Trophic Transfer Potential of Nanoparticles in Terrestrial Food Chains

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Nanomaterials and Agriculture

- There has been significant interest in using nanotechnology in agriculture
- The goals fall into several categories
  - 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

IB IN DEPTH—Special Section on Nanobiotechnology, Part 1

2012

Overview

www.ct.gov/caes

Review

2012

Bioactivity and Biomodification of Ag, ZnO, and CuO Nanoparticles with Relevance to Plant Performance in Agriculture

2012

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Nanomaterials in Plant Protection and Fertilization: Current State, Foreseen Applications, and Research Priorities

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
- Nanosensors 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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The Improvement of Spinach Growth by Nano-anatase TiO_2 Treatment Is Related to Nitrogen Photoreduction

Lei Yang · Chao Liu · Fengqing Gao · Mingyu Su · Xiao Wu · Lei Zheng · Fashui Hong · Ping Yang

2012

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

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

2012

Carbon Nanotubes Induce Growth Enhancement of Tobacco Cells

Mariya V. Khodakovskaya, Kanishka de Silva, Alexandru S. Biris, Enkeleda Dervishi, and Hector Villagarcia

RESEARCH PAPER

Beneficial role of carbon nanotubes on mustard plant growth: an agricultural prospect

Anindita Mondal · Ruma Basu · Sukhen Das · Papiya Nandy

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

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

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

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

Mahendra Rai · Avinash Ingle

2012

small

DNA Delivery

Parameters Affecting the Efficient Delivery of Mesoporous Silica Nanoparticle Materials and Gold Nanorods into Plant Tissues by the Biolistic Method

*Susana Martin-Ortigosa, Justin S. Valenstein, Wei Sun, Lorena Moeller, Ning Fang, Brian G. Trewyn, Victor S.-Y. Lin, and Kan Wang**

Microbiological Research 166 (2011) 207–215

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

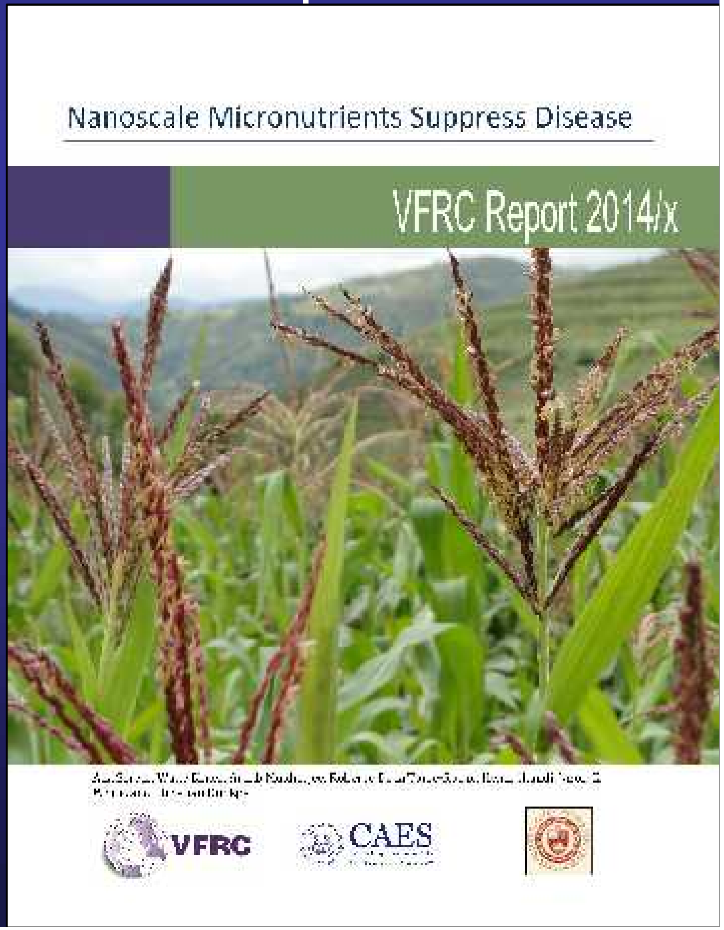
Microbiological Research

Antifungal activity of zinc oxide nanoparticles against *Botrytis cinerea* and *Penicillium expansum*

Lili He[1], Yang Liu[1], Azlin Mustapha, Mengshi Lin*

Nanomaterials and Agriculture

- Nanoscale based micronutrients or other elements for disease suppression
- A new research initiative at CAES
- Many micronutrients (Cu, Mn, Zn, Mg) stimulate plant defense systems



