Nanoscale Nutrients Suppress Plant Disease and Increase Crop Yield

Jason C. White, Ph.D.

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

Presented at the 252nd American Chemical Society National Meeting
Philadelphia PA August 21-25, 2016

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

2015

Biotechnology Advances 32 (2014) 1550–1561

Contents lists available at ScienceDirect

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

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

www.ct.gov/caes

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

2012

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Review

pubs.acs.org/JAFC

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

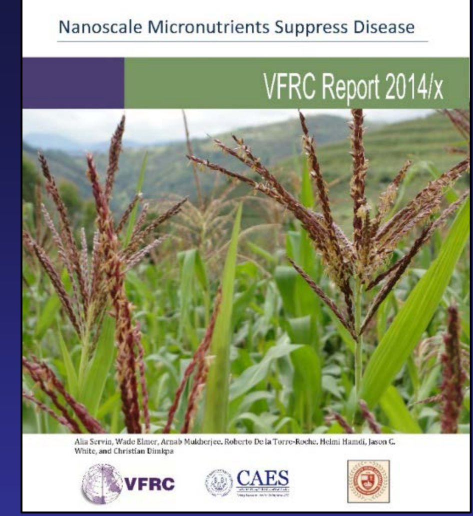
Alexander Gogos,[†] Katja Knauer,[‡] and Thomas D. Bucheli[*,†]

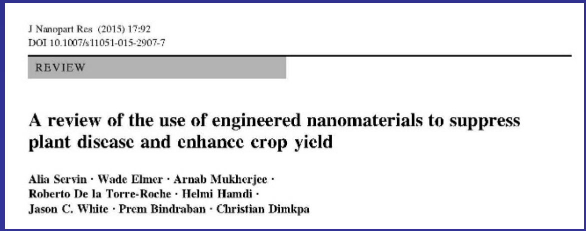
[†] Agroscope Reckenholz-Tänikon Research Station ART, 8046 Zurich, Switzerland
[‡] Federal Office for Agriculture, 3003 Berne, Switzerland

