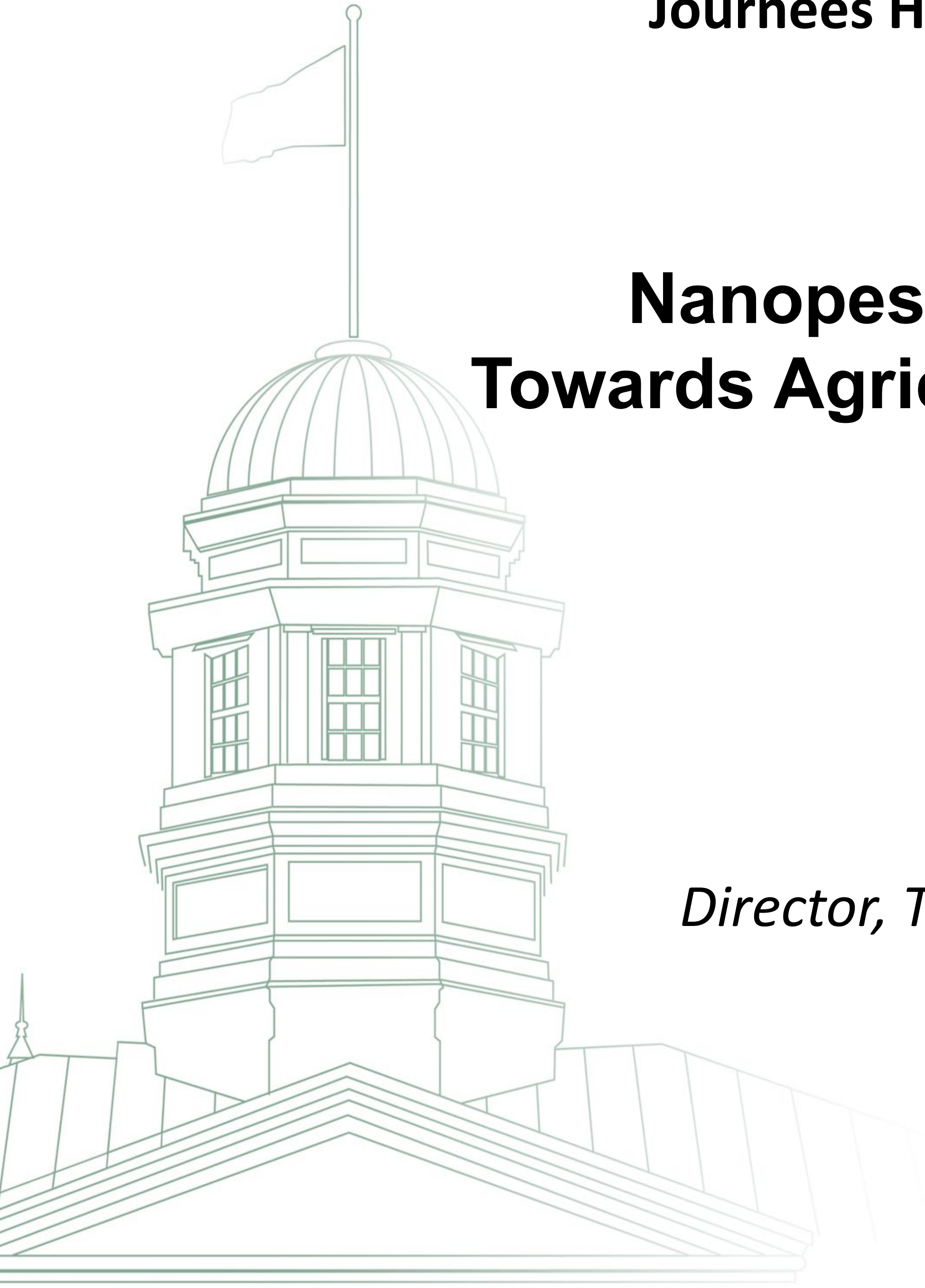
Journées Horticoles et Grandes Cultures 2025

27 November



Nanopesticides & Nanofertilizers: Towards Agriculture at the Nanoscale!

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Director, Trottier Institute for Sustainability

McGill University

McGill

TISED

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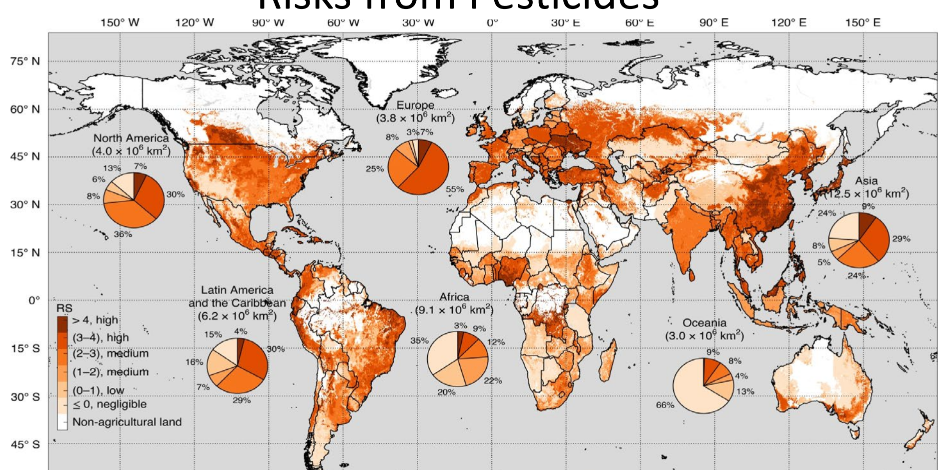
Background

World population is estimated to grow to 9 billion by 2050

60% increase in food demand due to population increase

Pesticides and fertilizers are <u>pivotal</u> for maintaining food security

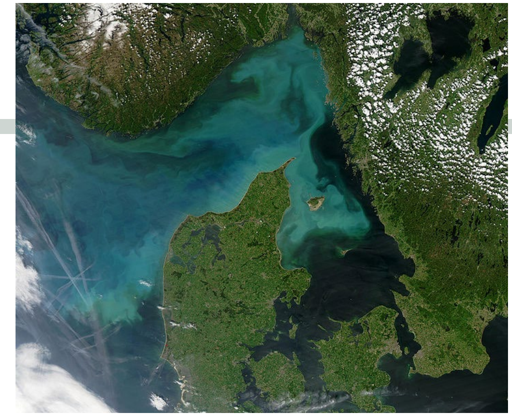
Risks from Pesticides



Tang et al. *Nat. Geosci.* **14**, 206–210 (2021).