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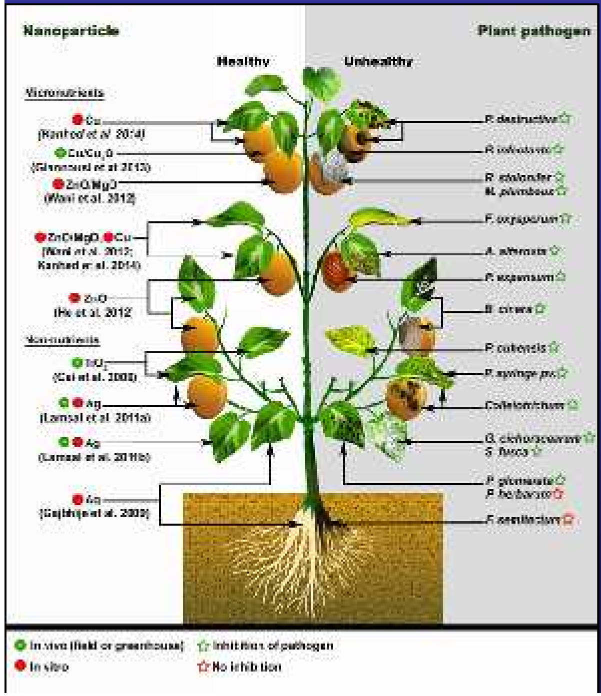

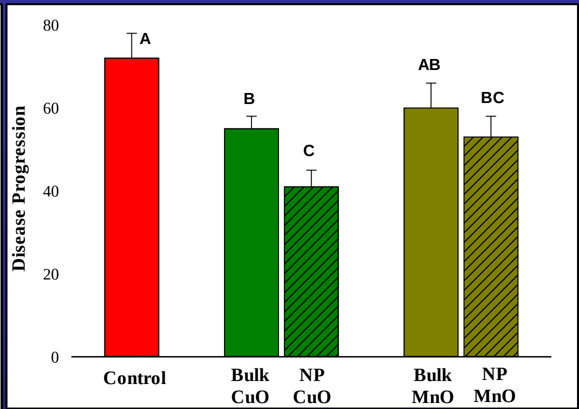

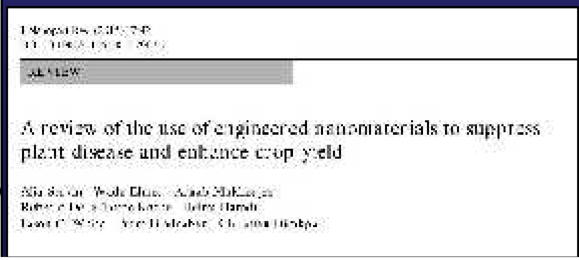
A review of the use of engineered nanomaterials to suppress plant disease and enhance crop yield

Nanomaterials and Agriculture

- Prior to 2010, data on NM interactions with plants was limited. Many early studies looked only at NPs with no bulk material/ion comparison.
  - This is a key point. It is irrelevant whether a NP/NM is toxic. The key questions are is that NM/NP more toxic than the bulk/ion and if so, is it by a different mechanism?
- Are NM an emerging class of contaminants?
- There have been a number of recent studies assessing the effects of specific NPs on germination, root elongation, and other physiological/"omic" parameters
- These studies have tended to focus on acute toxicity; relatively short exposure to high concentrations. This is where we start in toxicology but as is frequently the case, chronic low dose exposure may be more important.
- Larger issue may be food chain contamination and an uncharacterized pathway of human exposure.

CAES Nanotoxicology Program

- The entire program is based on a simple question- From a regulatory standpoint, bulk/ion and NMs are considered equal. Is that true? Or are there important instances where NM "behave" differently? The follow up question; does it matter (hazard and risk assessment)?
- USDA NIFA Grant 1- "Addressing Critical and Emerging Food Safety Issues." A 5-year $1.5 million grant "Nanomaterial contamination of agricultural crops."
  - Obj. 1: Determine the uptake, translocation, and toxicity of NM to crops.
  - Obj. 2: Determine the impact of environmental conditions on NM uptake, translocation, and toxicity to crops.
  - Obj. 3: Determine the potential trophic transfer of NMs.
  - Obj. 4: Quantify the facilitated uptake of pesticides through NM-chemical interactions.
- USDA NIFA Grant 2- Determine the impact of biochar on NM uptake and toxicity to crops and earthworm species.

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Objective 3- Determine the trophic transfer potential of NMs

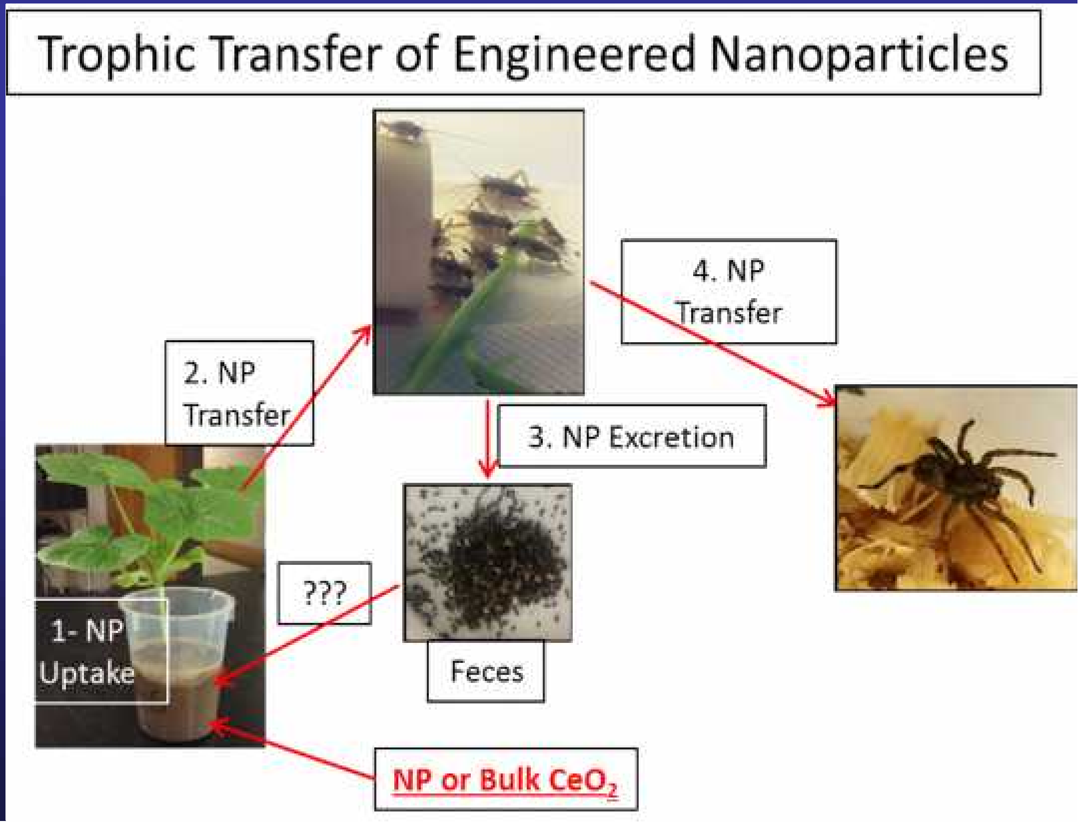
- Trophic transfer potential of engineered nanoparticles remains largely unknown
- There have been a few nice studies in aquatic systems
- For terrestrial systems, the published work is limited to group of 3 papers on Au NPs from the University of Kentucky
- For us, it is a three part question-
  - Does trophic transfer occur?
  - Is the rate and extent different for nanoparticles?
  - What is transferred? Ions or NPs or Both?

Gardea-Torresdey et al. *Environ. Sci. Technol.*, 2014, 48 (5), pp 2526–2540

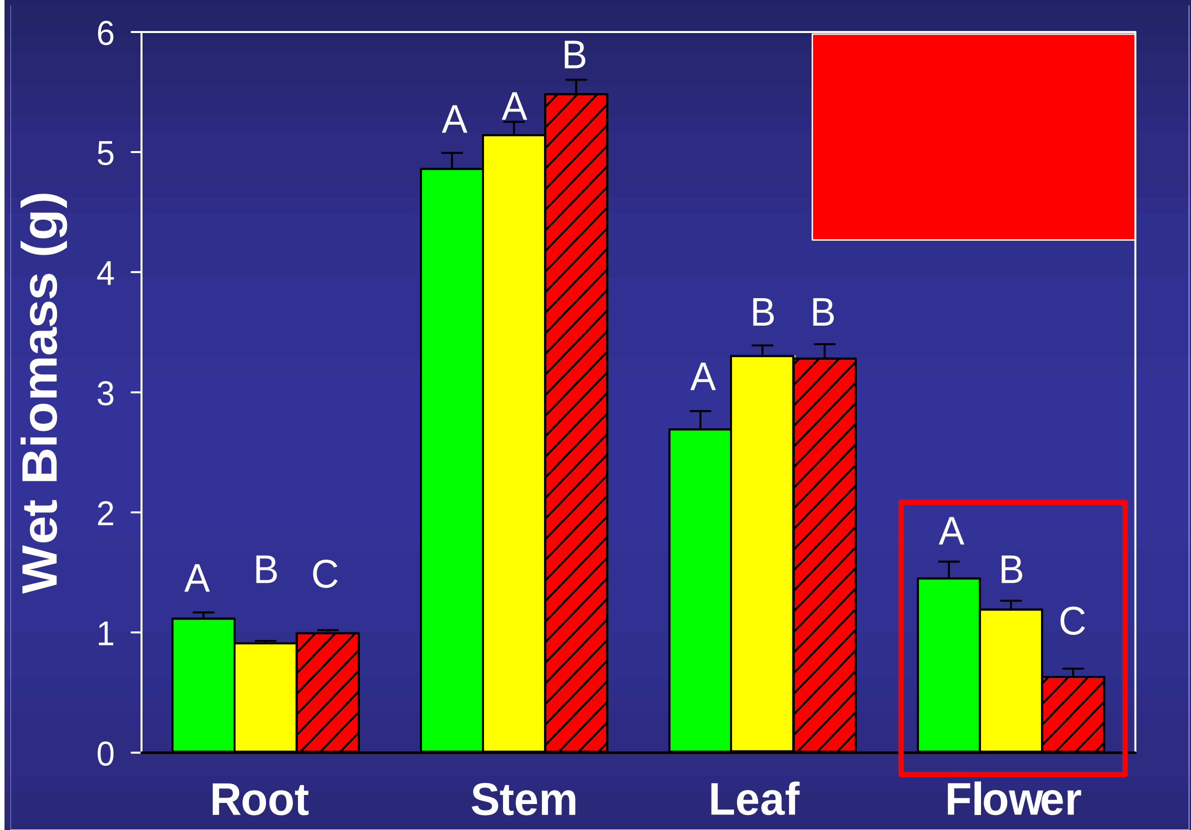
Objective 3- Determine the trophic transfer potential of NMs