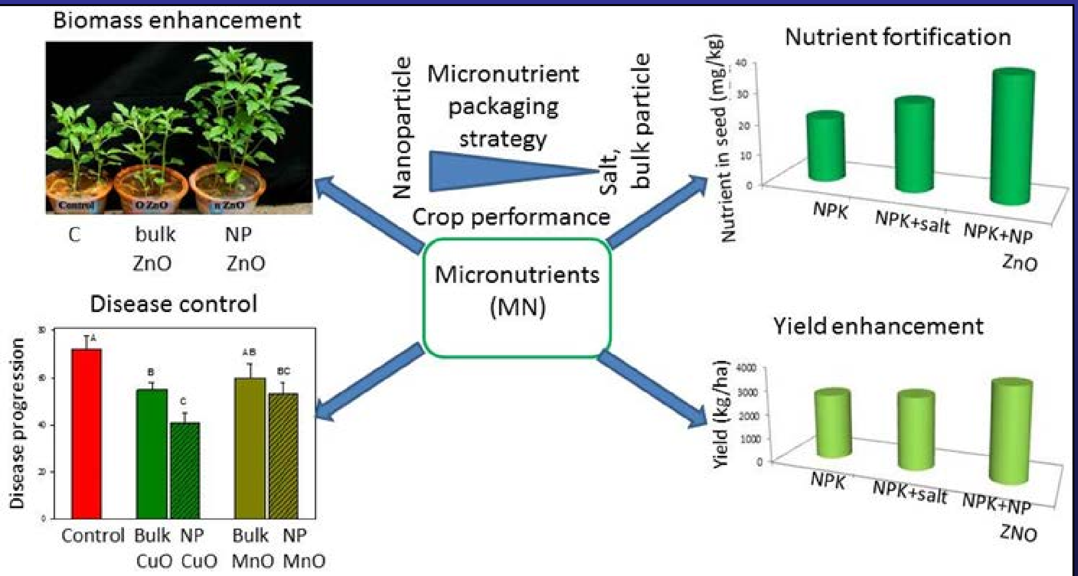
Supporting Information

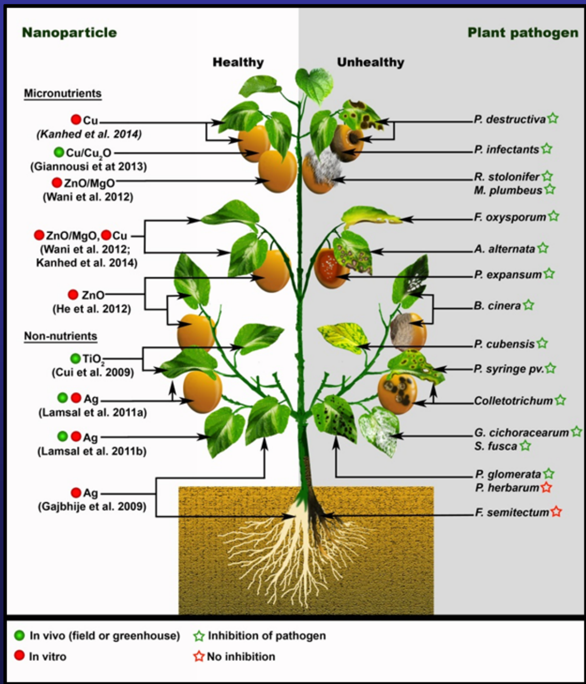
Nanomaterials and Agriculture

- Nanoscale based micronutrients for disease suppression (particularly **root disease**)
- A new research initiative at CAES
- Started with a small grant from VFRC/IFDC to write a report and a review article (*J. Nano. Res.* 2015, 17:92) on nanoscale nutrients and crop disease
- Generated some interesting data (Elmer and White, 2016, *ES: Nano;* DOI 10.1039/C6EN00146G) and wrote a grant
- USDA Grant- $480,000; 3/16-2/19.









Why Micronutrients?

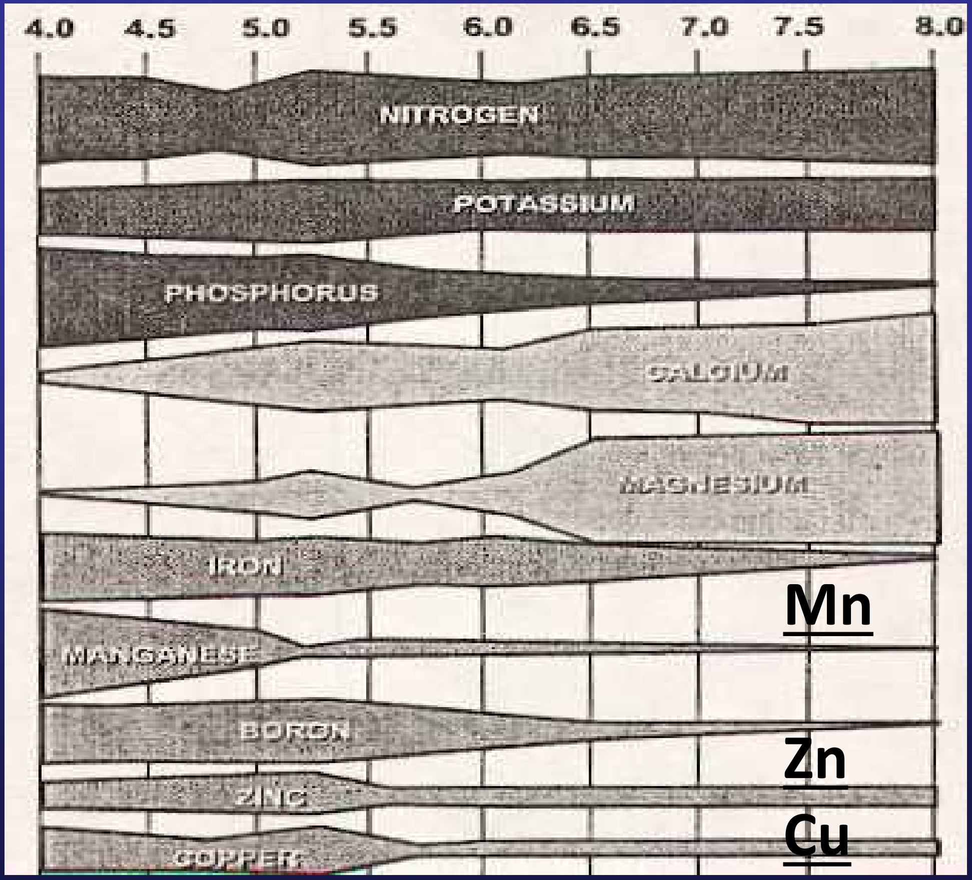
Nutrition is the first line of defense against disease. Micronutrients protect **roots** against soilborne diseases by activating enzymes to create defense products.