Coastal pollution

Visible eye, NASA



Current Fertilizer Application Practices are Inefficient

- *Less than 20% applied P, micronutrients applied to soils are utilized by plants*
- Soil degradation
- Eutrophication & CO_2 footprint

https://zentide.co/blog/the-impact-of-chemical-fertilizer-overuse-on-soil-quality-and-climate-change/

Environmental Science & Technology

Feature

pubs.acs.org/est

Feed the Crop Not the Soil: Rethinking Phosphorus Management in the Food Chain

Paul J. A. Withers,[*,†] Roger Sylvester-Bradley,[‡] Davey L. Jones,[†] John R. Healey,[†] and Peter J. Talboys[†]

Environ. Sci. Technol. 2014, 48, 6523−6530

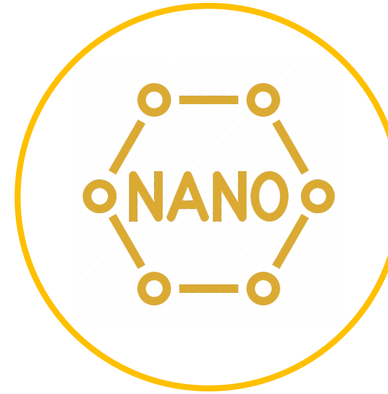

https://www.elgalabwater.com/blog/occurrence-pesticides-dutch-drinking-water-sources
2,450,000,000 kg
OF PESTICIDES ARE
WASTED YEARLY

Background

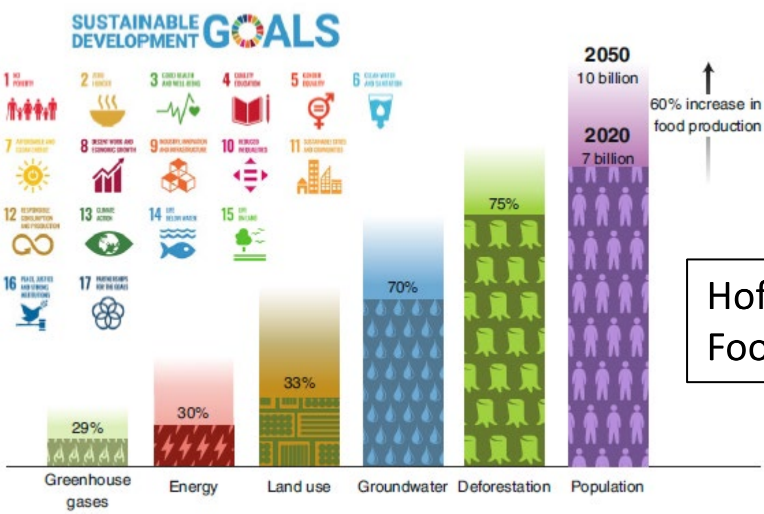
World population is estimated to grow to 9 billion by 2050

60% increase in food demand due to population increase

Pesticides and fertilizers are pivotal for maintaining food security

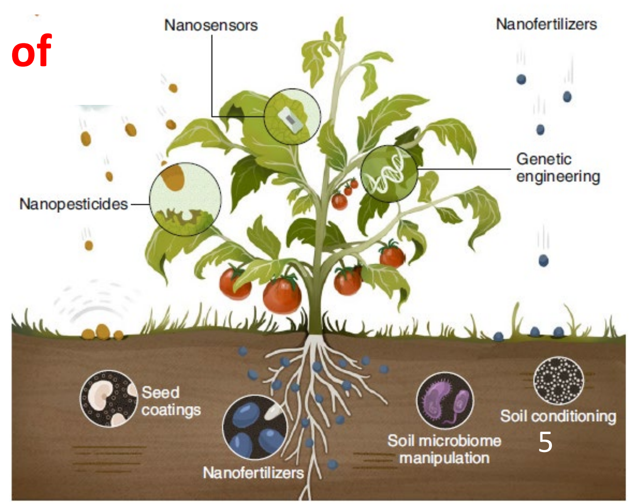


Nanotechnology offers some promising solutions

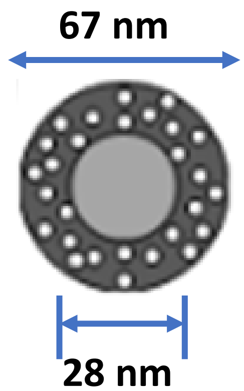


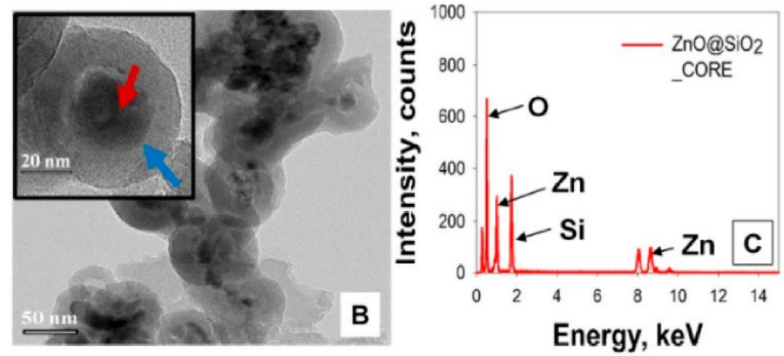
Foliar application of Nanofertilizers & Nanopesticides

Hofmann et al. Nature Food, 2020, 1, 416–425



Foliar application of nanoencapsulated pesticides and fertilizers

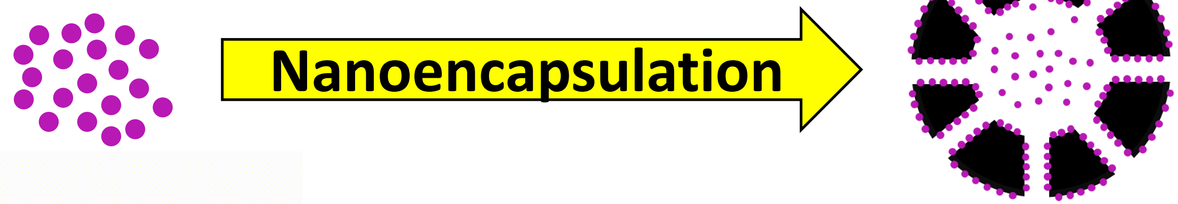


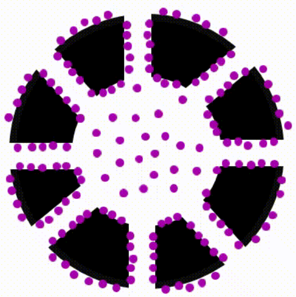


Core: ZnO
Shell: mesoporous SiO_2

- **By-pass adverse effects of soil application**
- NPs can be designed to act as **controlled release carriers**
- Targeted to specific plant parts, tissue, cellular organelles
- Minimize damage to the leaf by direct pesticide/fertilizer application

Nanocapsulation as a solution





Controlled release and targeted delivery

Reduced frequency of application

Prevent premature degradation/evaporation

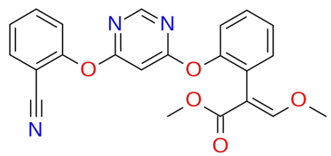
Lower toxicity to non-target organisms

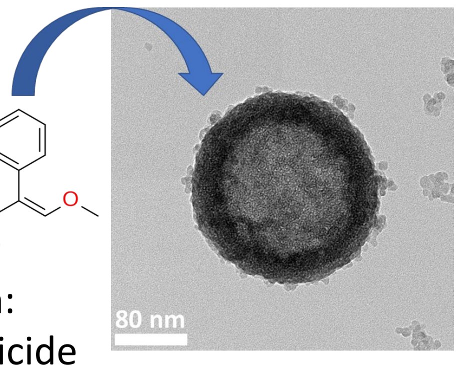
Azoxystrobin
Bifenthrin
Rosemary oil
P, Mn, Zn

Slow-Release Properties of Mesoporous Silica Nanoparticles

Bueno & Ghoshal, *Langmuir,* 2020, 36, 14633-14643

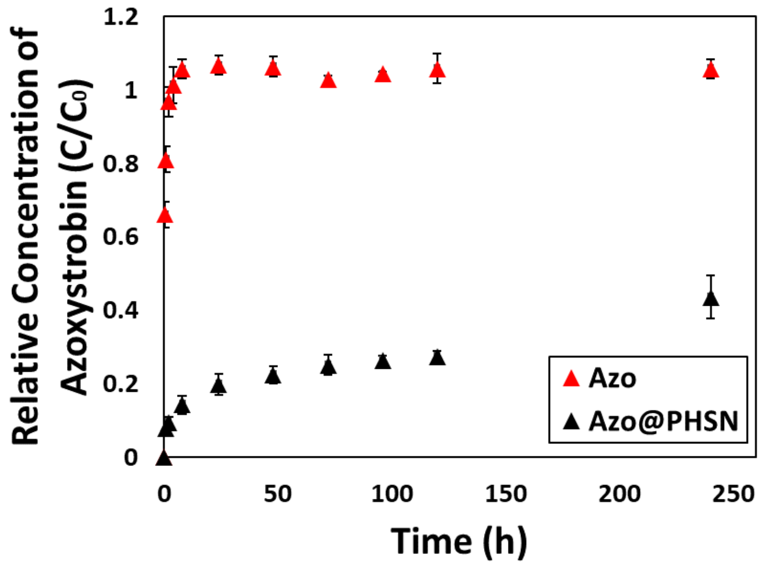
Porous hollow
Mesoporous SiO_2 NP





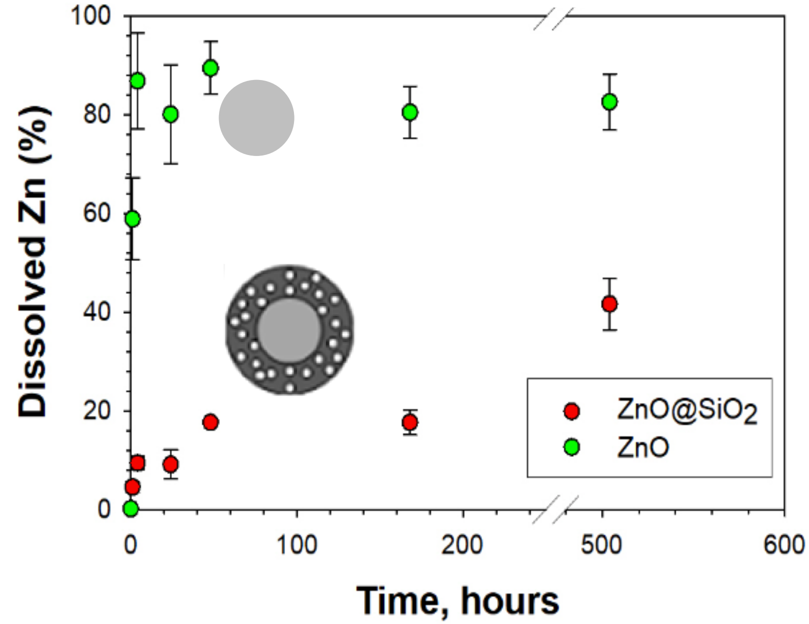
Azoxystrobin:
Strobilurin pesticide

Azo Release Profile



Bueno et al. *Environ. Sci.: Nano*, 2022, 9, 1476-1488

Zn Release Profile



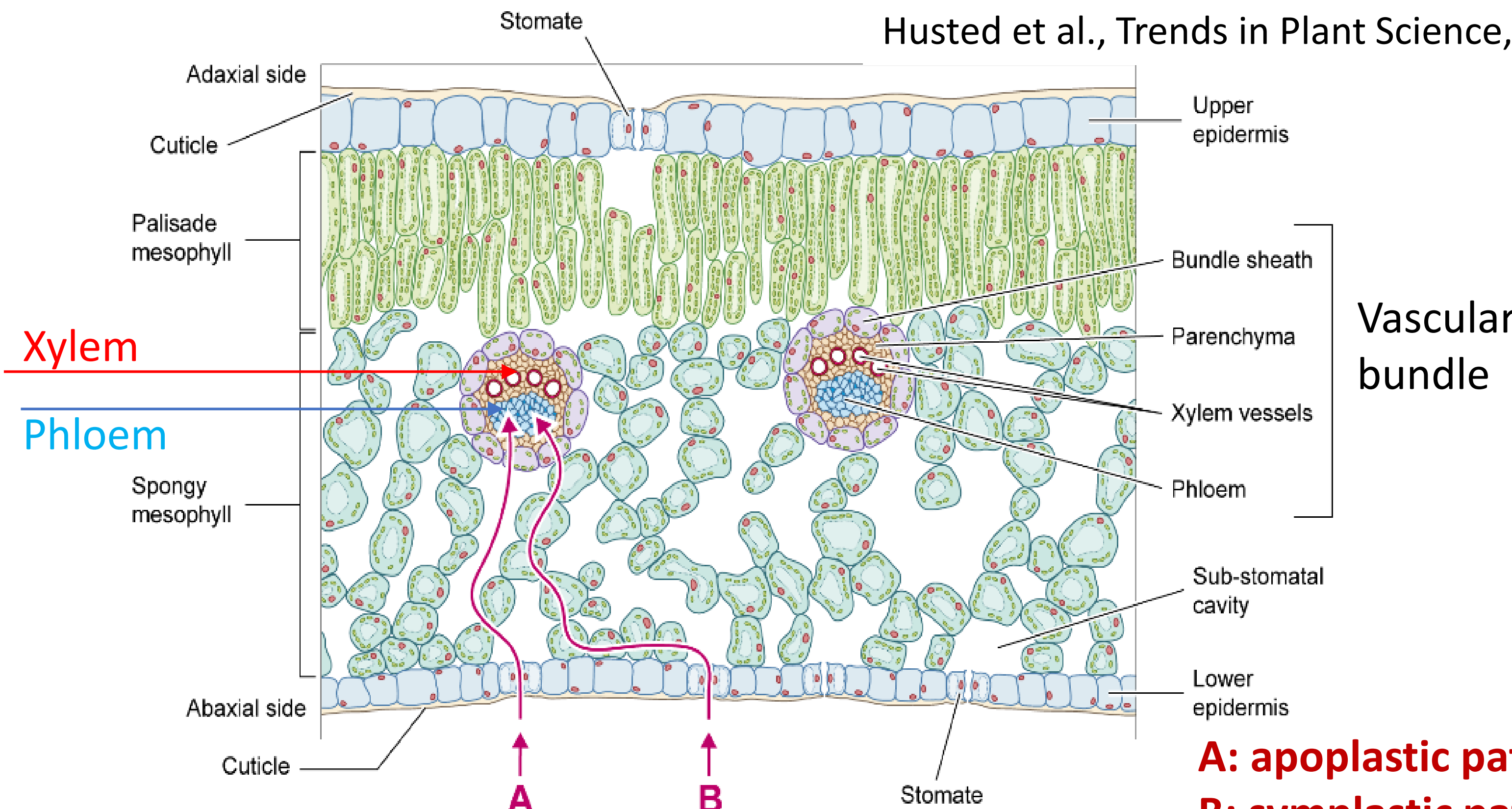
Bueno et al. *Environ. Sci. Technol.* 2022, 56: 6722-6732

<u>Takeaway:</u>

Silica nanocarrier promoted slow release of soluble (pesticide Azoxystrobin) and solid (ZnO) species

Phloem loading is critical for efficient translocation & pathogen targeting

Husted et al., Trends in Plant Science, 2022



A: apoplastic pathway
B: symplastic pathway

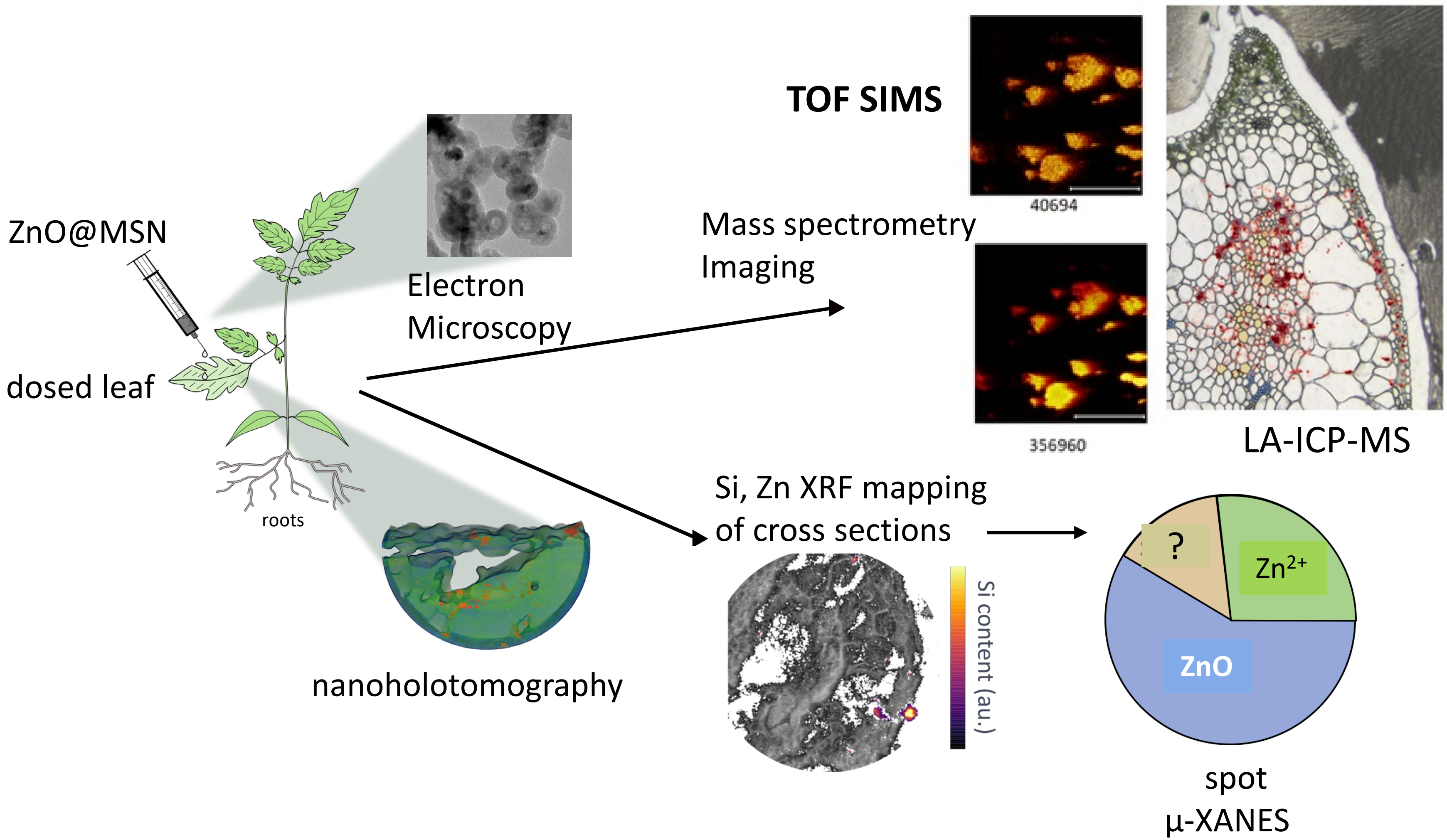
For NPs to be translocated to all plant parts:

- NPs will have to enter at least one cell to enter the vascular bundle
- Phloem in the vascular bundle can transport NPs to the root, shoot and foliage

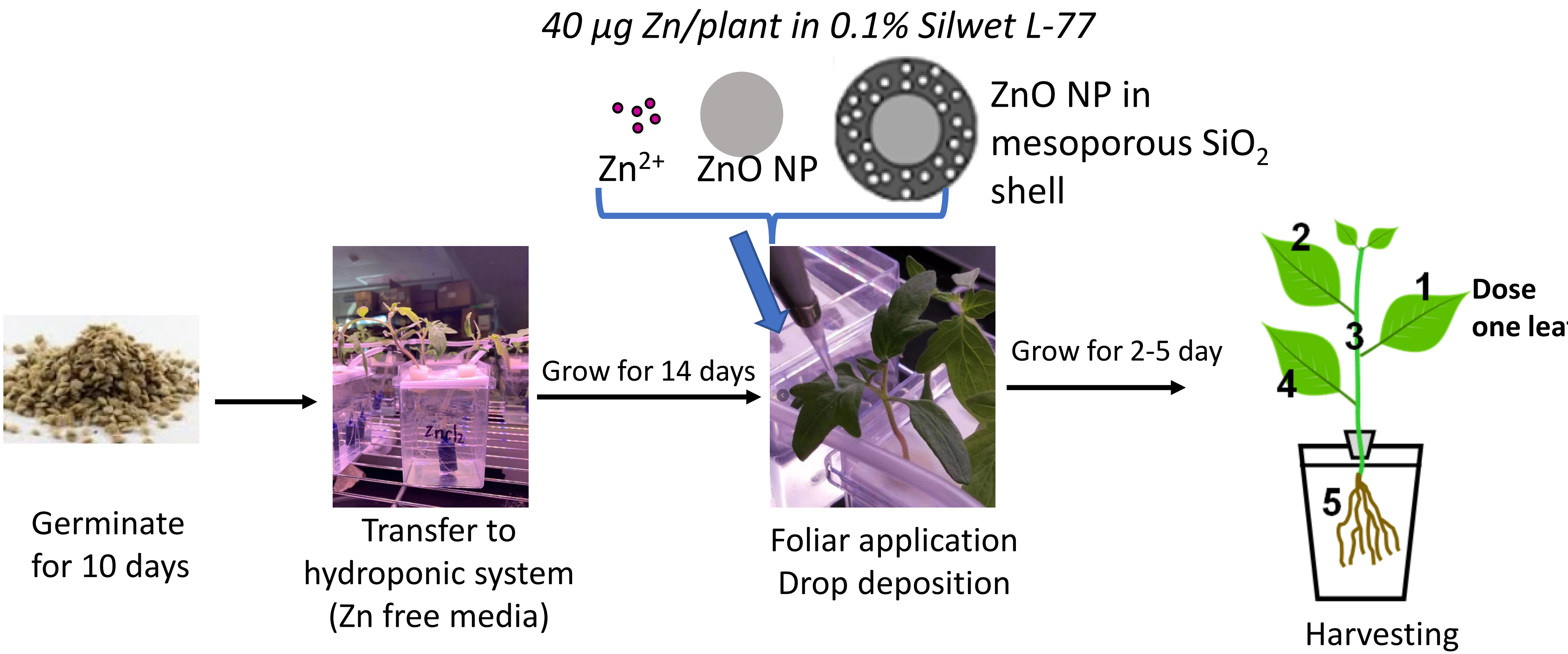
Targeting bacterial and fungal pathogens

- Pathogens propagate via the phloem

Foliar application of nanopesticides and nanofertilizers



(Nanoencapsulated) Zn: Foliar application



- Compare Zn uptake efficiency:
  - $ZnO@SiO_2$ NPs vs other Zn species
- Understand translocation mechanism of $ZnO@SiO_2$:
  - Dissolved vs particulate species translocation

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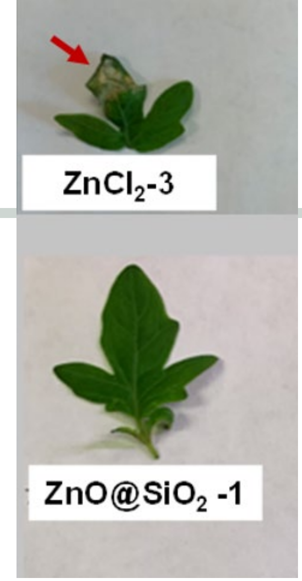
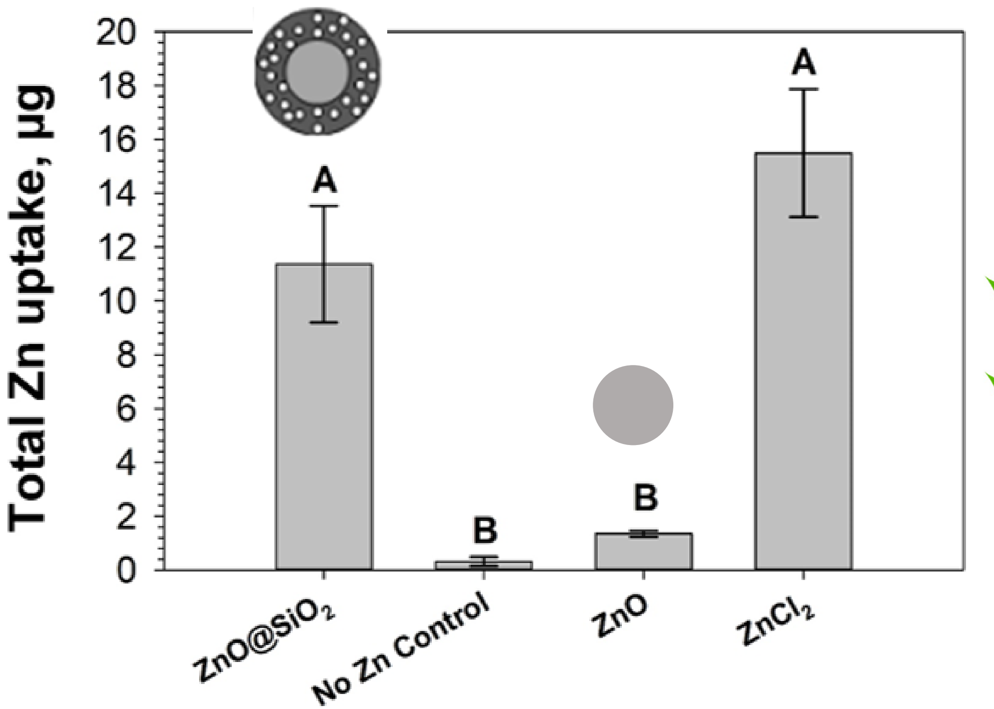
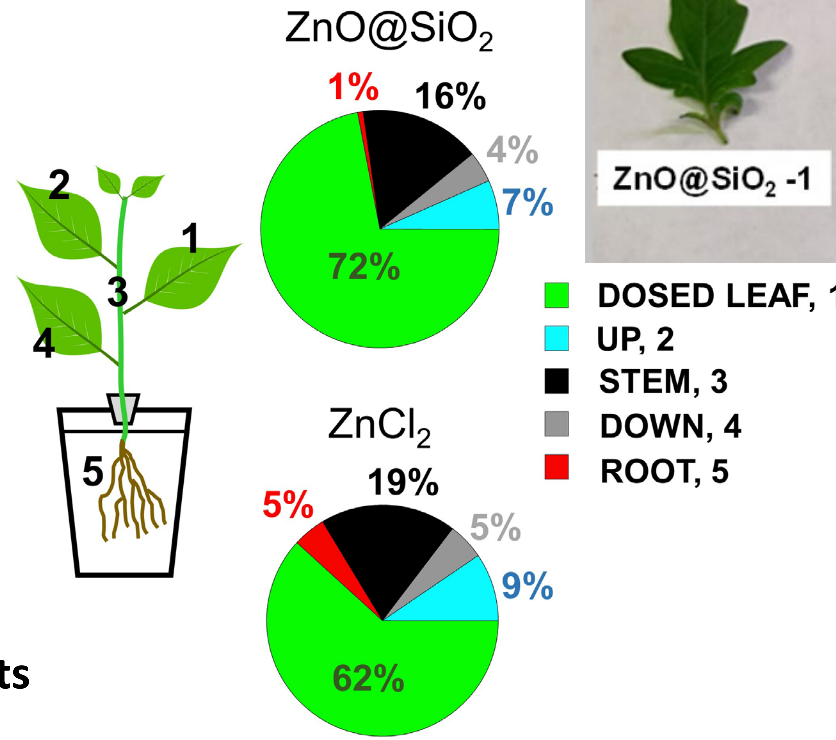
Uptake and translocation of Zn: foliar applied ZnO, $ZnCl_2$ and $ZnO@SiO_2$





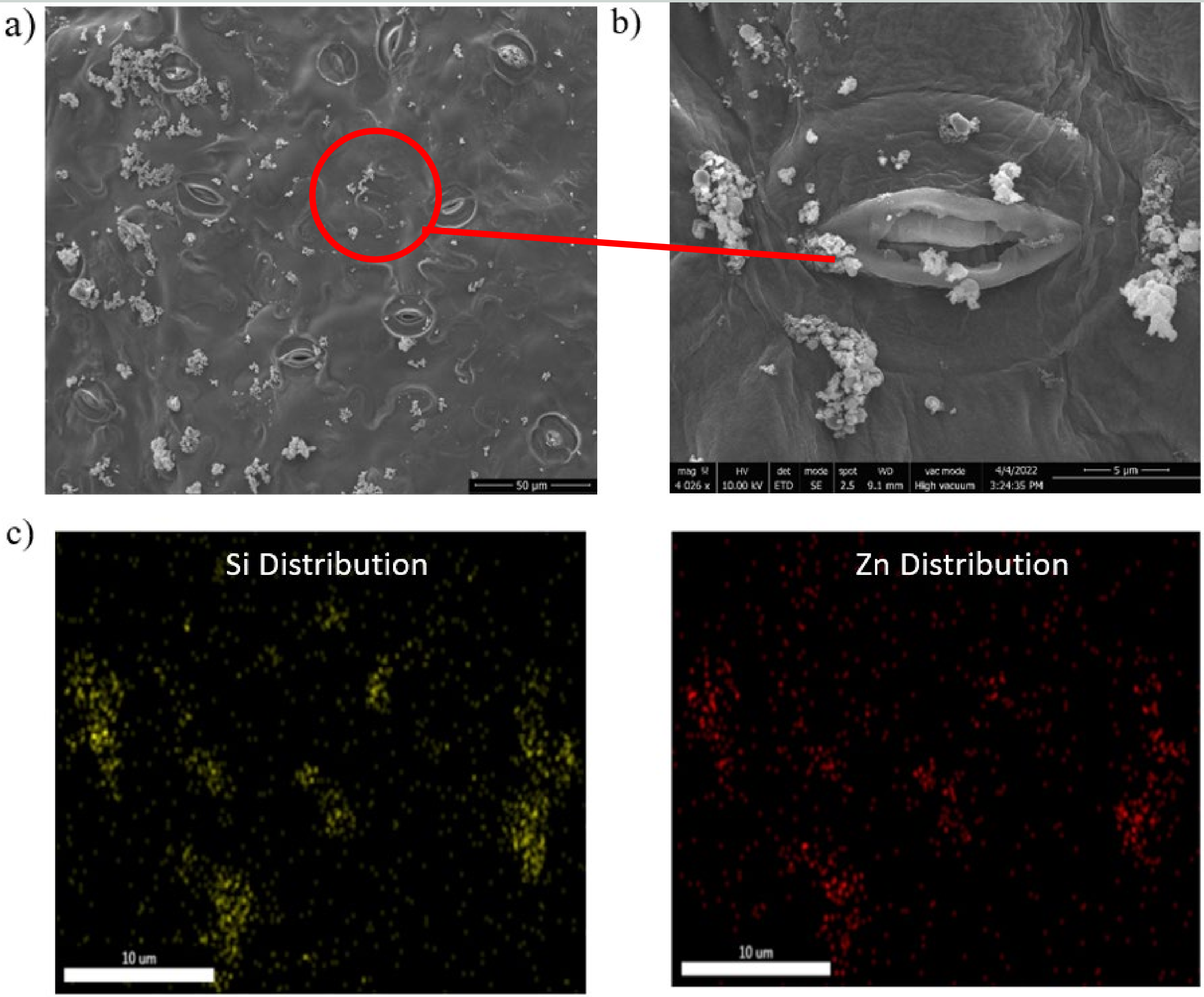


2 day Zn exposure in 14 day old tomato plants

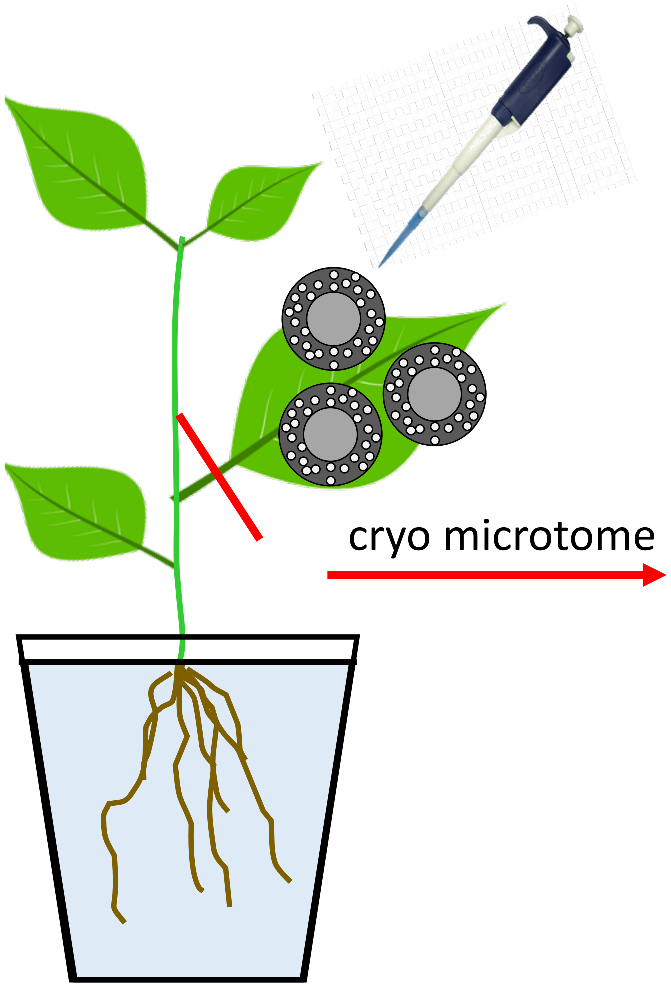
- **Bare ZnO NPs was not delivered effectively to different plant parts**
- **Same total Zn uptake but different distribution for $ZnO@SiO_2$ and $ZnCl_2$**
- **Uptake from $ZnO@SiO_2$ result of particulate uptake**

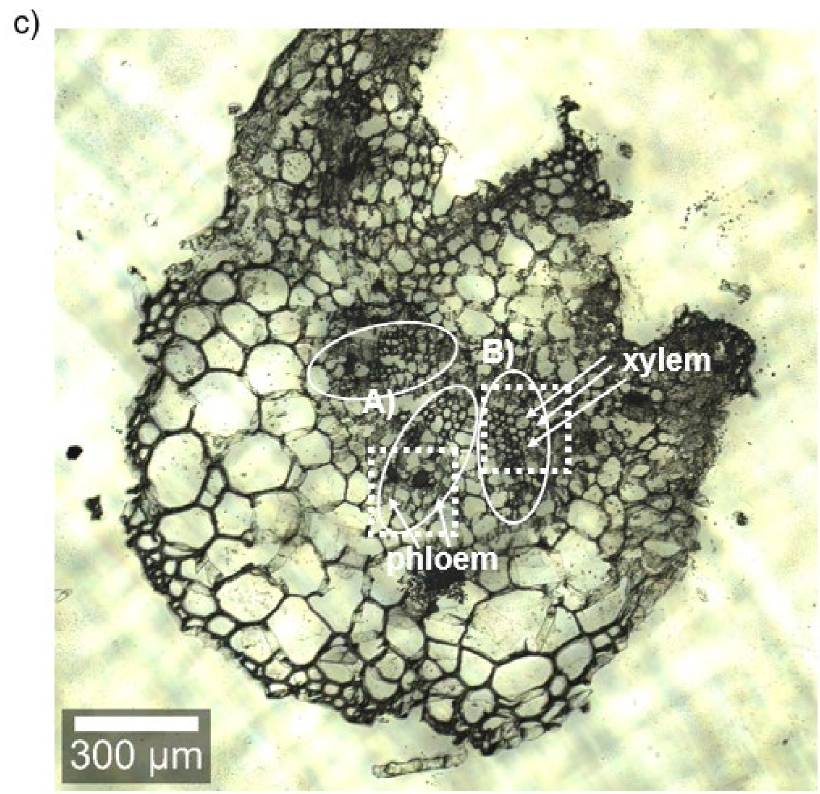
Gao et al, Environ. Sci. Technol., 2021, 55, 13551−13560

Uptake of ZnO@SiO2 NPs by plant stoma



Time of Flight Secondary Ion Spectrometery

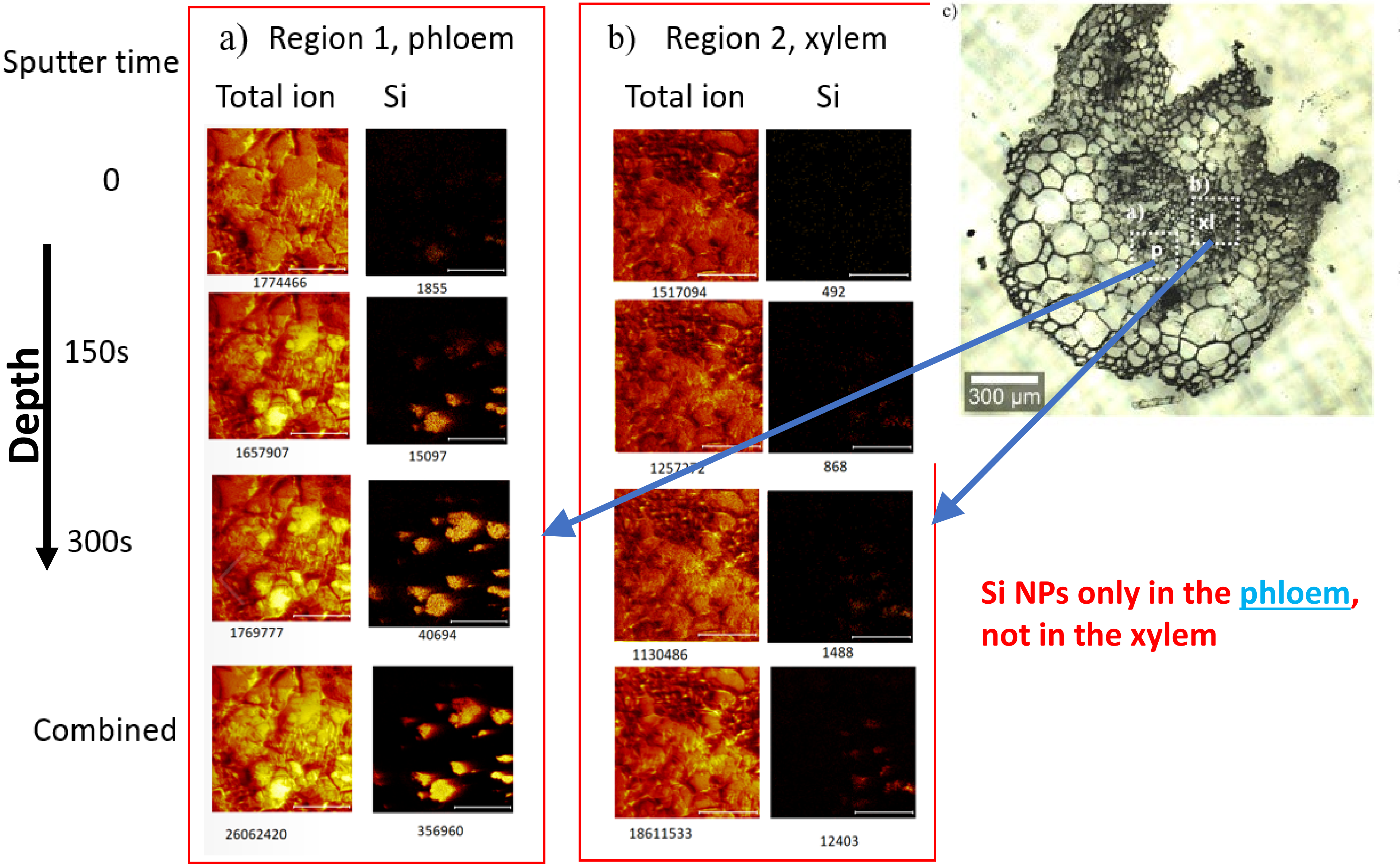




Petiole cross-section

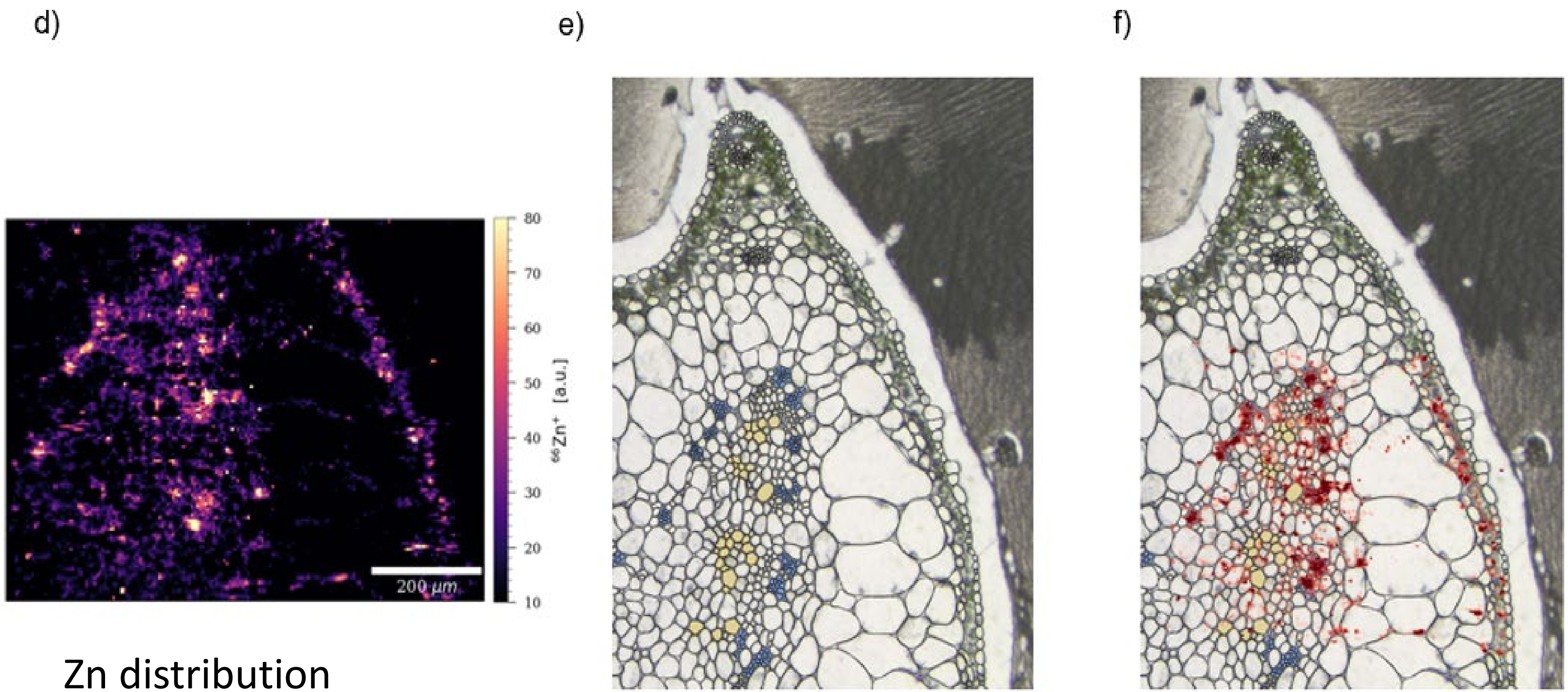
Time of Flight Secondary Ion Mass Spec

Gao et al., Environ. Sci. Technol., 2023, 57, 21704-21714



Si NPs only in the phloem, not in the xylem

Laser Ablation ICP MS for Zn



Zn distribution raw image

Microscope image
Blue: phloem

Zn overlay from ICP MS
Red: Zn

Zn (total) also present largely in phloem

Gao et al., Environ. Sci. Technol., 2023, 57, 21704-21714

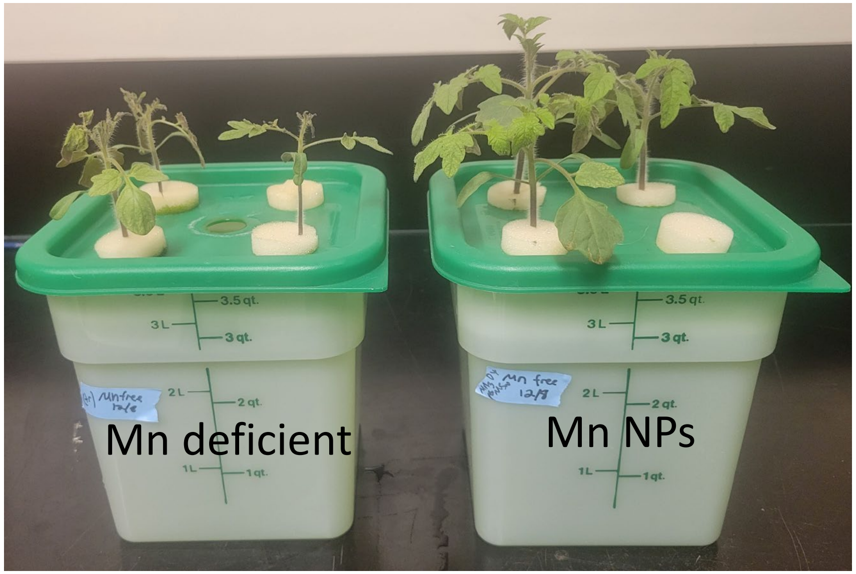
Challenges & Opportunities

We need:

- Benign, safe nanocarriers
- Lab to field studies
  - Application on large crop fields
  - Produce nanopesticides and nanofertilizers at scale
- Precision agriculture for nanoparticle applications
- Cost-benefit analyses
- Good agricultural outcomes
  - Higher *edible product* yields (not just biomass)
  - Increase *nutritional value* of edible parts
- Environmental and Social Considerations
  - Minimize unintended effects: environmental and human toxicity
  - Environmental footprint of nanoenabled agriculture
  - Consumer acceptance

Conclusions from our lab

- SiO_2 core-shell NPs showed controlled release of active ingredients compared to their direct application
- SiO_2 shell enhanced the uptake of Zn and other nutrients, and pesticides (Azoxystrobin)
- Nanofertilizers and nanopesticides can be distributed in the plant efficiently to increase growth and protection



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