- Experiment 1- **NP or 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 for ICP-MS

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



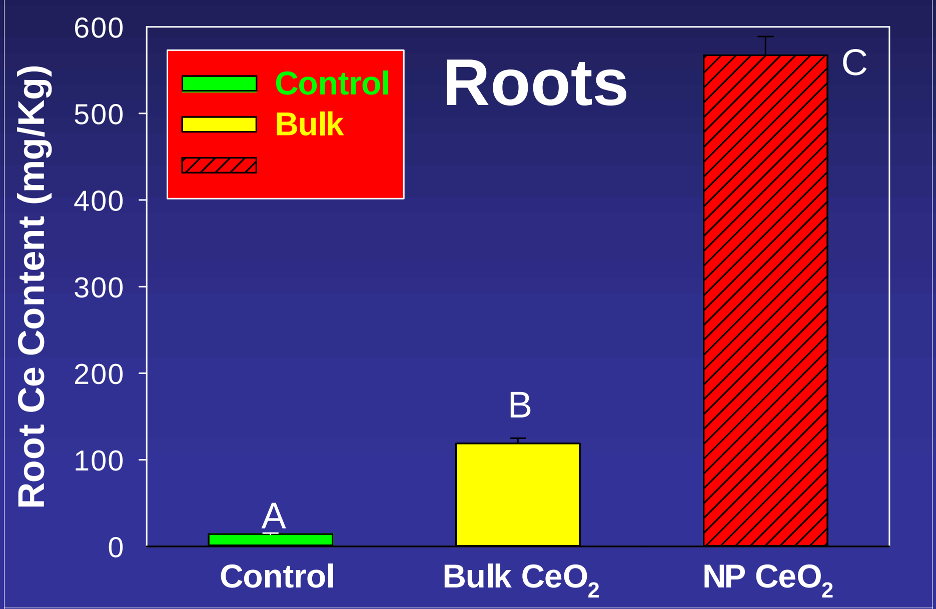
NP/Bulk CeO_2: Biomass Effects

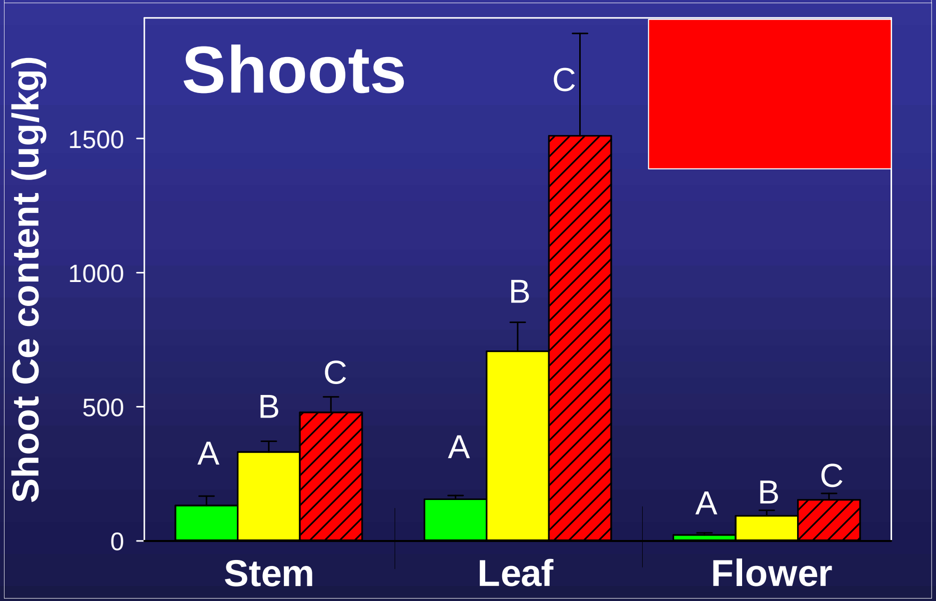


- No effect of Ce exposure on total wet or dry biomass
- Particle-size specific effects evident in root mass (decreases with exposure), stem mass (increase), and leaf mass (increase)
- NP CeO_2 reduced flower mass (reproductive tissues by more than 50%)

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

NP/Bulk CeO_2: Plant Ce content

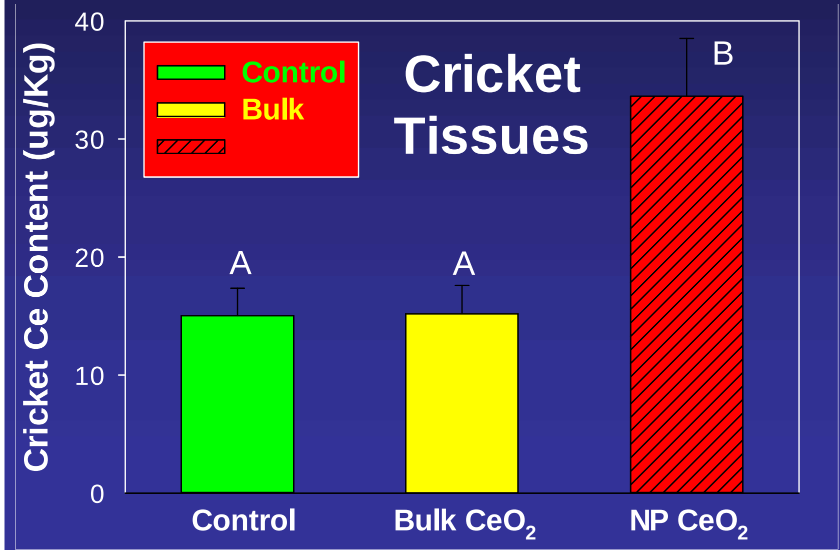


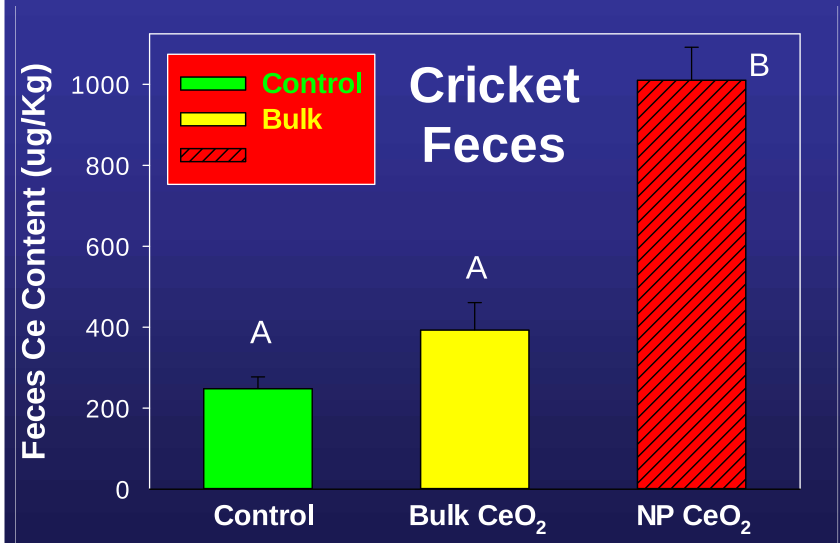


- Soil had background Ce at 21 mg/Kg so Ce present in controls
- NP-exposed tissues contained significantly more Ce than did bulk treatments!!
- Bulk and NP-exposed roots contained Ce at 119 and 576 mg/Kg (dilute acid-rinsed)
- NP-exposed shoot tissues contained 30-53% more Ce than bulk plants

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

NP/Bulk CeO_2: Cricket Ce Content





- Crickets fed bulk Ce contaminated leaves contained Ce at 15 ng/g
- NP exposed crickets had Ce at 33 ng/g
- Cricket feces for control and bulk-exposed insects were 250-380 ng/g
- Feces from NP-exposed crickets contained nearly 1000 ng/g

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

NP/Bulk CeO_2: Spider Ce Content

- All replicates (3 each) of control and bulk CeO_2-exposed spiders contained Ce at levels below the LOQ (4.6 µg/Kg)
- Two of the three NP-exposed spiders contained Ce at 8.8 and 5.9 ng/g; the third replicate was below the LOQ

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

Objective 3- Determine the trophic transfer potential of NMs

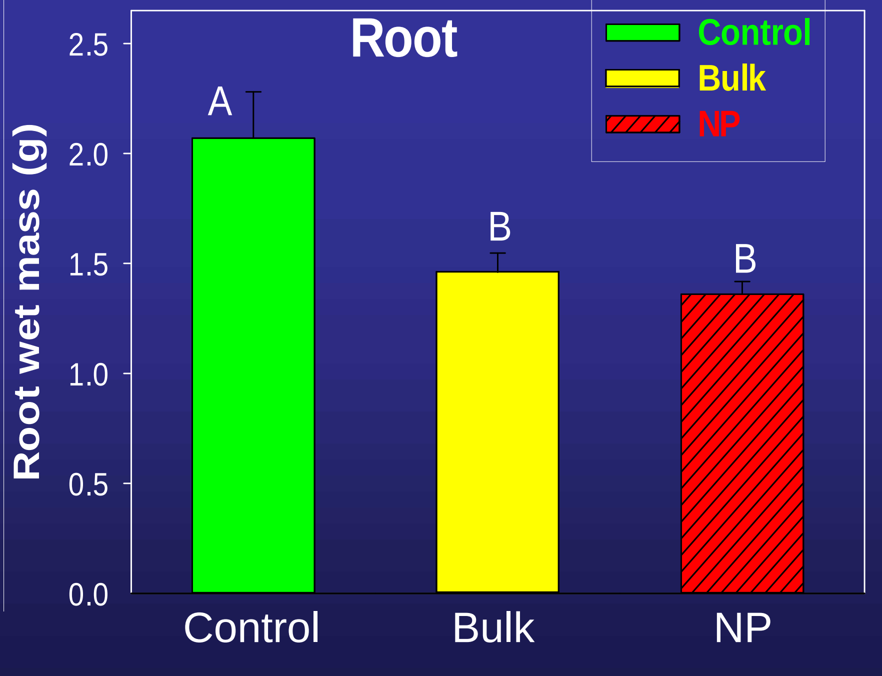
- Experiment 2- **NP or bulk** La_2O_3 (0 or 500 mg/Kg) added to an agricultural loam (a January soil-run in CT by post-docs from Texas…)

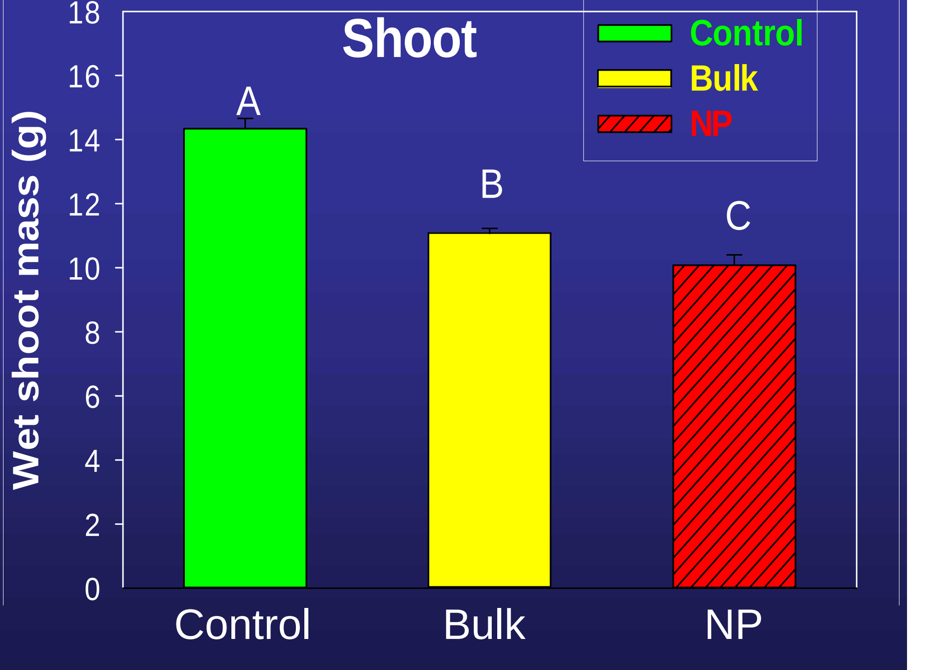
- Lettuce grown for 50d from seedling.
- Roots and shoots analyzed by ICP-MS.
- Leaves used to feed crickets and darkling beetles for 15d.
- Crickets used to feed mantids for 10d.
- Arthropod tissues for ICP-MS; S/TEM-EDS.

De la Torre-Roche et al; in preparation.

NP/Bulk La_2O_3: Biomass Effects

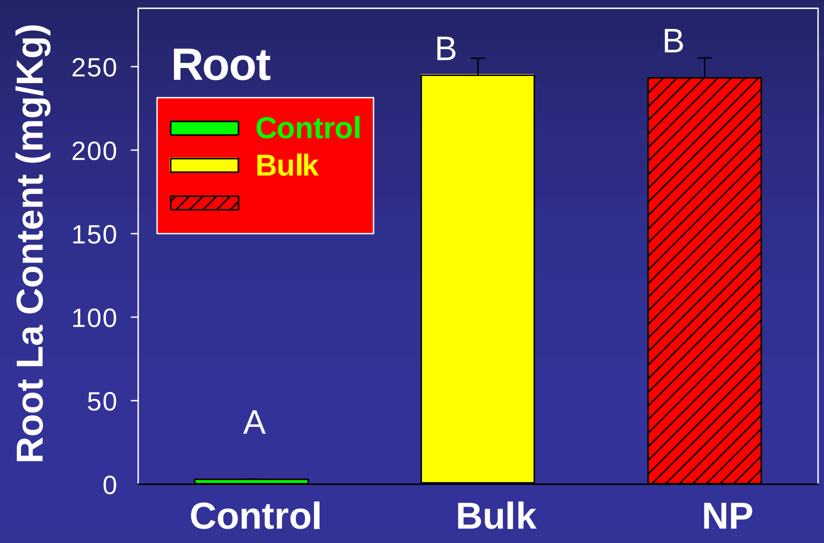
- La_2O_3 reduced root mass regardless of particle size
- La_2O_3 NPs reduced shoot biomass significantly more than did the bulk metal oxide

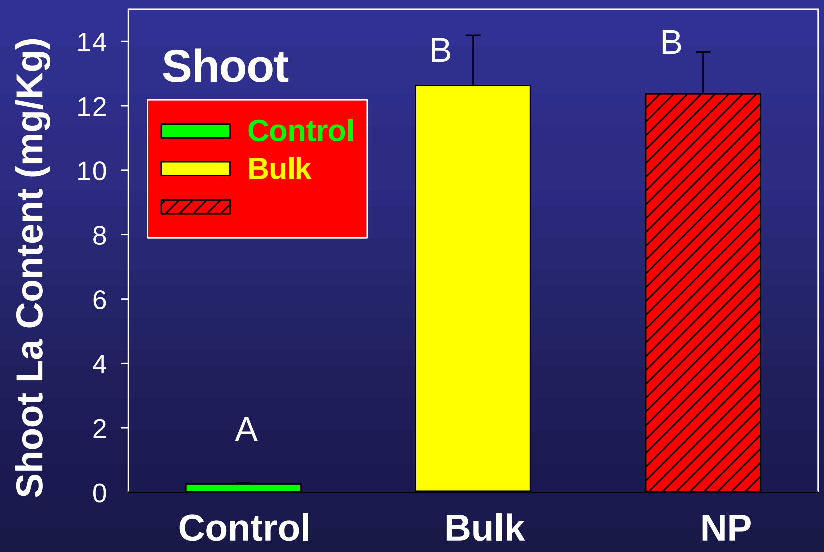




De la Torre-Roche et al; in preparation.

NP/Bulk La_2O_3: Plant La Content

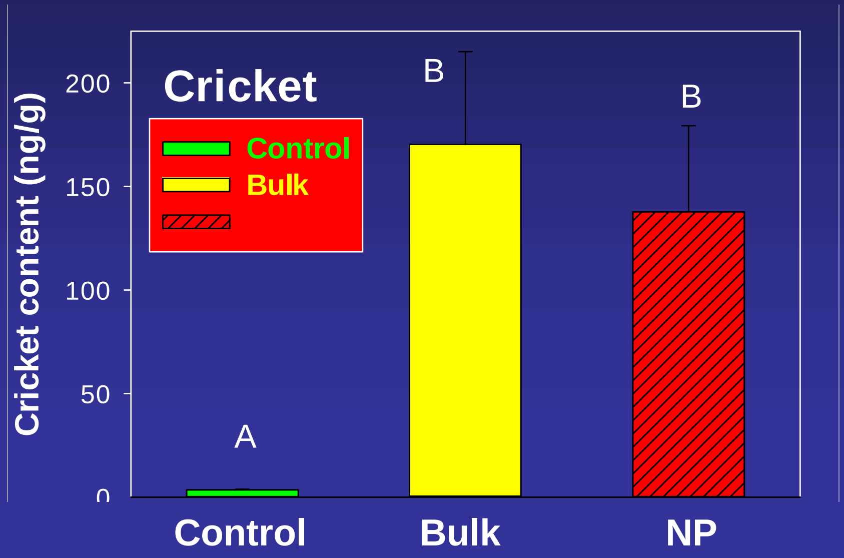


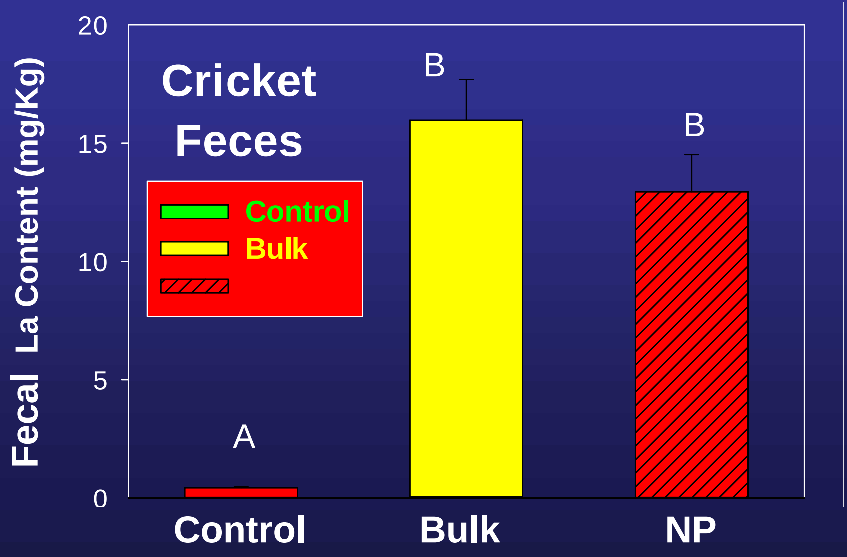


- La root and shoot content was **unaffected** by particle size
- La translocation much greater that in lettuce than Ce in zucchini

De la Torre-Roche et al; in preparation.

NP/Bulk La_2O_3: Insect La Content





- La content in crickets and cricket feces was unaffected by particle size
- Similar to Ce, fecal content was **much** higher than tissue content

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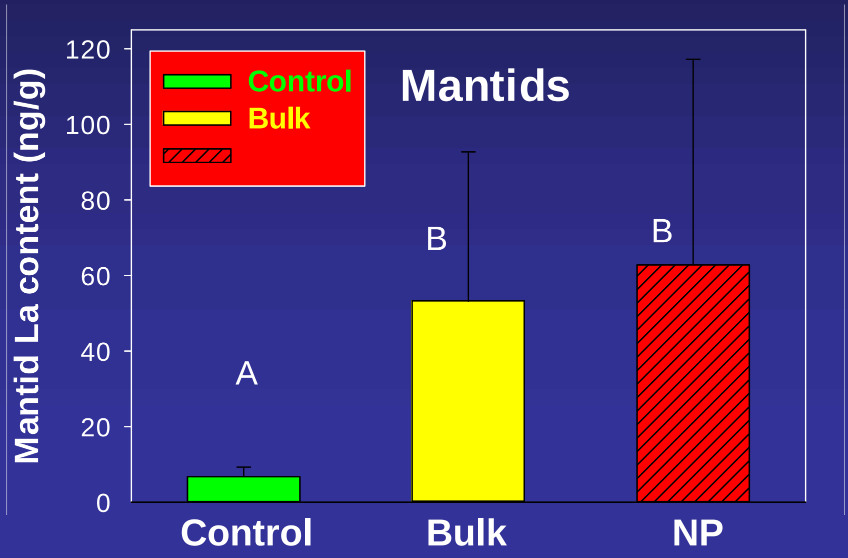
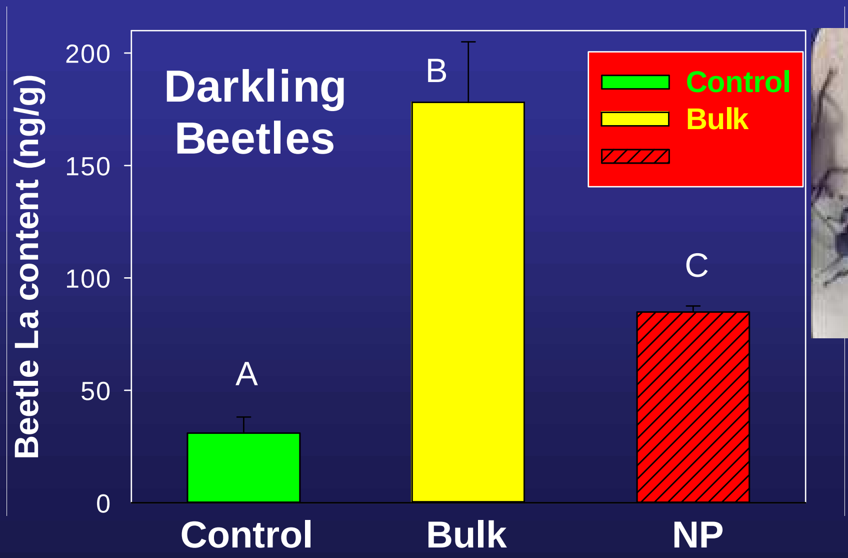
De la Torre-Roche et al; in preparation.

NP/Bulk La_2O_3: Insect La Content



- La content in mantids was unaffected by particle size
- La content in beetles was actually decreased for the NP



De la Torre-Roche et al; in preparation.

Trophic Transfer Studies- Ongoing Work

- NP and bulk cerium trophic transfer part II- conducted at UTEP with TX soil (1000-2000 mg/kg CeO_2), kidney bean, Mexican bean beetle

Majumdar et al; in preparation.

- Trophic transfer of NP and bulk CuO- 500 mg/kg in soil for 0 or 60 days, lettuce, cricket, anolis lizards.

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Gardea-Torresdey et al. *Environ. Sci. Technol*., 2014, 48 (5), pp 2526–2540

Trophic Transfer Studies- Future Work

- Determine why CeO_2 bioaccumulates in a particle-size specific fashion and La_2O_3 does not
- Measure ion release from metal oxides in soil
- Determine impact of root exudation on metal oxide dissolution
- “omics” endpoints
- Determine the nature of the accumulated Ce and La
  - S/TEM-EDX
  - Synchrotron (µXRF, XANES)

Gardea-Torresdey et al. *Environ. Sci. Technol*., 2014, 48 (5), pp 2526–2540

Conclusions

- Are engineered nanomaterials an emerging class of contaminants in agricultural systems? Do they behave different from their non-nano counterparts in a toxicologically significant fashion?
- In agriculture, exposure routes are numerous and can occur directly through NM-containing pesticide/ fertilizer formulations, as well as spills, or indirectly through the application of NM-containing biosolids
- Trophic transfer studies just completed or underway
  - NP CeO_2 seems to be accumulated from soil and trophically transferred in particle size specific fashion.
  - NP La_2O_3 presents a different scenario, albeit with a different plant
- Clearly, much more work is needed

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- 2011-2016: USDA AFRI -Addressing Critical and Emerging Food Safety Issues- "Nanomaterial contamination agricultural crops"
- 2012-2015: USDA AFRI –Nanotechnology for Agricultural and Food Systems- "Nanoscale interactions between engineered nanomaterials and black carbon (biochar) in soil"

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