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

Micronutrient Availability?

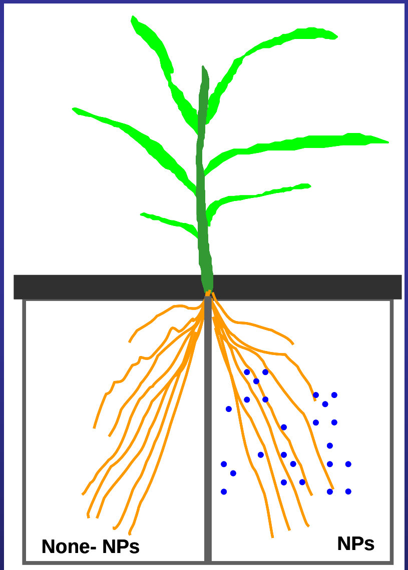
- Increasing micronutrient levels in roots is problematic in neutral soils.
- Micronutrients are not basipetally (shoot to root) translocated.
- When applied to soil they frequently precipitate and become unavailable to the plant
- Limited options for preventing and treating root disease (host resistance,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

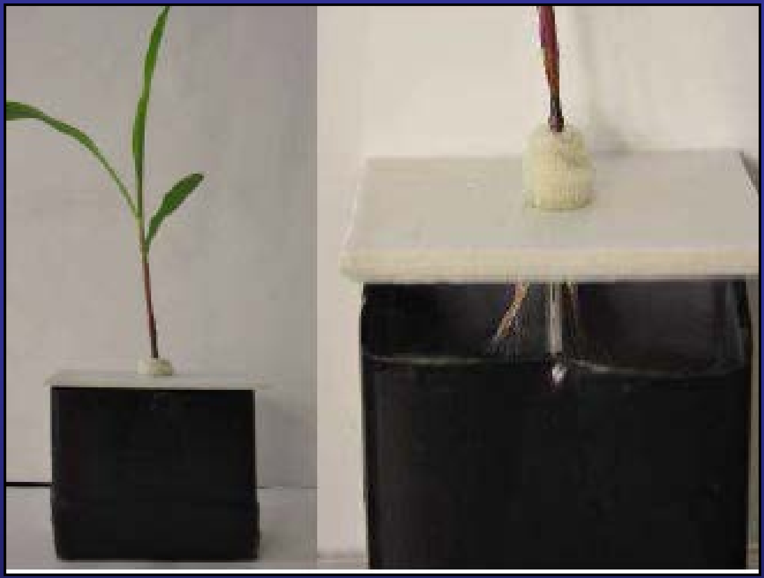
www.ct.gov/caes

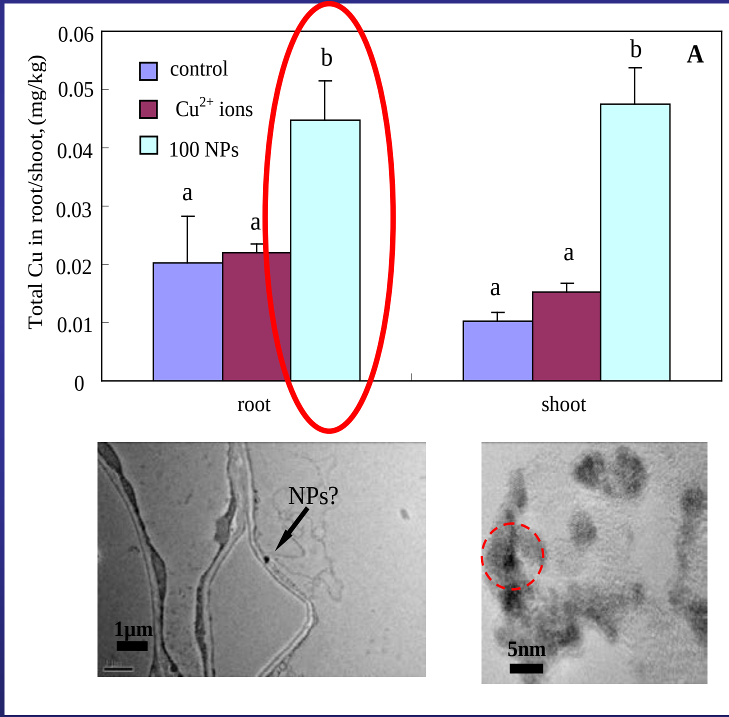


When Chemists talk to Plant Pathologists…

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



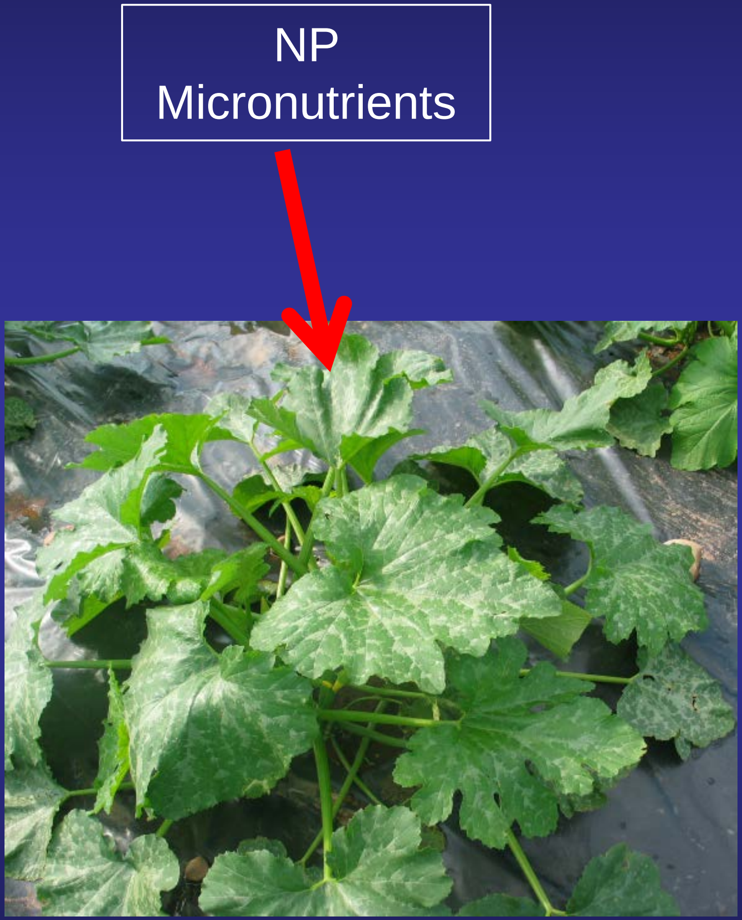




Wang, White et al. 2012. Xylem- and phloem-based transport of CuO nanoparticles in Maize (*Zea mays* L.) *Environ. Sci. Tech*. 46:4434-4441.

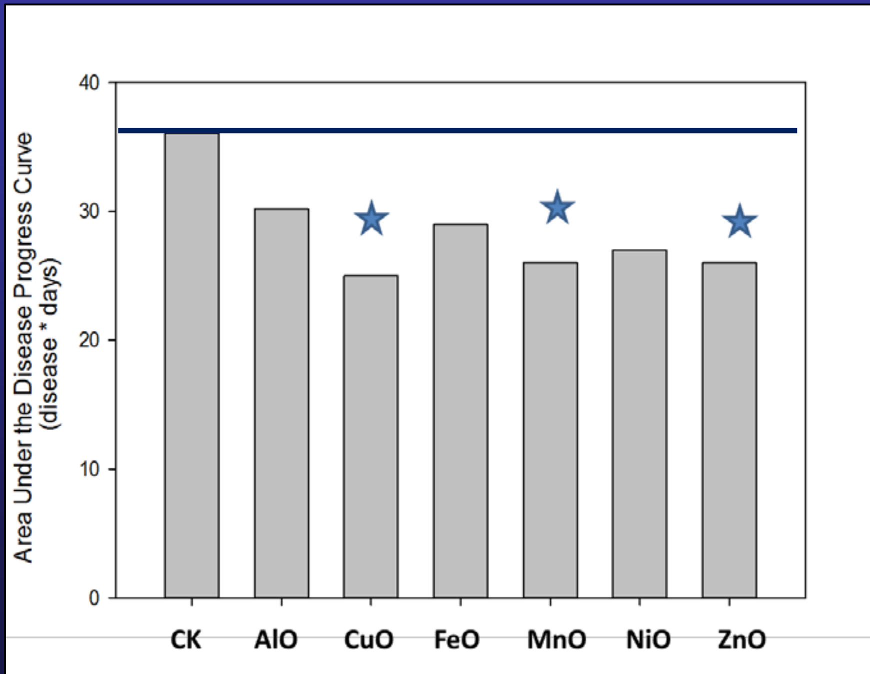
The Hypotheses?

- 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)?



The Initial Study

- Used Tomato and *Fusarium* (fungal root pathogen)
- Two rates (100 or 1,000 mg/L) of NP Al, Fe, Cu, Mn, Ni, or Zn were sprayed onto tomatoes in the greenhouse.
- Plants were inoculated with *Fusarium* and disease was measured



Elmer and White. 2016. *Environ. Sci.: Nano* DOI 10.1039/C6EN00146G.

Verticillium Wilt of Eggplant

- Caused by soilborne fungus, *Verticillium dahlia*; can reduce yields by 30%
- In greenhouse trials, would foliarly applied NPs of Cu, Mn, or Zn suppress Verticillium?
- Would they behave the same as their bulk oxide equivalents?

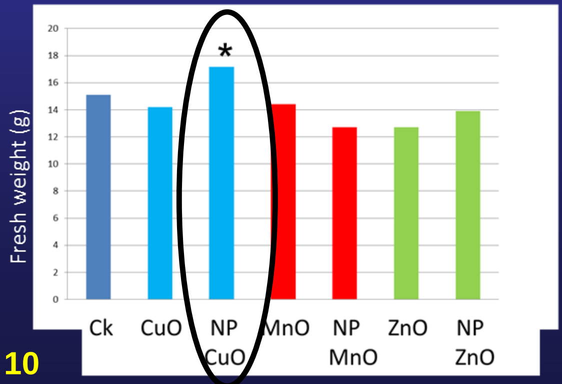
Elmer and White. 2016. *Environ. Sci.: Nano* DOI 10.1039/C6EN00146G.

Verticillium Wilt of Eggplant

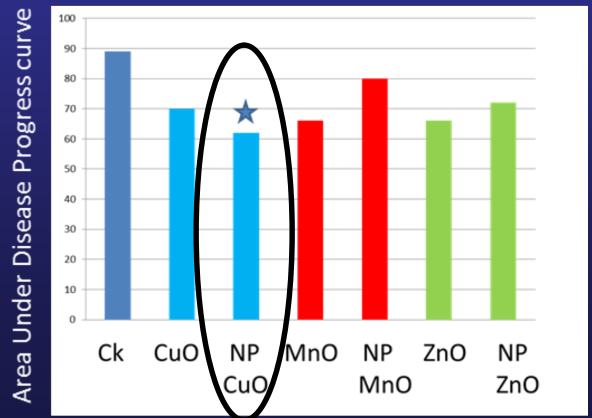
- NP of Cu, Mn, and Zn oxides were compared to the bulk oxide equivalent (1000 mg/L).
- Plants were sprayed (15ml), allowed to dry and grown in soil with *V. dahliae.*
- CuO NP treated plants had greater biomass (left), less disease progress (center) and higher Cu root content (right)

www.ct.gov/caes

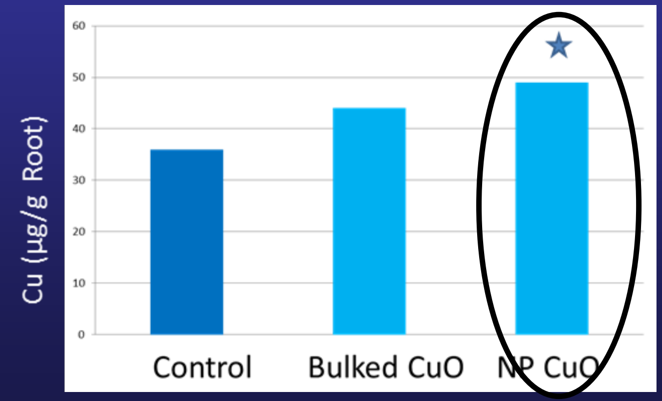
Biomass



Disease Progress



Cu Root Content



Elmer and White. 2016. *Environ. Sci.: Nano* DOI 10.1039/C6EN00146G.

Field Trials 2013-2014
Verticillium Wilt of Eggplant

- Treatments included NP or bulk CuO, MnO, and ZnO
- Single application in greenhouse followed by transplant to infested field soil
- Yield and fruit element content measured

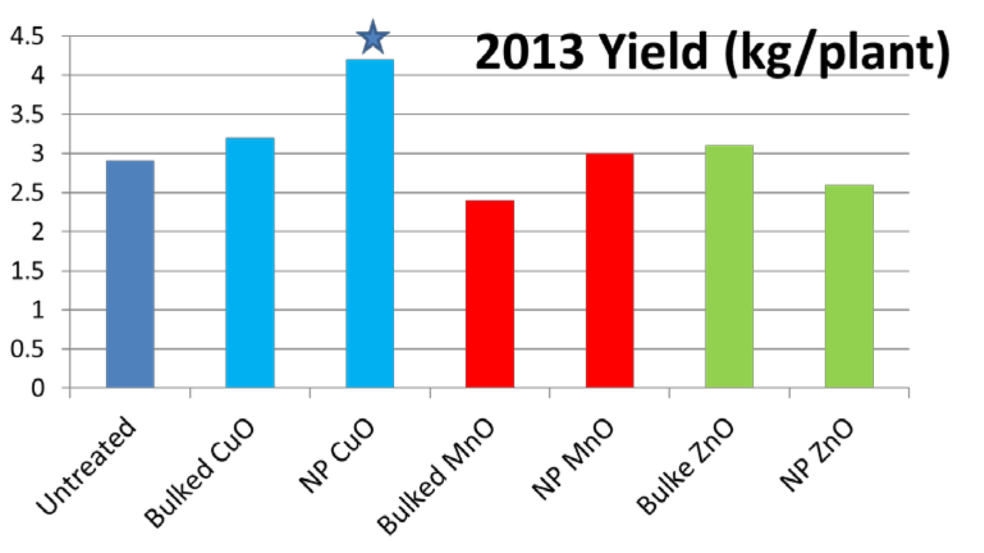
Elmer and White. 2016. *Environ. Sci.: Nano* DOI 10.1039/C6EN00146G.

www.ct.gov/caes

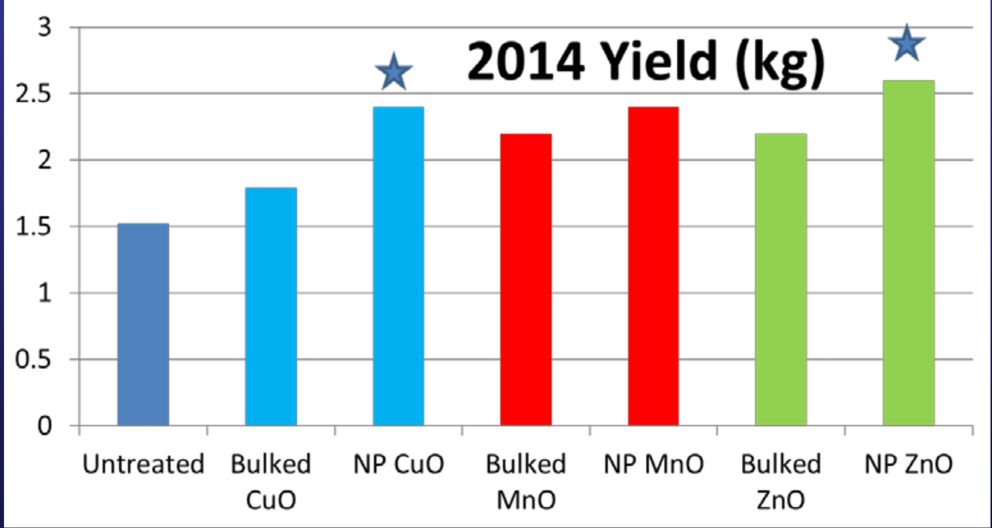
Field Trials 2013-2014
Verticillium Wilt of Eggplant

- In two separate field trials, NP CuO increased fruit yield, decreased disease, but did not increase fruit Cu content

- $44 per acre investment for NP CuO suppressed a root pathogen of eggplant, increasing yield from $17,500/acre to $27,650/acre.



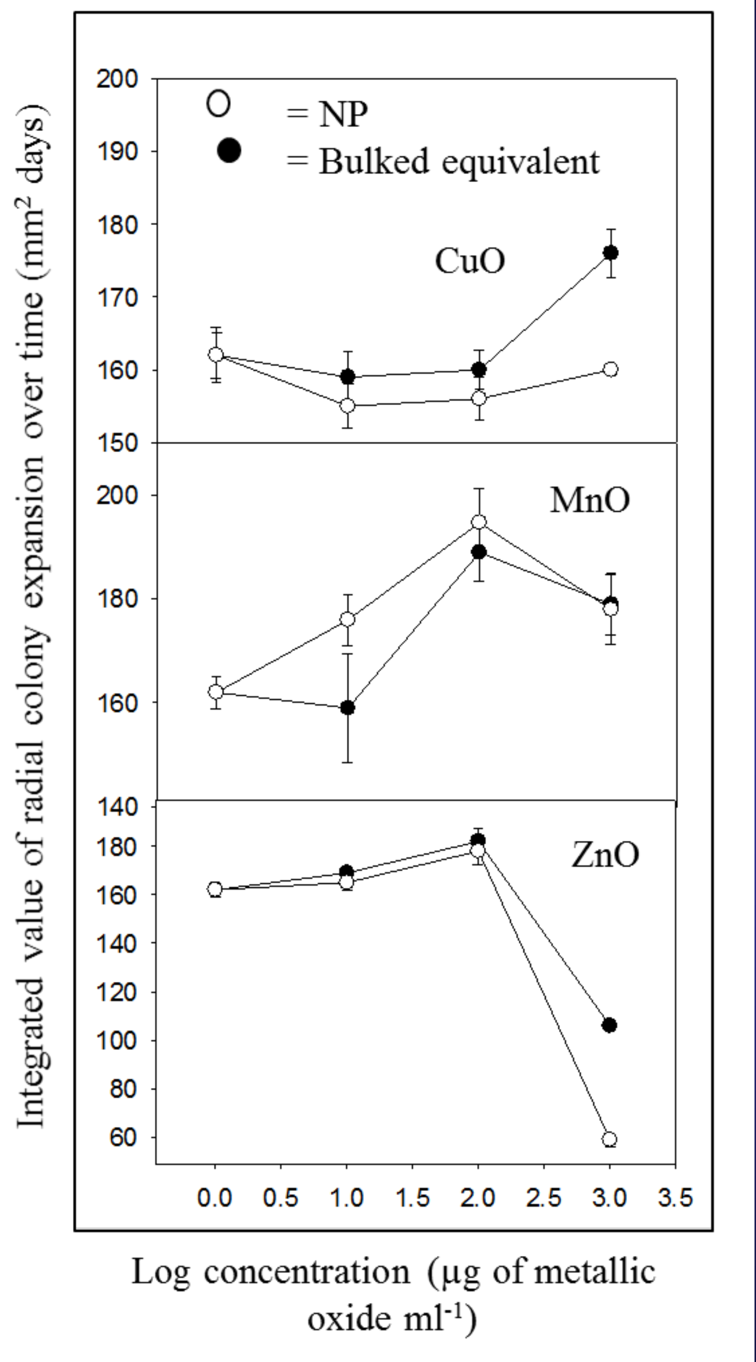
Elmer and White. 2016. *Environ. Sci.: Nano* DOI 10.1039/C6EN00146G.



Direct Effect on the Pathogen?

- There has been work on nano-fungicide formulations to **directly** suppress fungal pathogens (Ag, Zn, Cu), although not a lot root pathogens.
- We've run vitro assays with NP and bulk metal oxides against Fusarium (25% potato dextrose agar).
- Bulk and NP ZnO had significant toxicity but MnO and CuO either had no effect or promoted fungal growth
- Our CuO effects are driven by nutrition and disease resistance

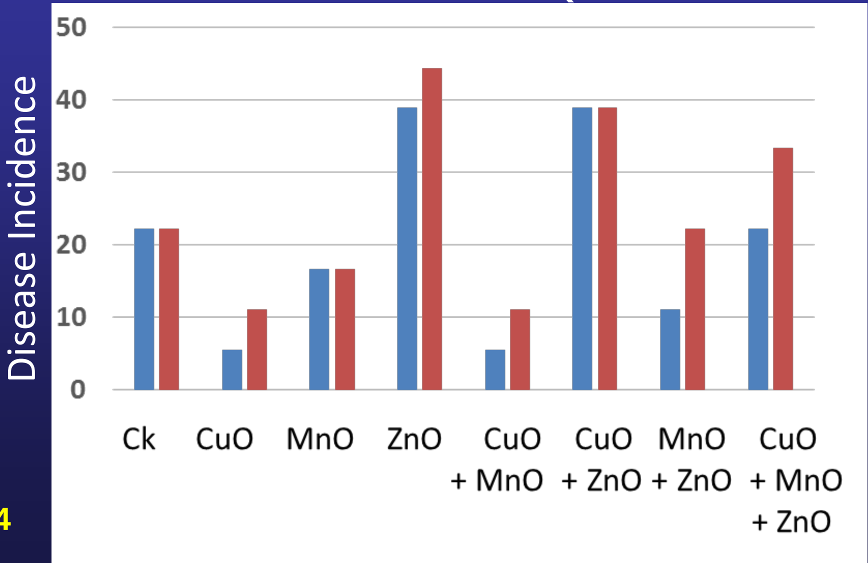
Elmer and White. 2016. *Environ. Sci.: Nano* DOI 10.1039/C6EN00146G.



Field Trial 2016: Verticillium Wilt of Eggplant

- Treatments include NP CuO, MnO, ZnO, CuO + MnO, CuO + ZnO, MnO + ZnO, CuO + MnO + ZnO
- Greenhouse application (1000 mg/L) followed by transplant to infested soil; periodic applications in field ongoing at 2 farms
- Yield and fruit elemental to be content measured
- Initial disease progress data taken on 2 occasions (blue and red bars)

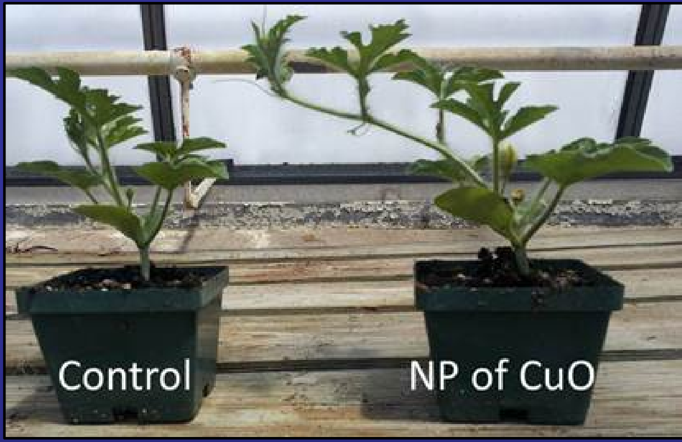
www.ct.gov/caes

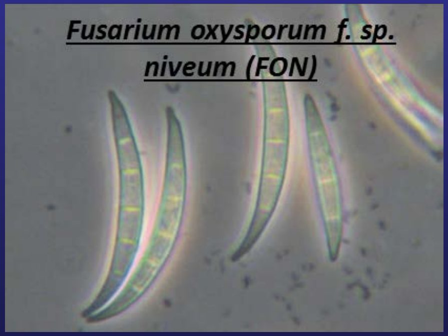


Fusarium Wilt of Watermelon-Greenhouse 2015

- Another Fusarium pathogen attacks watermelons; increased occurrence in Florida has been reported (significant economic impact)
- Similar infection through roots causing whole plant wilt
- