Nanomaterials and Food/Agriculture: Assessing the Balance Between Implications and Applications

Sustainable Nanotechnology Organization

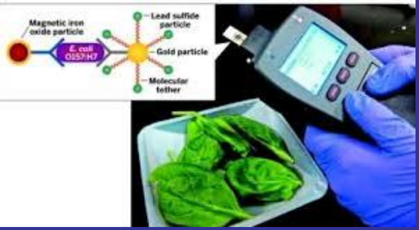
Jason C. White, Ph.D.

State Chemist, Vice Director & Chief Analytical Chemist,
The Connecticut Agricultural Experiment Station, New Haven CT

Presented at the 2017 Sustainable Nanotechnology Organization (SNO) Conference
Los Angeles CA; November 5-7, 2017

Nanomaterials and Food Protection

- Food Safety- microbes and chemicals/elements
  - Antimicrobials in food packaging
  - Nano-enabled coatings for food/equipment; EWNS & HSPH
  - Nanosensors for pathogen detection




Available online at www.sciencedirect.com
ScienceDirect
Current Opinion in Biotechnology
ELSEVIER
Nanotechnology to the rescue: using nano-enabled approaches in microbiological food safety and quality
Mary Eleftheriadou[1,3], Georgios Pyrgiotakis[2,3] and Philip Demokritou[2]

- Food Defense- microbes and chemicals/elements
  - Nanosensors for specific agents of concern (biological weapons such as *B. anthracis,* Ebola [Harvard/MIT]) and others; plant proteins such as ricin and abrin

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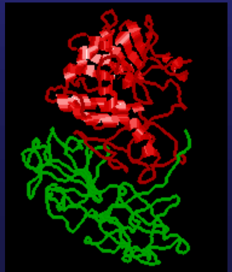
FERN
Uniting Federal, State and Local Laboratories for Food Emergency Response



Nanomaterials and Agriculture

- The goals fall into several categories; efficiency is the driver (precision ag.)
  - Increase production rates and yield
  - Increase efficiency of resource utilization
  - Minimize waste production
- Specific applications include:
  - Nano-fertilizers, Nano-pesticides
  - Nano-based treatment of agricultural waste
  - Nanosensors

Biotechnology Advances 32 (2014) 1550–1561
Contents lists available at ScienceDirect
ELSEVIER
Biotechnology Advances
journal homepage: www.elsevier.com/locate/biotechadv
Research review paper

Application of nanotechnology for the encapsulation of botanical insecticides for sustainable agriculture: Prospects and promises

Jhones Luiz de Oliveira [a,1], Estefânia Vangelie Ramos Campos [a,b,1], Mansi Bakshi [c], P.C. Abhilash [c], Leonardo Fernandes Fraceto [a,b,*]
[a] Department of Biochemistry, State University of Campinas, Campinas, SP, Brazil
[b] Department of Environmental Engineering, São Paulo State University – UNESP, Sorocaba, SP, Brazil
[c] Institute of Environment & Sustainable Development, Banaras Hindu University, Varanasi 221005, India

2015

IB IN DEPTH—Special Section on Nanobiotechnology, Part 1

2012

NORMAN SCOTT AND HONGDA CHEN, GUEST EDITORS

(Part 2 of the IB IN DEPTH—Special Section on Nanobiotechnology will appear in the February 2013 issue)

Overview

Nanoscale Science and Engineering for Agriculture and Food Systems

frontiers in Chemistry
PERSPECTIVE
published: 16 November 2015
doi: 10.3389/fchem.2015.00064

2015

Nanopesticides and Nanofertilizers: Emerging Contaminants or Opportunities for Risk Mitigation?

Melanie Kah *
Department of Environmental Geosciences, University of Vienna, Vienna, Austria

Environmental Science Nano
ROYAL SOCIETY OF CHEMISTRY
TUTORIAL REVIEW
View Article Online
View Journal | View Issue
Check for updates
Cite this: Environ. Sci.: Nano, 2017, 4, 767

2017

Nanotechnology for sustainable food production: promising opportunities and scientific challenges

Sónia M. Rodrigues,[a] Philip Demokritou,[b] Nick Dokoozlian,[c] Christine Ogilvie Hendren,[de] Barbara Karn,[f] Meagan S. Mauter,[gh] Omowunmi A. Sadik,[fi] Maximilian Safarpour,[j] Jason M. Unrine,[dk] Josh Viers,[l] Paul Welle,[h] Jason C. White,[m] Mark R. Wiesner[de] and Gregory V. Lowry[*dg]

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frontiers in Environmental Science
PERSPECTIVE
published: 10 April 2017
doi: 10.3389/fenvs.2017.00012

2017

Interaction of Nanomaterials with Plants: What Do We Need for Real Applications in Agriculture?

Alejandro Pérez-de-Luque *
Área de Mejora y Biotecnología, IFAPA Centro Alameda del Obispo, Córdoba, Spain

Nanomaterials and Agriculture

- Nano-fertilizers often contain nutrients/growth promoters encapsulated in nanoscale polymers, chelates, or emulsions
  - Slow, targeted, efficient release becomes possible
  - In some cases, the nanoparticle itself can stimulate growth
- Nano-sensors can be used to detect pathogens, as well as monitor local, micro, and nano-conditions in the field (temperature, water availability, humidity, nutrient status, pesticide levels…)

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OPEN ACCESS
IOP Publishing | Vietnam Academy of Science and Technology Advances in Natural Sciences: Nanoscience and Nanotechnology
Adv. Nat. Sci.: Nanosci. Nanotechnol. 7 (2016) 045018 (11pp) doi:10.1088/2043-6262/7/4/045018

Biofabricated zinc oxide nanoparticles coated with phycomolecules as novel micronutrient catalysts for stimulating plant growth of cotton

N Priyanka[1] and P Venkatachalam[1,2]

2016

2017

ACS central science
FIRST REACTIONS

Slow Release Nanofertilizers for Bumper Crops

Manish Chhowalla

2014

Agric Res
DOI 10.1007/s40003-014-0113-y

FULL-LENGTH RESEARCH ARTICLE

Development of Zinc Nanofertilizer to Enhance Crop Production in Pearl Millet (*Pennisetum americanum*)

J. C. Tarafdar · Ramesh Raliya · Himanshu Mahawar · Indira Rathore

2012

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY
Article
pubs.acs.org/JAFC

Dissolution Kinetics of Macronutrient Fertilizers Coated with Manufactured Zinc Oxide Nanoparticles

Narges Milani,*,† Mike J. McLaughlin,†,‡ Samuel P. Stacey,† Jason K. Kirby,‡ Ganga M. Hettiarachchi,‡,§ Douglas G. Beak,‡,∥ and Geert Cornelis†,⊥

Nanomaterials and Agriculture

- Nano-pesticides often follow a similar model to nano-fertilizers; active pesticidal (insecticide, fungicide,…) ingredient associated with or within a nanoscale product or carrier
  - Increased stability/solubility, slow release, increased uptake/translocation, and in some cases, targeted delivery (analogous to nano-based delivery in human disease research)
  - Can result in lower required amounts of active ingredients

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2017

RSC Advances

PAPER

View Article Online
View Journal | View Issue

Cite this: RSC Adv., 2017, 7, 11271

Development of functionalized abamectin poly(lactic acid) nanoparticles with regulatable adhesion to enhance foliar retention†

Manli Yu, Junwei Yao, Jie Liang, Zhanghua Zeng,* Bo Cui, Xiang Zhao, Changjiao Sun, Yan Wang, Guoqiang Liu and Haixin Cui*

2011

Mycobiology 39(1) : 26-32 (2011)
© The Korean Society of Mycology
DOI:10.4489/MYCO.2011.39.1.026

Inhibition Effects of Silver Nanoparticles against Powdery Mildews on Cucumber and Pumpkin

Kabir Lamsal[1], Sang-Woo Kim[1], Jin Hee Jung[1], Yun Seok Kim[1], Kyoung Su Kim[2] and Youn Su Lee[1]*

[1]Division of Bio-Resources Technology, Kangwon National University, Chuncheon 200-701, Korea
[2]Department of Agricultural Biotechnology, Center for Fungal Genetic Resources and Center for Fungal Pathogenesis, Seoul National University, Seoul 151-724, Korea

2015

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

ACS Editors' Choice

Perspective

pubs.acs.org/JAFC
Terms of Use

Nanopesticides: Guiding Principles for Regulatory Evaluation of Environmental Risks

Rai S. Kookana,*[,†,‡] Alistair B. A. Boxall,[§] Philip T. Reeves,[∥] Roman Ashauer,[§] Sabine Beulke,[⊥] Qasim Chaudhry,[⊥] Geert Cornelis,[#] Teresa F. Fernandes,[□] Jay Gan,[●] Melanie Kah,[△] Iseult Lynch,[▼] James Ranville,[○] Chris Sinclair,[⊥] David Spurgeon,[■] Karen Tiede,[⊥] and Paul J. Van den Brink[○,▲]

2014

Environment International 63 (2014) 224–235

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

ELSEVIER

Review

Nanopesticide research: Current trends and future priorities

Melanie Kah *, Thilo Hofmann *

Department of Environmental Geosciences, University of Vienna, Althanstrasse 14, 1090 Vienna, Austria

2012

Appl Microbiol Biotechnol (2012) 94:287–293
DOI 10.1007/s00253-012-3969-4

MINI-REVIEW

Role of nanotechnology in agriculture with special reference to management of insect pests

Mahendra Rai · Avinash Ingle

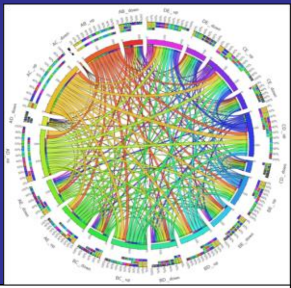
“Nano” Research at the CAES

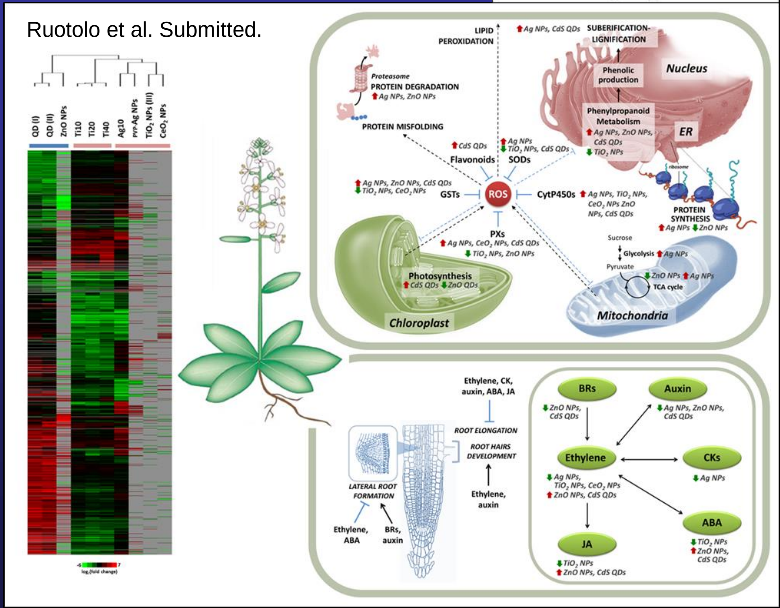
Applications: Nutrition and Crop Disease Suppression

- Evaluating the use of nanoscale micronutrients to promote crop health and suppress fungal and other plant pathogens.
- Evaluating nanoscale Ag and ZnO directly on fungal pathogens.

Implications: Nanotoxicology

- Studying the fate and effects of engineered nanomaterials (NM) on plants and related biota. NM effects are often unique.
- Investigating the molecular basis of plant response; this level of understanding will be needed to ensure accurate risk assessment and safe use of nanomaterials.
- Investigating trophic transfer in the food chain.
- Investigating co-contaminant interactions (NM co-exposure on the fate of pesticides, pharmaceuticals, heavy metals).

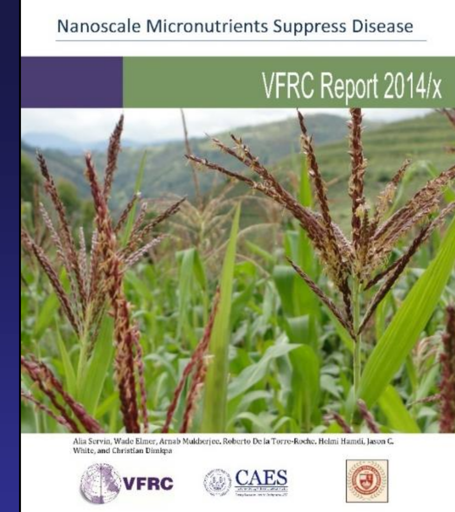




Ruotolo et al. Submitted.

Nanoscale Nutrients and Disease

- Nanoscale based micronutrients for disease suppression (particularly root disease)
- Many micronutrients (Cu, Mn, Zn, Mg) stimulate or are part of plant defense systems
- However, these nutrients have low availability in soil and are not readily transferred from shoot to root. What about "nano" versions of these nutrients?
- USDA NIFA Grant- \$480,000; 3/16-2/19 (UTEP, IFDC) IFDC)
- USDA SCBG- \$60,000; 2/17-1/19
- Center for Sustainable Nanotechnology- New seed grant

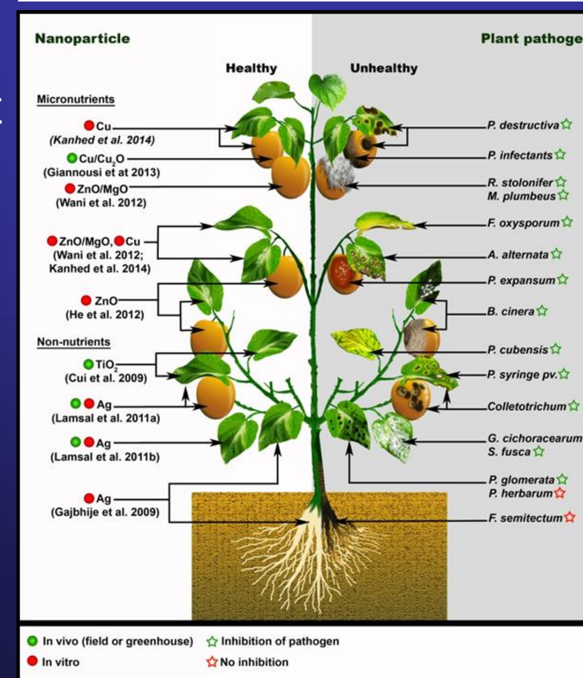


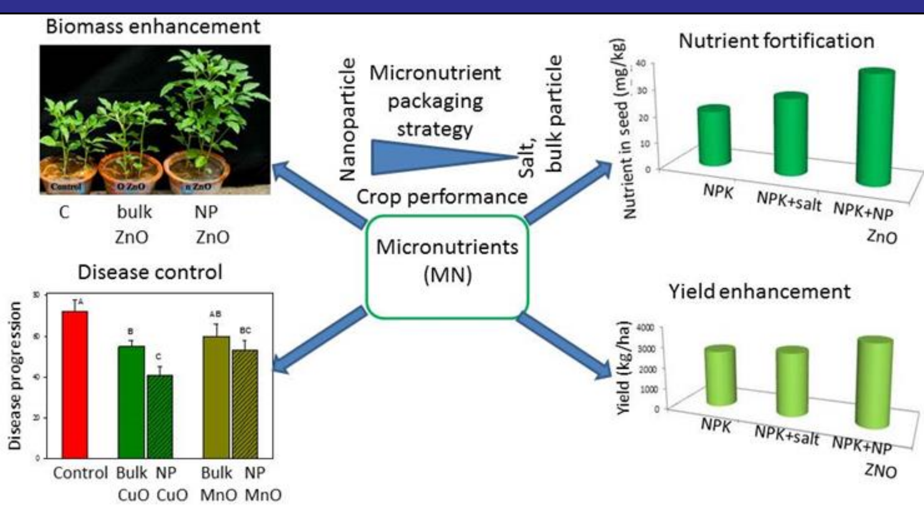
J Nanopart Res (2015) 17:92
DOI 10.1007/s11051-015-2907-7

REVIEW

A review of the use of engineered nanomaterials to suppress plant disease and enhance crop yield

Alia Servin · Wade Elmer · Arnab Mukherjee · Roberto De la Torre-Roche · Helmi Hamdi · Jason C. White · Prem Bindraban · Christian Dimkpa





Why Micronutrients?

Nutrition is the first line of defense against disease. Micronutrients protect **roots** against soilborne diseases by activating enzymes to create defense products.

- Cu: activates polyphenol-oxidases
- Mn: activates enzymes in the Shikimic acid and Phenylpropanoid pathways
- Zn: activates superoxide dismutases

Micronutrient Availability?

- Increasing micronutrient levels in roots is problematic in neutral soils
- Micronutrients are not basipetally (shoot to root) translocated
- When applied to soil they frequently precipitate and become unavailable to the plant
- Limited options for preventing and treating root disease (host resistance, fumigation)

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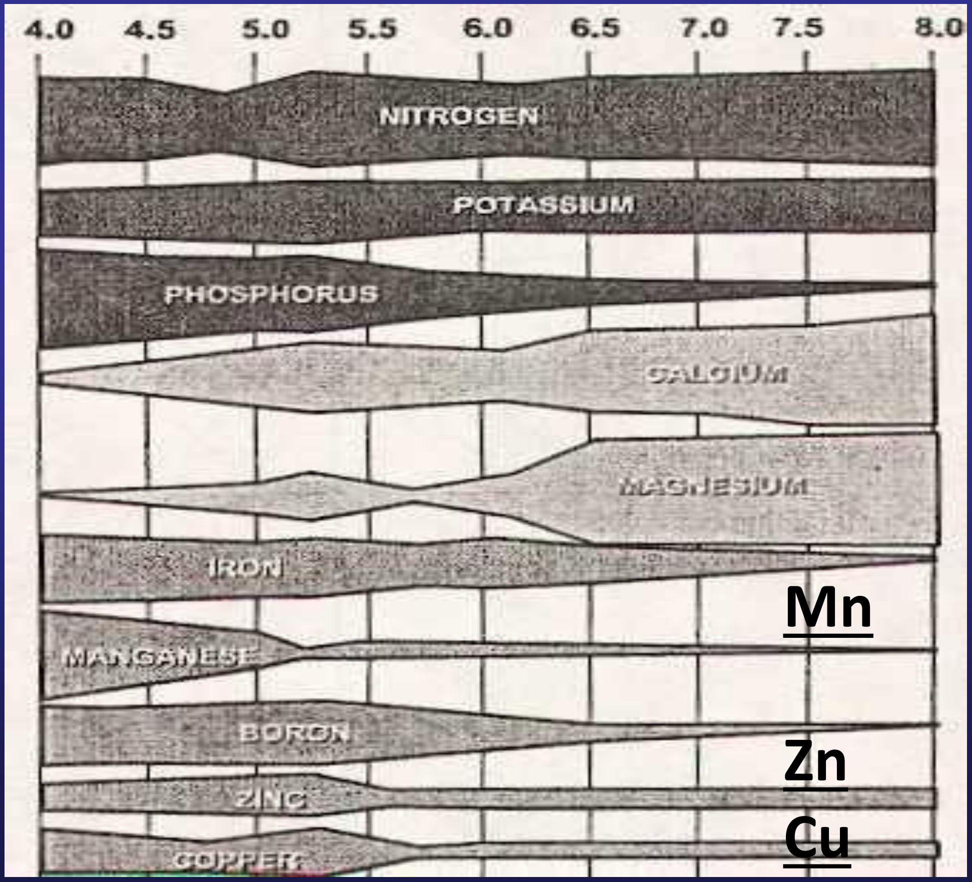
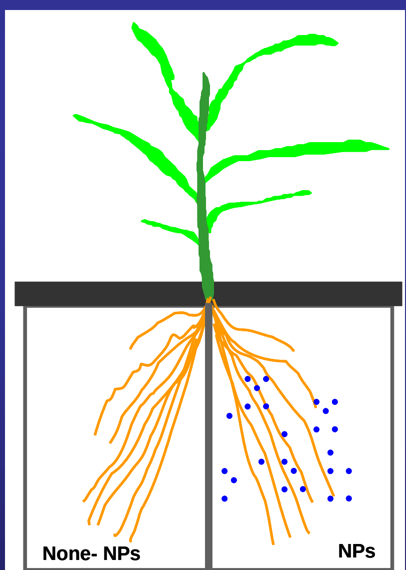
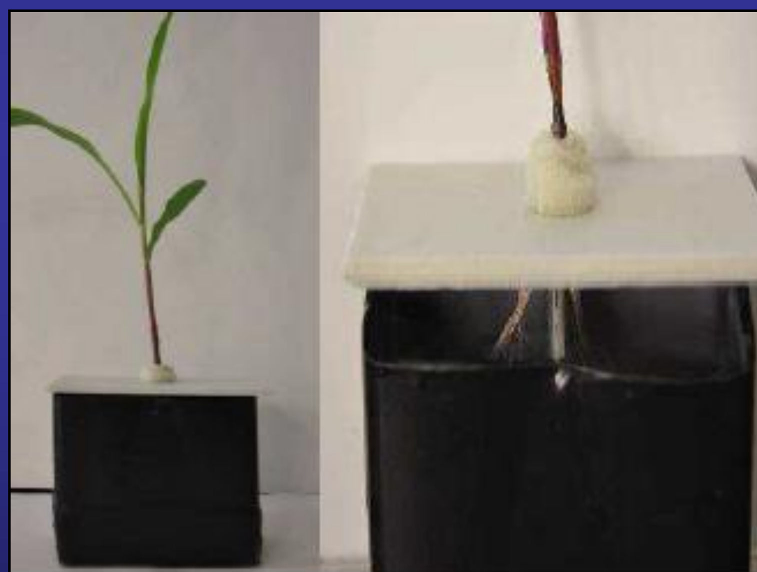
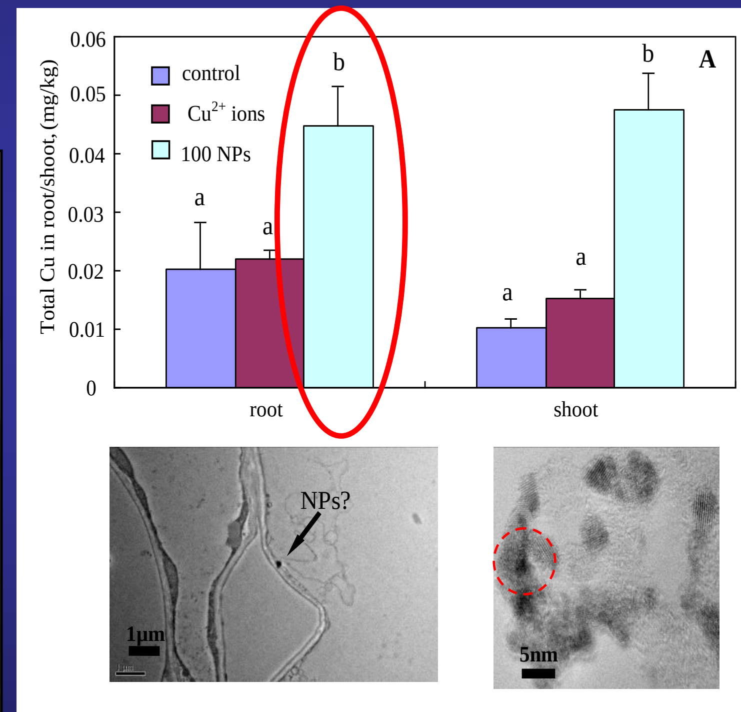


So, a chemist and a plant pathologist walk into a bar…

- NP CuO (and other metal NPs?) can move basipetally whereas bulk equivalents do not.







Wang, White et al. 2012. Xylem- and phloem-based transport of CuO nanoparticles in Maize (*Zea mays* L.) *Environ. Sci. Tech*. 46:4434-4441.

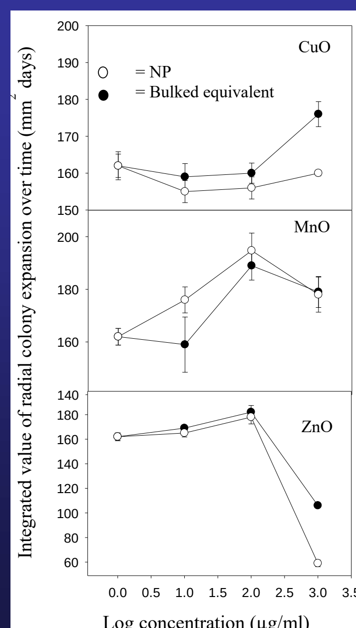
The Hypotheses?

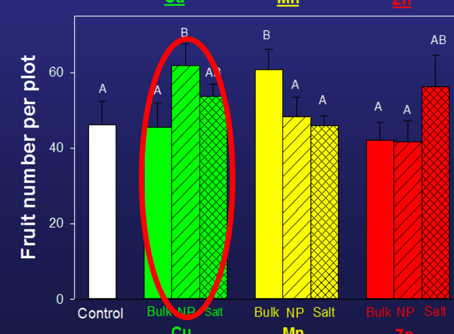
- Would applying ***nanoscale*** micronutrients to leaves affect growth?
- Would these metals be translocated to roots?
- Could these translocated nutrients stimulate plant defense and suppress root disease (mostly fungi, nematodes)?

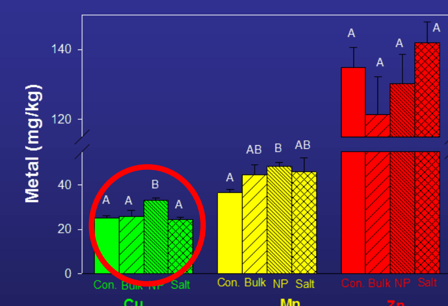
Nanoscale micronutrients (Cu, Zn, B, Si…)

Nanoscale micronutrients for disease suppression

- Greenhouse and field trials with eggplant and tomato
- Single foliar application of NP (bulk, salt) CuO, MnO, or ZnO (100 mg/L) during seedling stage. Transplant to infested soil
- NP CuO had greater disease suppression, higher Cu root content, and increased yield. NP CuO had no direct affect on the pathogen
- **$44 per acre for NP CuO suppressed a root pathogen of eggplant, increasing yield from $17,500/acre to $27,650 acre**







Elmer and White. 2016. *Environ. Sci.: Nano.* 3:1072-1079.

Nanoscale based micronutrients for disease suppression

- 2016/2017 field trials in CT involved eggplant, watermelon, asparagus.
- Single foliar applications of NP CuO, ZnO, MnO alone or in combination.
- Two farms/soil types used; a range of concentrations, salt only controls.
- Also, collaborative work in FL where field trials involve tomato growth with multiple applications during the growing season (Kocide, CuO and MgO NPs). New project with the Center for Sustainable Nanotechnology focused on better designed materials.
- A USDA SCBG- strawberries and nematodes (2017-2019).

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Foliar Application of Nanoscale Micronutrients to Watermelon

- NP CuO foliar application on watermelon seedlings suppressed *Fusarium* infection and increased plant biomass/ yield.
- Transcriptomics confirmed the upregulation of polyphenol oxidase (a Cu-activated enzyme for host defense) and Plant Resistance 1 Protein (associated with resistance) with CuO NP/infection.

- This data suggests that NP CuO may activate defense mechanisms in plants, likely via basipetal translocation of the nanoscale nutrient.

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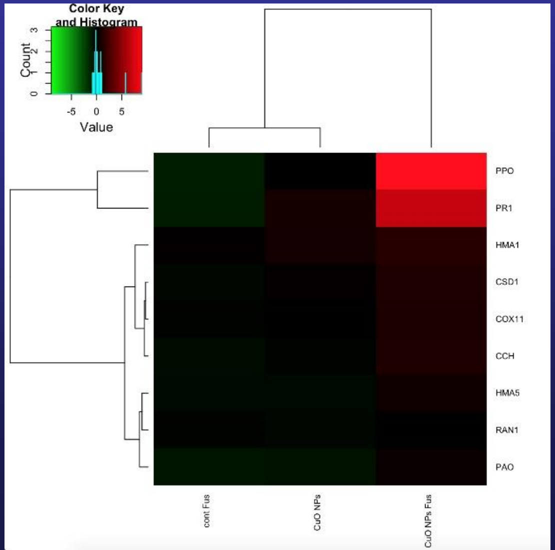
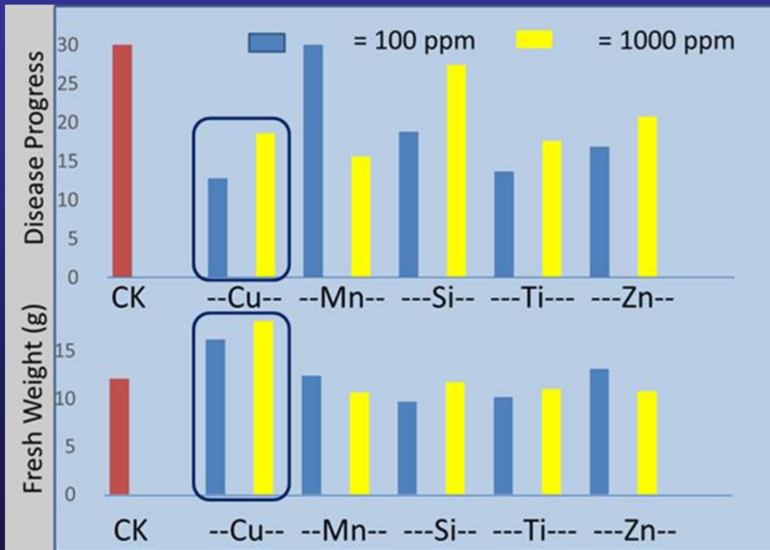
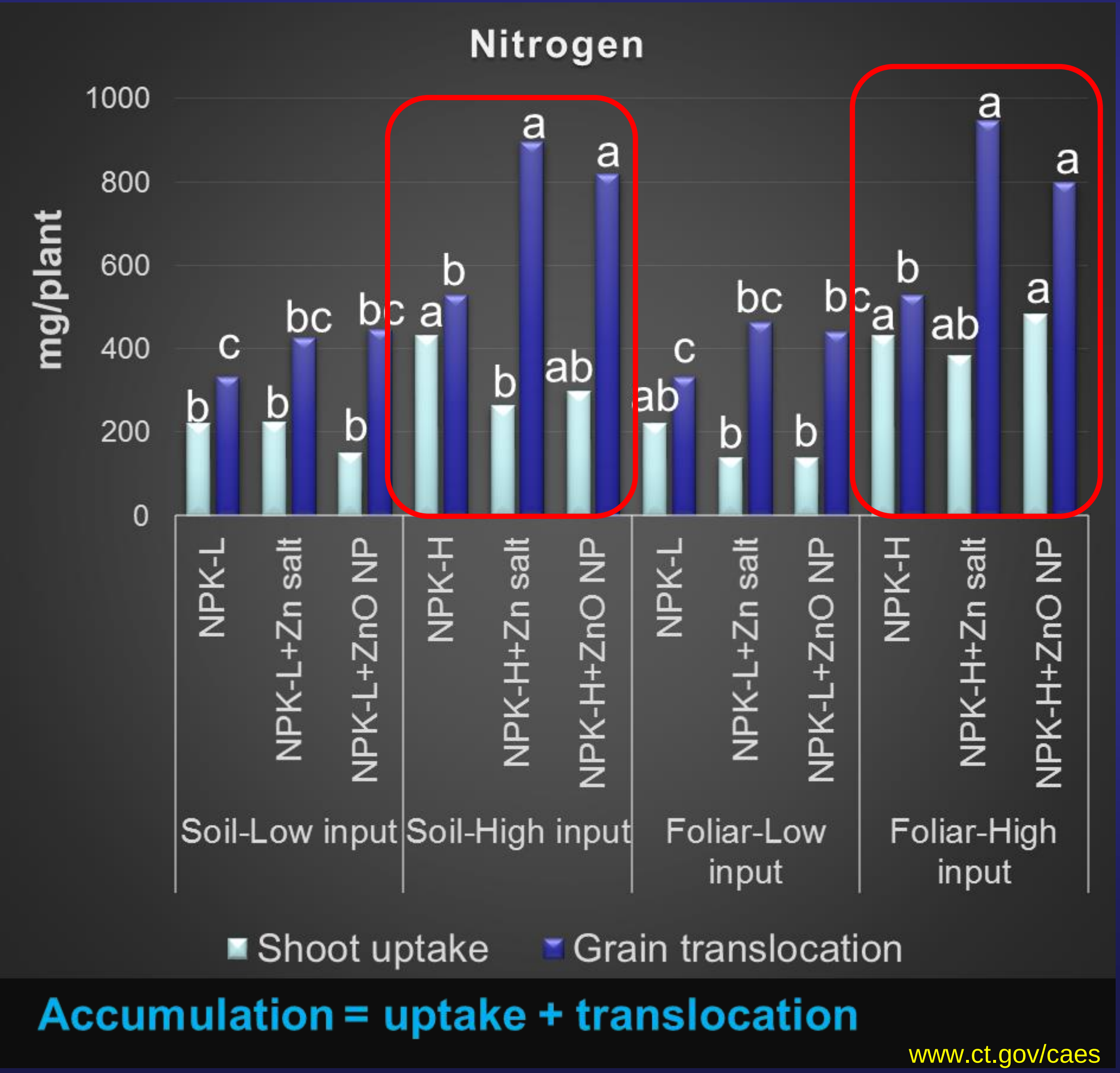




Elmer, White et al. 2017. *Plant Disease Submitted*.

Nitrogen accumulation by Sorghum is Enhanced by Zn NP and Salts



- Zn fertilization improved overall N accumulation between 4% and 38%, dependent on NPK regime Zn application route.
- Packaging Zn as NP (slightly) mitigated inhibition of N uptake by Zn at high NPK.
- Grain translocation of N (P,K as well) at high NPK more efficient with Zn salt than with NP.

Dimkpa et al. 2017. *J. Agric. Food Chem.* 65:8552–8559

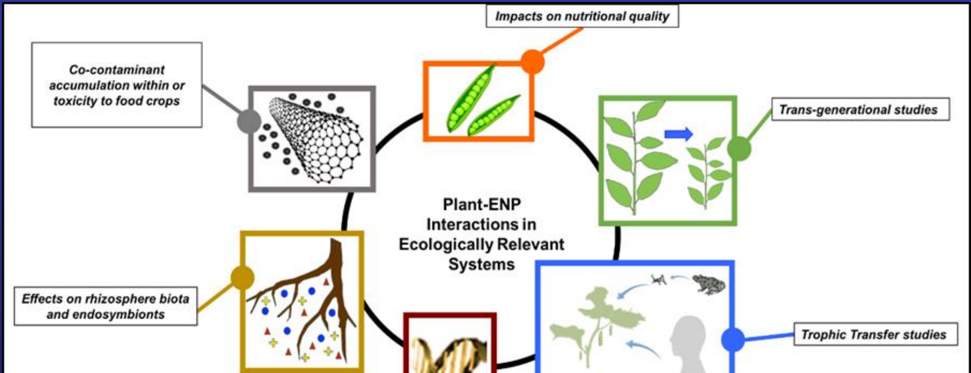
SNO 2017 Session 6B: Nanoscale nutrients and disease suppression

- “Use of Engineered Nanomaterials to Suppress Crop Disease and Enhance Yield” C. Ma, Ph.D., 4:00pm

- “Evaluating the Role of CeO_2 Nanoparticles in the Suppression of Fusarium Wilt Disease in Tomato Plants” I. A. Olarewaju, 5:10pm

Implications: Nanotoxicology at CAES

- NM interact uniquely with crops. One "simple" question- **Does this matter**? **Is this difference in behavior of concern with regard to exposure and risk**? A necessary component of sustainable applications work.
- USDA NIFA -Addressing Critical and Emerging Food Safety Issues- "Nanomaterial contamination of agricultural crops."
- USDA NIFA- Nanotechnology for Ag. and Food Systems- "Nanoscale interactions between engineered nanomaterials and biochar."
- USDA Hatch- "Impact of particle coating and weathering on nanomaterial fate and effects on crops."
- **Three main lines of inquiry**
  - **Mechanisms of plant response.**
  - **Trophic transfer.**
  - **Co-contaminant interactions.**



Servin and White, 2016. NanoImpact 1:9-12.

UNIVERSITÀ DEGLI STUDI DI PARMA
NIST National Institute of Standards and Technology U.S. Department of Commerce
universiteit hasselt
CEINT Center for the Environmental Implications of NanoTechnology
北京大学 PEKING UNIVERSITY
Harvard School of Public Health
USDA ARS Agricultural Research Service www.ars.usda.gov
Academy of Sciences of the Czech Republic Institute of Experimental Botany
TEXAS A&M UNIVERSITY
UTEP
UNIVERSITY OF CALIFORNIA UC CEIN Center for Environmental Implications of Nanotechnology
ESF State University of New York College of Environmental Science and Forestry
Southern Illinois University Carbondale
USDA National Institute of Food and Agriculture

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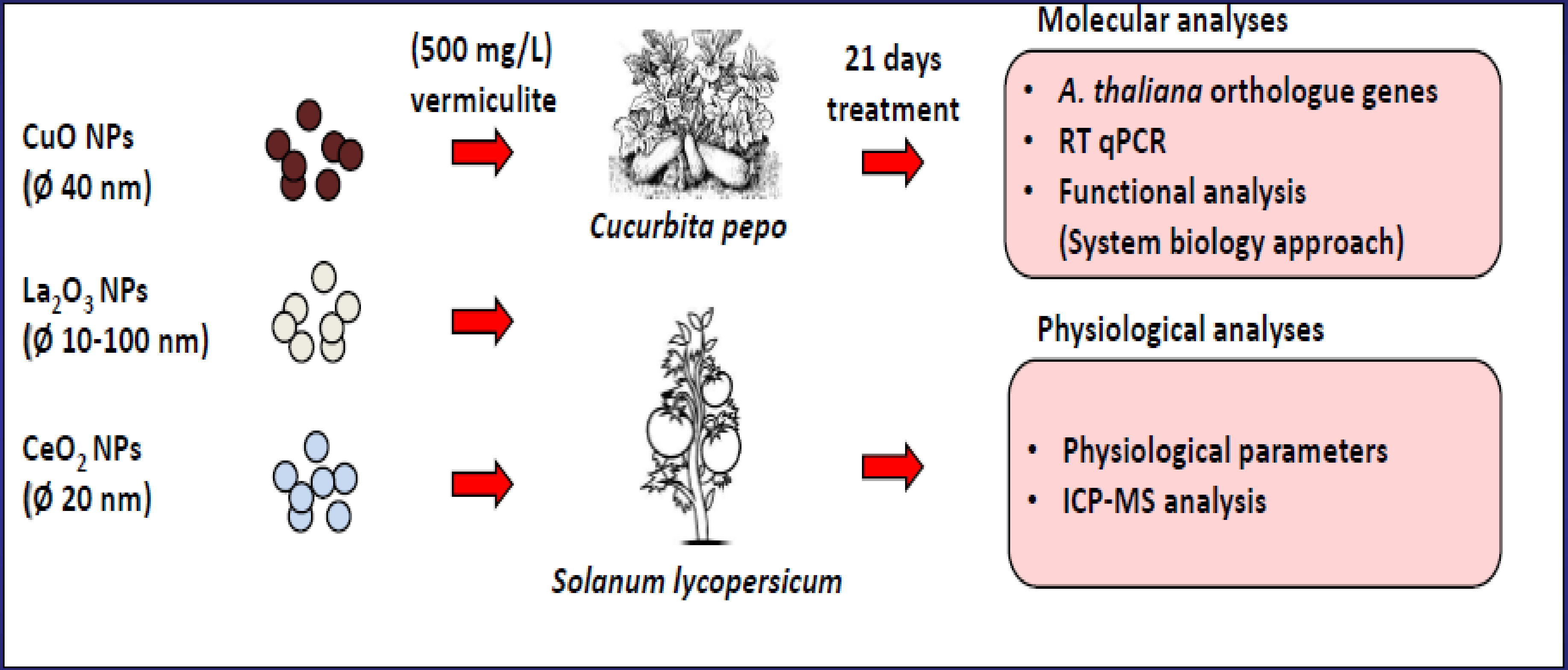
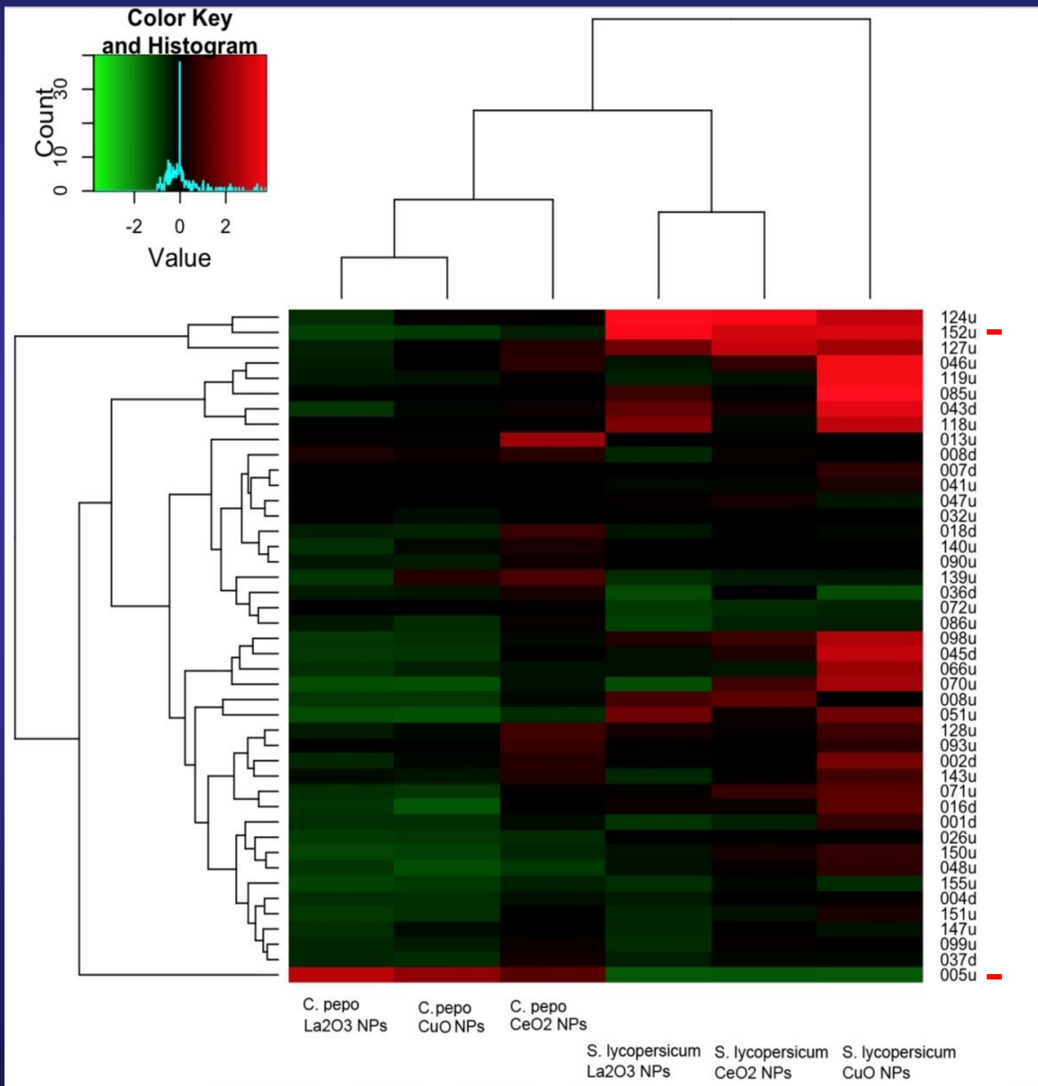
1. Toxicity, Mechanisms, and Biomarkers



About 70 candidate/target genes identified in *A. thaliana* were located and validated through transcriptomic analyses in zucchini (*C. pepo*) and tomato (*S. lycopersicum*).

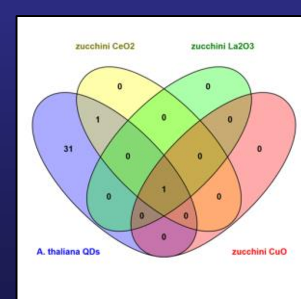
Pagano *et al.* 2016 *Environ. Sci. Technol*. 50:7198–7207

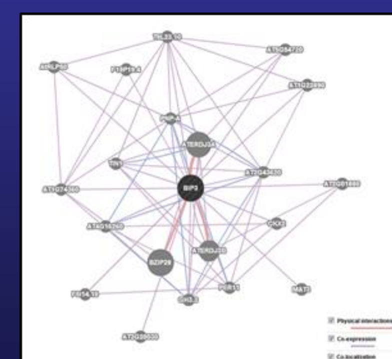
Response: Zucchini vs Tomato



Comparison between the tomato and zucchini:

- **005u** (heat shock protein) up regulated in all the treatments of zucchini, down regulated in all the treatments of tomato
- **152u** (chloroplast electron carrier) up regulated in all the treatments of tomato, down regulated in all the treatments of zucchini



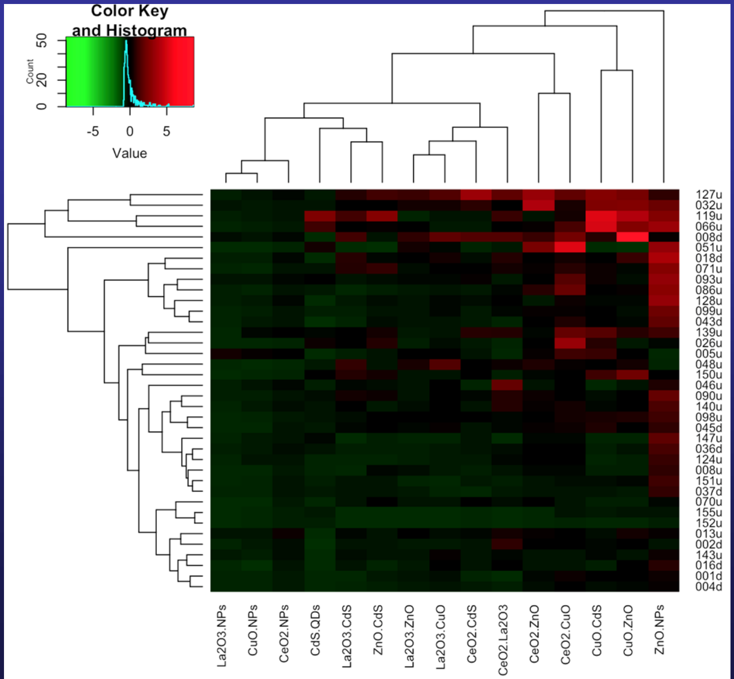


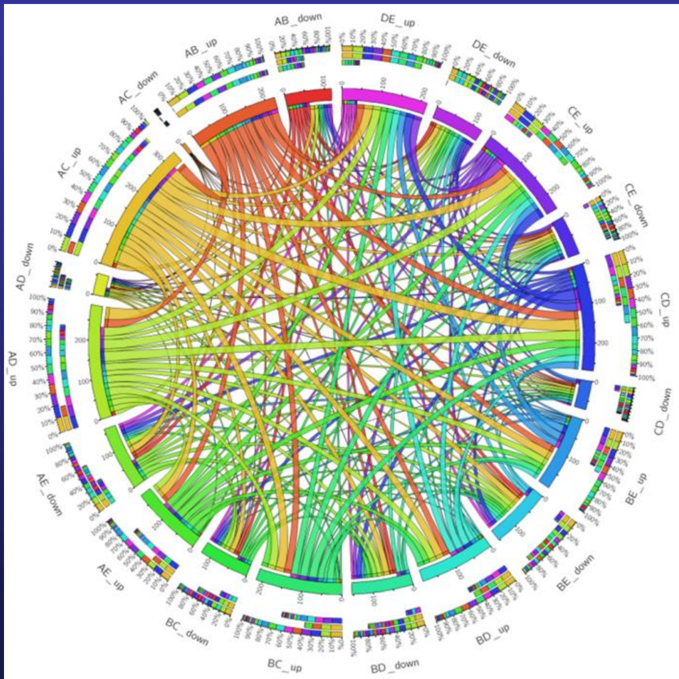
Pagano *et al.* 2016 *Environ. Sci. Technol.* 50:7198–7207

Pagano et al. 2017

- Exposure of zucchini to NP CeO_2, La_2O_3, CuO, ZnO and CdS Quantum Dots. Not only single analyte exposure but also all possible binary combinations (11 treatments).
- Physiological (mass, water content, length, pigments, cell viability) and molecular endpoints (37 genes) monitored.
- Just published in *ES: Nano*. Co-contaminant effects were consistently observed, at both the physiological and molecular level. Examples of additive and antagonistic effects noted, as well as potential synergism.

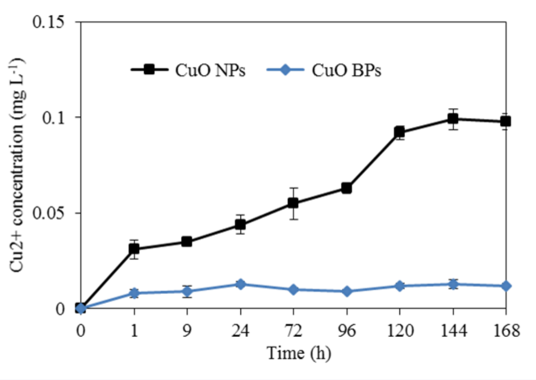
Pagano *et al.* 2017. ES Nano. 4:1579-1590.





Mechanisms of CuO NP toxicity and transgenerational effects

- *A. thaliana* seeds (3 ecotypes) were soaked in CuO NPs (0, 20,50 mg/L) or BPs (50 mg/L) suspensions or in Cu^{2+} ion solution (0.15 mg/L) for 48 h.
- Ion levels determined based on measured dissolution.



Time dependent dissolution of 50 mg/L CuO NPs and BPs.

- All seeds were placed in the MS-agar for a germination or aqueous solution for growth.
- Root morphology evaluated by SEM and WinRHIZO Pro 2005b.
- Harvested pollen and seed viability was determined.
- Cu content determined by ICP-MS; Cu speciation (seeds) determined by X-ray absorption near-edge spectroscopy (XANES).
- Differential Display Reverse Transcription Polymerase Chain Reaction (DDRT-PCR) used to measured gene expression.

Transgenerational effects of CuO NP exposure

- ➢The germination of pollen (A) and seeds (B) collected from NP-exposed plants was reduced.
- ➢The root length of seeds (C) obtained from CuO NPs-treated plants and overall seedling biomass (D) was also reduced.
- ➢Pollen (Col-0) was grown in distilled water, 50 mg/L CuO NPs (center), and 0.15 mg/L Cu^{2+} ions. Damage to the plasma membrane is evident in the NP exposure (E).

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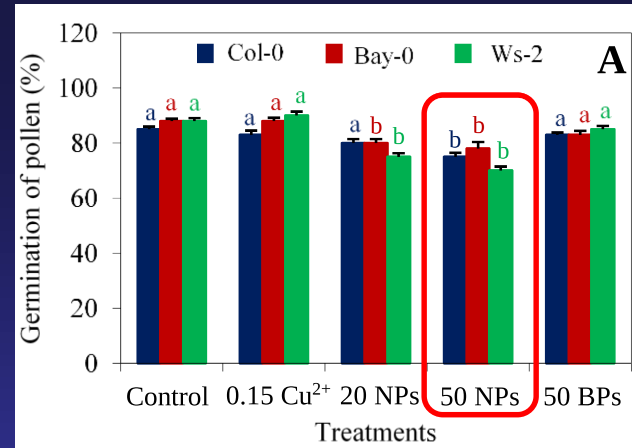
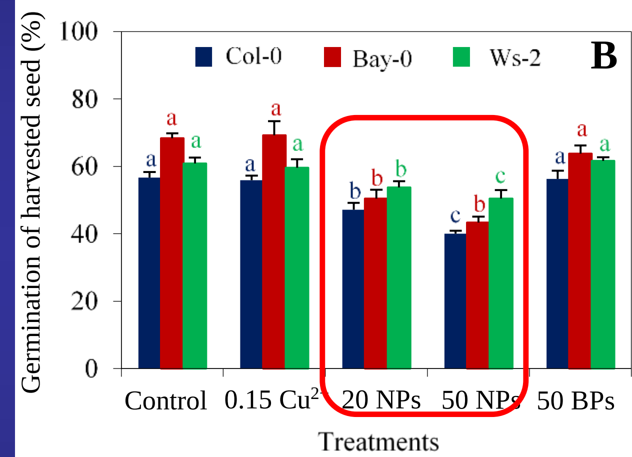
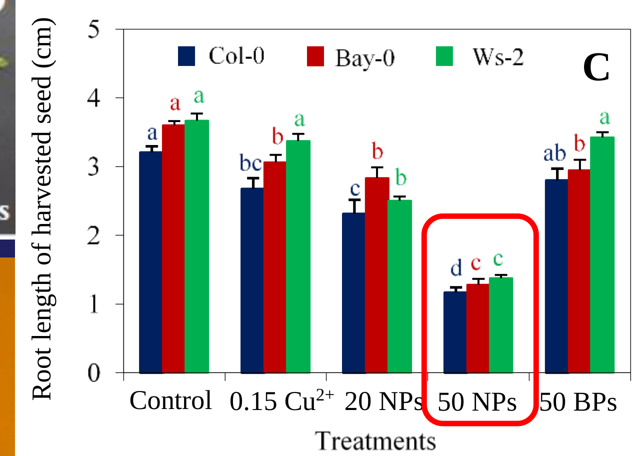
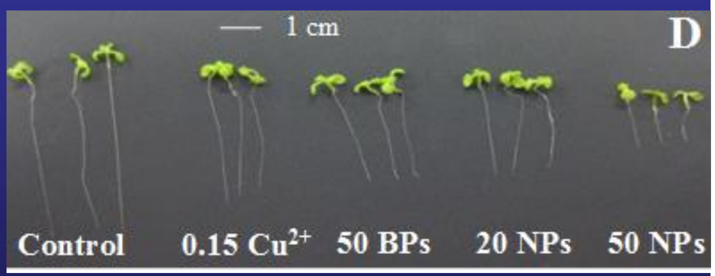




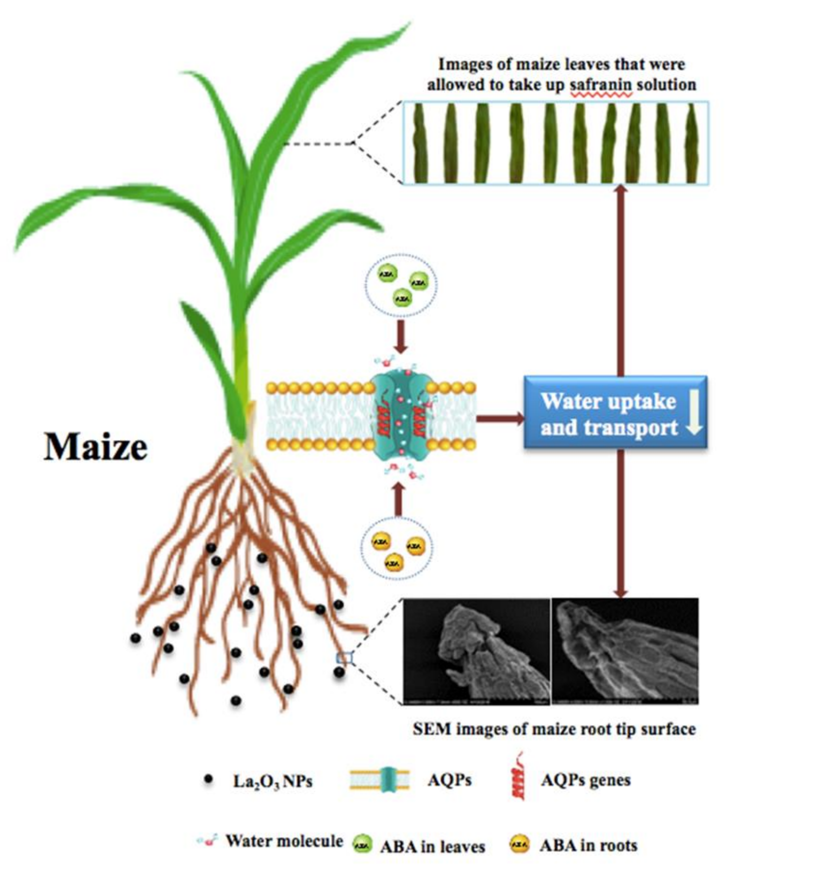




Wang et al. 2016 *Environ. Sci. Technol*. 50:6008-6016.

Yue et al. 2017: NP La_2O_3 and maize aquaporin gene expression

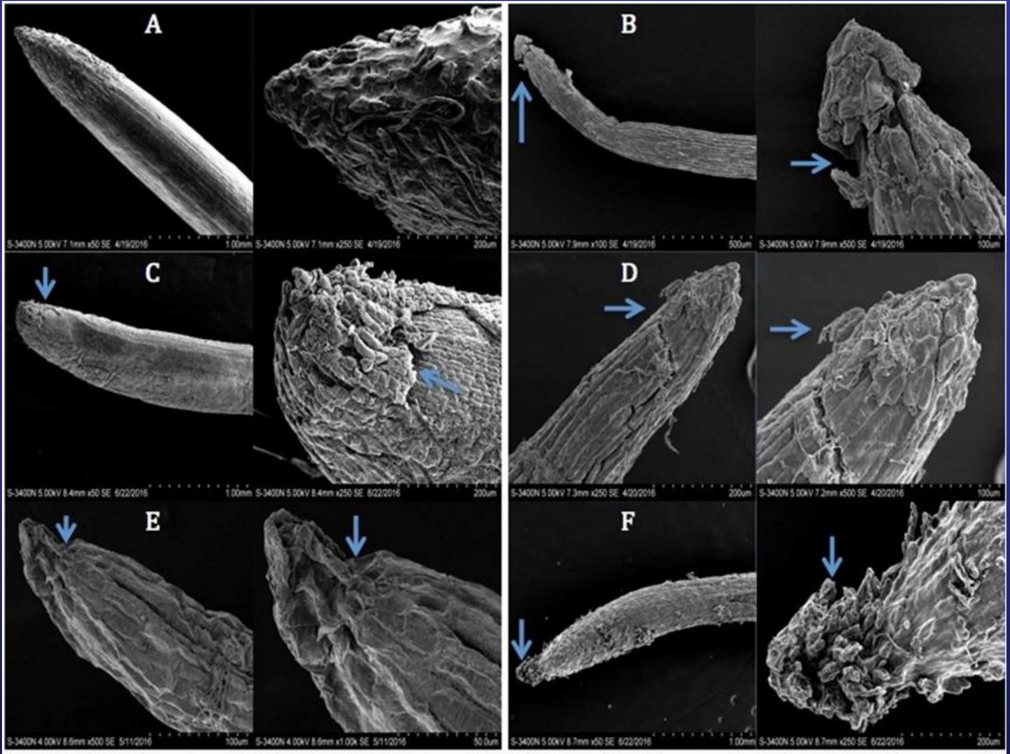
- Conducted with collaborators at Nanjing Agricultural University and the University of Massachusetts Amherst.
- Due to La_2O_3 nanoparticle (NPs) use in medical, industrial, and agricultural products, concerns over the risks of exposure have increased.
- Plants are obviously receptor of concern, but the mechanisms of La_2O_3 NPs phytotoxicity are unknown.
- The potential for growth inhibition and reduced water uptake in corn upon exposure to La_2O_3 NPs (50-500mg L^{-1}) were investigated.

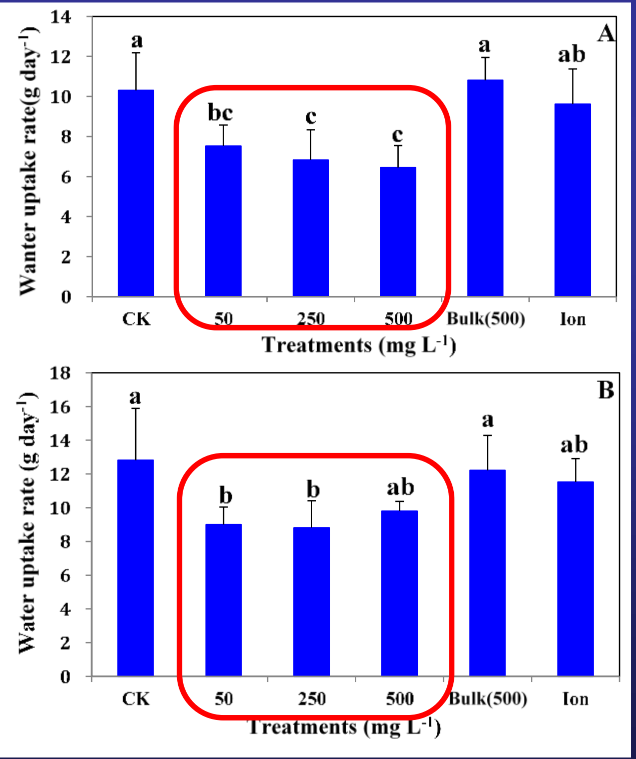


Yue et al. 2017 *Environ. Sci.: Nano* DOI: 10.1039/c6en00487c

Root Damage and Water Uptake

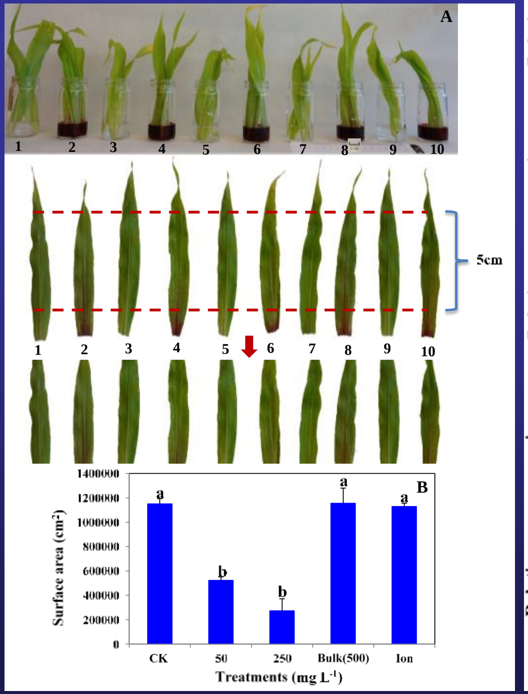
- SEM images of morphological changes (depressions) and physical damage (cracks, shrinkage, root cap loss) in plant root tips upon NP exposure.
- Given the damage to the root system, the results suggest that La_2O_3 NPs may impact the water status of maize seedling.
- Across nearly all La_2O_3 NPs treatments, the water uptake rate was significantly reduced relative to the unexposed, bulk, and ion controls

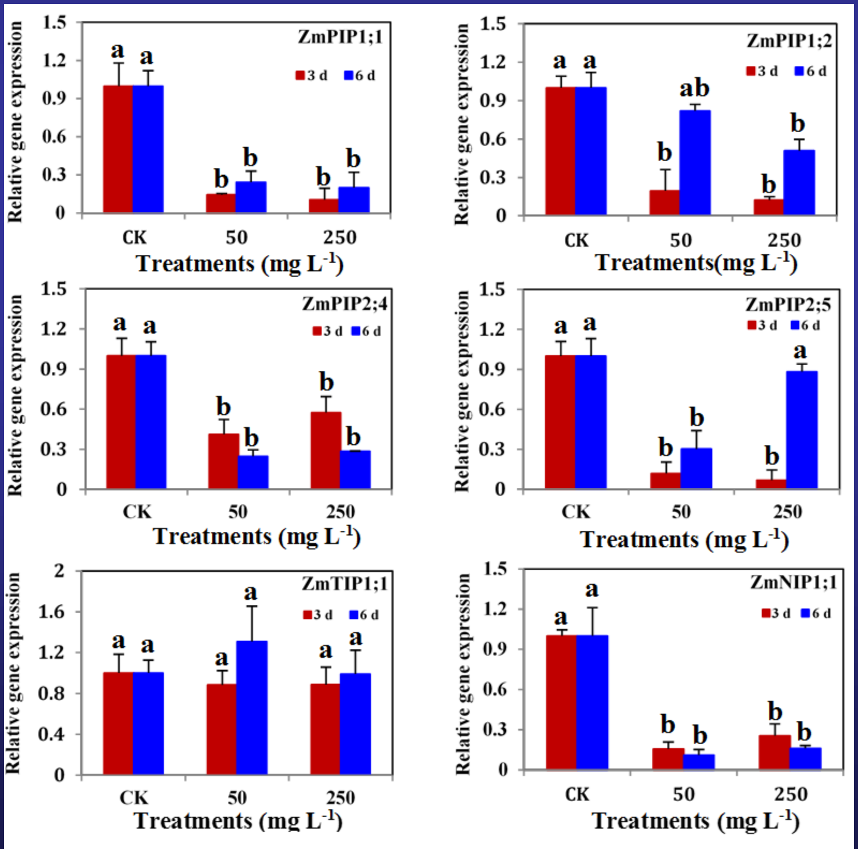




Water Transport and AQP Expression

- Water transport in leaf vasculature was investigated with safranin.
- NPs disrupted the water transport in plants. Upon treatment with 50-250 mg/L NPs, most leaf minor veins exhibited incomplete staining (55-76% reductions), suggesting reduced functionality.
- In roots and shoots (to a lesser extent), most AQPs genes in NPs-exposed were down regulated.
- Abscisic acid (stress-induced phytohormone) may act as a signaling molecule in response to NPs exposure, adjusting water uptake by regulating AQPs gene expression.





Metal oxide NPs reduce peanut (*Arachis hypogaea* L.) nutritional quality

- Conducted with collaborators at China Agricultural University, Guangxi University, the Chinese Academy of Agricultural Sciences, and UMass

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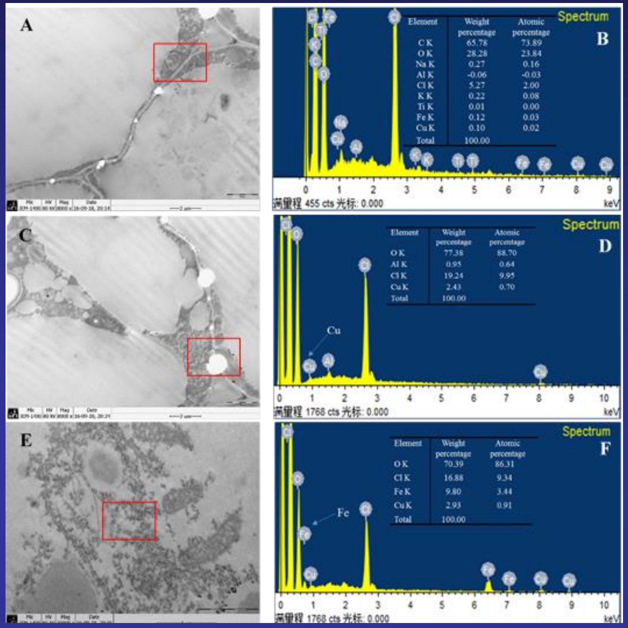
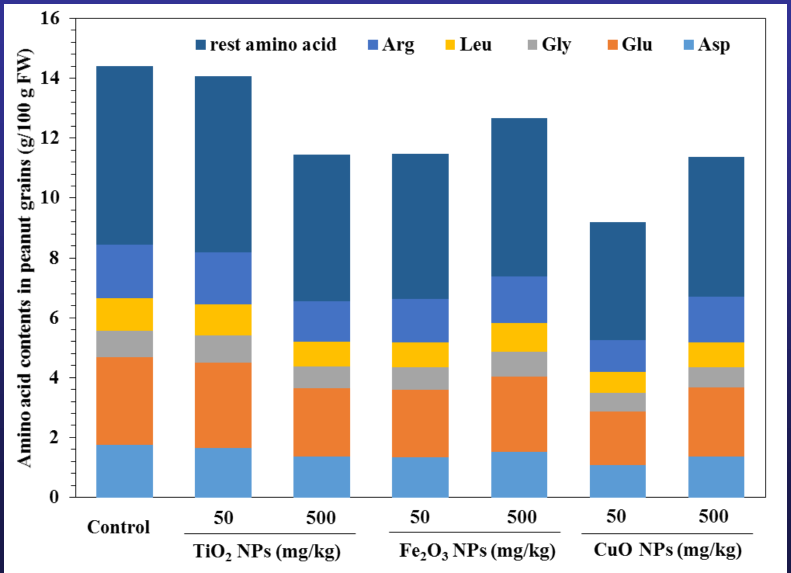
- Peanut was exposed to NP Fe_2O_3, CuO, and TiO_2 at 50 and 500 mg/kg in a 145-d full life cycle study.
- Biomass, shoot height, per plant yield, and element content were determined.
- Amino acid content, fatty acid profile, and resveratrol in the peanut grain were measured.

Rui et al. In preparation

Metal oxide NPs reduce peanut (*Arachis hypogaea* L.) nutritional quality

- Exposure had no impact on plant biomass.
- NPs decreased the grain weight by 10-31% (greatest at 500 mg/kg CuO NP).
- The Cu grain content increased in a dose-dependent manner; Fe_2O_3 and TiO_2 NPs did not increase the Fe or Ti content.
- TEM-EDX showed NPs of all 3 elements in the grains.
- NPs CuO altered the amino acid content as related to glycolysis, the citric acid cycle, and defense pathways.
- Elevated resveratrol content in CuO and TiO_2 NP treated grains were indicative of plant stress response

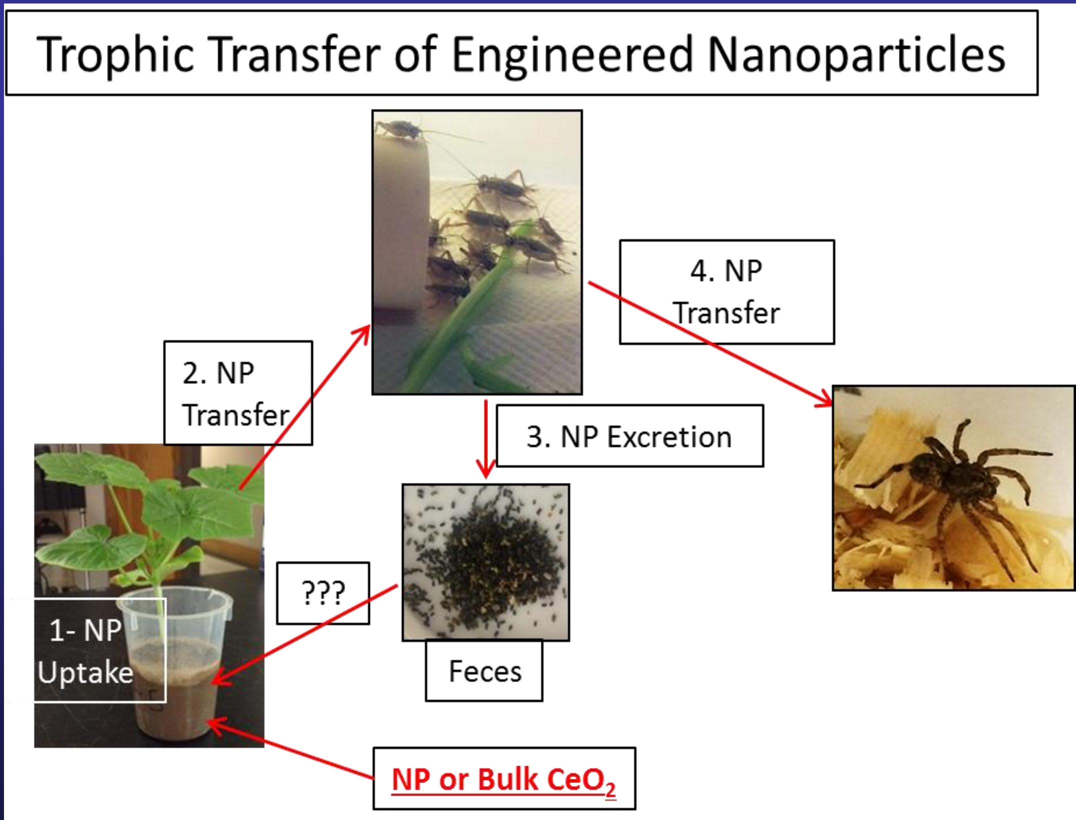




2. Determine the trophic transfer potential of NMs

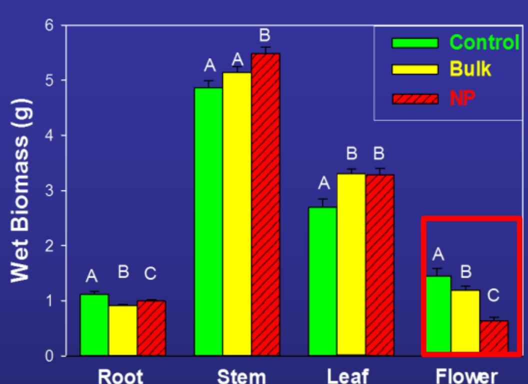
- Experiment 1- NP/bulk CeO_2 (0 or 1000 mg/Kg) added to an agricultural loam.
- Zucchini grown for 28d from seedling.
- Roots, stems, leaves, and flowers analyzed by ICP-MS.
- Leaves used to feed crickets for 14d.
- Crickets used to feed wolf spiders for 7d.
- Insect tissues/feces by ICP-MS.

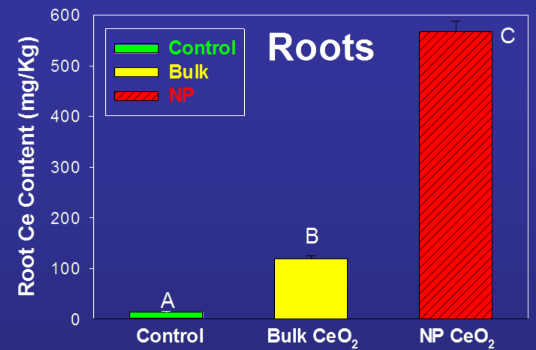
Hawthorne et al. 2014. *Environ. Sci. Technol.* 48:13102-13109

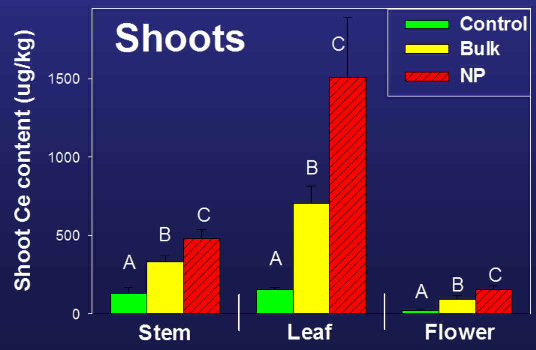


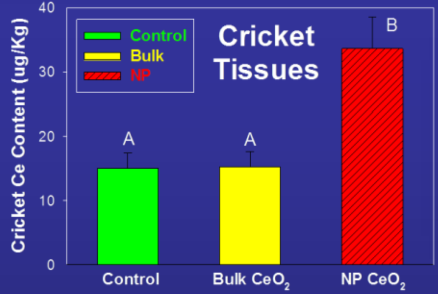
Determine the trophic transfer potential of NMs: Exp. 1

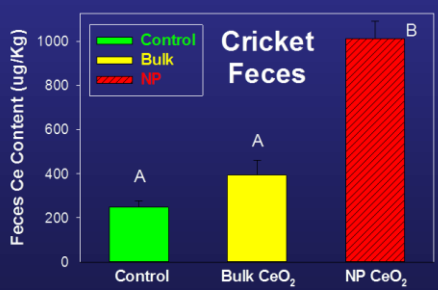
- Particle size-dependent transfer from soil → plant → herbivore → carnivore observed
- NP CeO_2 reduced biomass of reproductive tissues by 50%
- No biomagnification; 10-100 fold decreases at each level
- Insect feces contained 10x more Ce than insect tissues











Hawthorne et al. 2014. *Environ. Sci. Technol.* 48:13102-13109

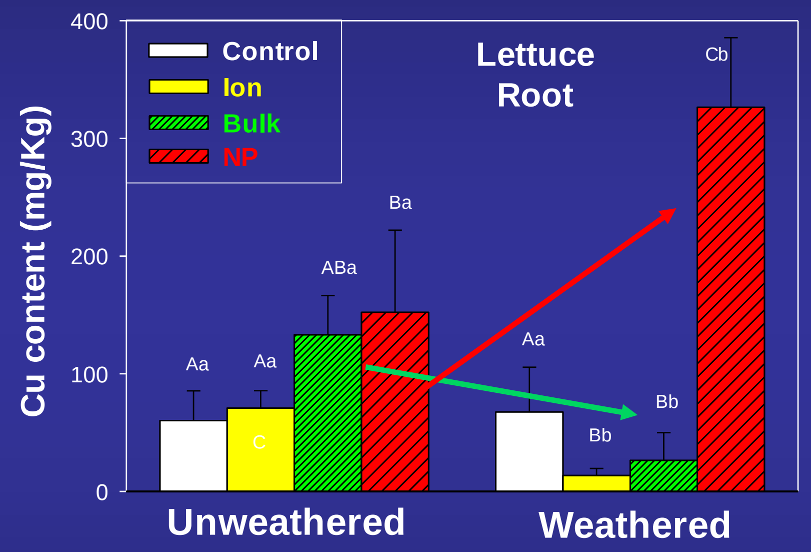
Determine the trophic transfer potential of NMs: Exp. 2

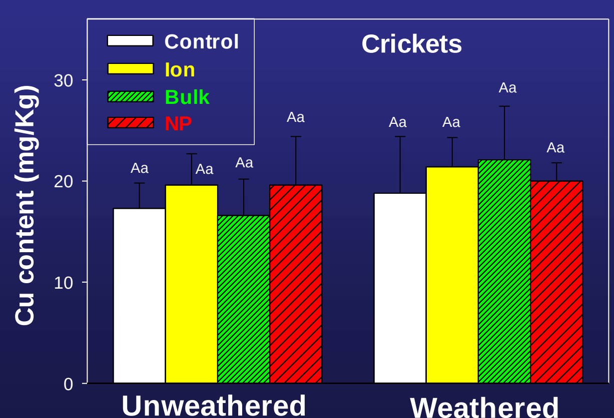
- Trophic transfer of NP and bulk CuO
  - 500 mg/kg in soil for 0 or 70 days, lettuce, cricket, Anolis lizards.
  - Soil was contaminated with weathered chlordane (3 mg/kg) and DDX (0.2 mg/kg)
  - Tracked Cu, chlordane and DDX content and form (ICP-MS, µXRF, XANES, biomass, and gene expression in the plant (transcriptomics)

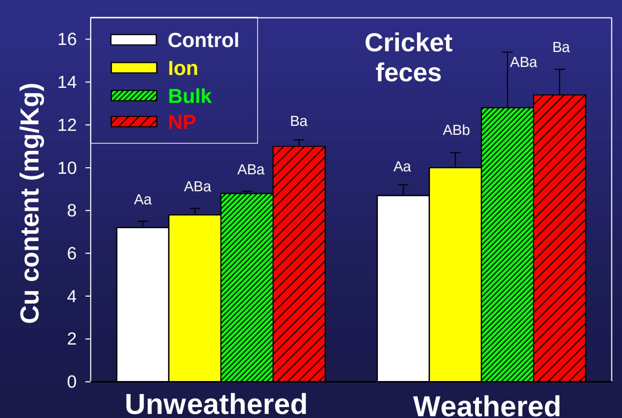
Servin et al. 2017. *Nanotox*. 11:98-111.

Determine the trophic transfer potential of NMs: Exp. 2

- Leaf Cu content unaffected by particle type or weathering
- Root Cu content affected by particle size upon weathering
- Cricket and fecal Cu content largely unaffected by particle type, weathering or even Cu amendment
- Lizard Cu content (head, intestine, body, feces) unaffected by Cu amendment, type or weathering ☹







Servin et al. 2017. *Nanotox*. 11:98-111.

Determine the trophic transfer potential of NMs: Exp. 2

- In NP-exposed roots, Cu distribution and speciation varied with weathering status (ESRF, Grenoble France)
- Unweathered treatment had Cu hot spots in the roots; the weathered treatment had homogeneous Cu
- Cu in the weathered roots was more <u>reduced/transformed</u> to Cu_2O and Cu_2S forms

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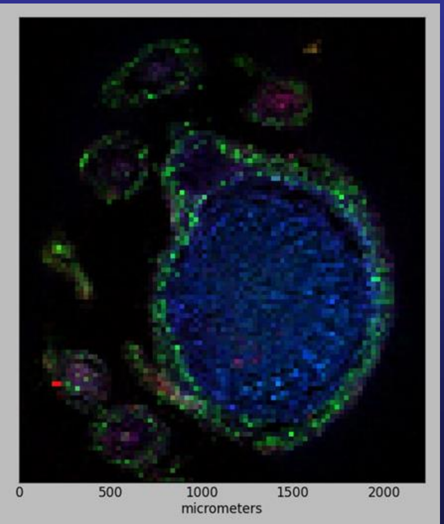
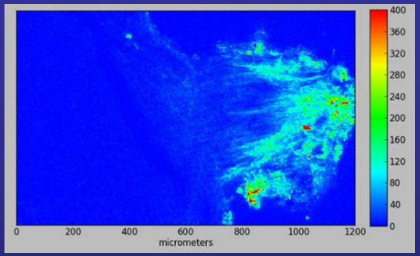
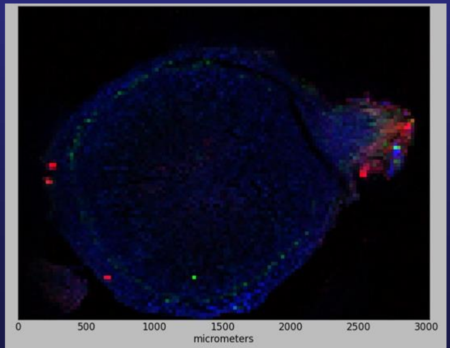
Servin et al. 2017. *Nanotox*. 11:98-111.







Unweathered

Spot	Components CuO	Cu2O	Cu2S	R-factor
SR(175)	0.6580	0.342	0.0000	0.004
SR(178-)	0.0000	0.554	0.446	0.002
SR(192-)	0.458	0.355	0.187	0.001
ASR (208)	1	0.0000	0.0000	0.000
SR(231-)	0.635	0.430	0.0000	0.006
SR(242-)	0.229	0.353	0.417	0.004
AMR(263)	1	0.0000	0.0000	0.000
EMR(250-)	0.314	0.238	0.447	0.009

Weathered

Spot	Components CuO	Cu2O	Cu2S	R-factor
A	0.0000	0.9425	0.0575	0.0009
E	0.0000	0.4599	0.4354	0.0009
SR	0.0000	0.3402	0.6239	0.0029
MR	0.0000	0.0877	0.8511	0.0019
C	0.0000	0.4647	0.4835	0.0029

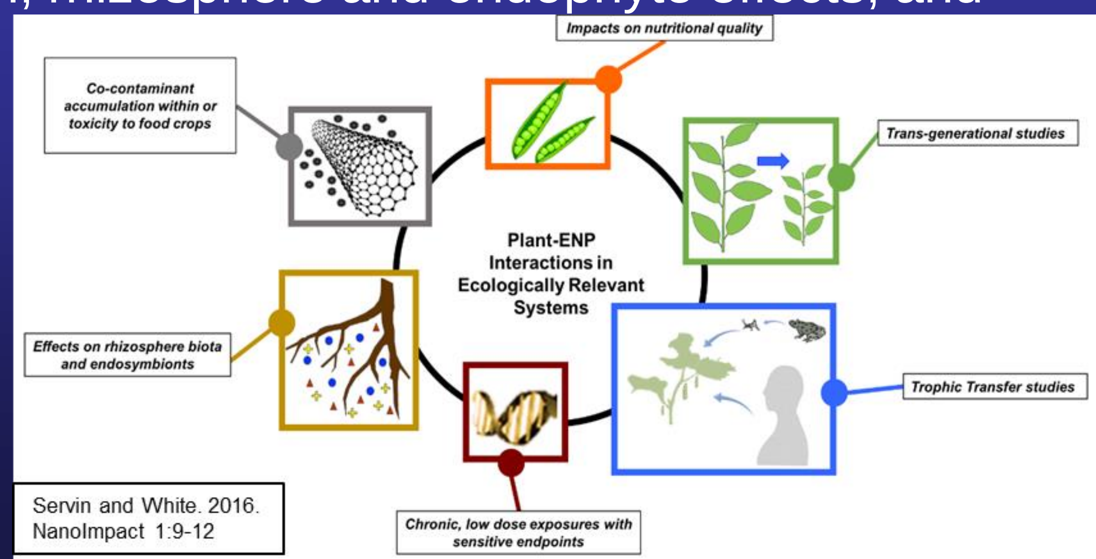
A; aggregate sec root, E; Epidermis, SR; secondary root, MR; Main root, C; Cortex

3. Nanomaterial interactions with co-existing contaminants

- NMs are entering agricultural systems directly (pesticide/ fertilizers) or indirectly (biosolids)
- Agricultural soils contain a number of other organic chemicals
- Interactions between NM and these co-existing contaminants may be important
  - Could bioavailability of legacy pesticides be affected? A food safety issue?
  - Could efficacy of intentional agrichemicals be affected? An economic issue?
- Nine publications since 2012; two more underway and one review article published.

Conclusions

- Nanotechnology has the potential to dramatically improve agriculture; to literally help feed the world.
- Because of this and because of widespread use of nanomaterials in other sectors, exposure in the food supply will be significant.
- As such, a thorough and comprehensive understanding of mechanisms of action/interaction is needed to enable accurate assessment of risk and the sustainable application of nanotechnology.
- Species- and soil-type differences, trophic transfer, co-contaminant interactions, biomagnification, rhizosphere and endophyte effects, and robust detection platforms for presence/effects are all part of the sustainable solution.



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  - Nelson Marmiroli, University of Parma, Italy
  - Jason C. White, Connecticut Agricultural Experiment Station (USA)
  - Jing Song, Inst. Soil Science, Chinese Academy of Sciences, China

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  - Chapter 1.1 Synthesis and production of ENMs for laboratory and industrial use
  - Chapter 1.2 Characterization of the physical and chemical properties of ENMs: advances in technologies and approaches
  - Chapter 1.3 Worldwide efforts for standardization of testing for ENMs applicability
- Section 2. ENMs in the environment: fate, transfer and interactions with organisms
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  - Chapter 2.2 Fate of ENMs in agroenvironments and impacts on agroecosystems
  - Chapter 2.3 Fate of ENMs in urban and work environments
  - Chapter 2.4 ENMs presence in everyday's life and impact on consumers: food, drugs and recreational products
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  - Chapter 3.4 Evaluation of ENMs impacts on human health: from occupation to recreation
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  - Chapter 4.1 ENMs and the civil society: social and economic impacts
  - Chapter 4.2 ENMs and consumers: acceptance and rejection
  - Chapter 4.3 Ethical issues of ENMs application and regulatory solutions

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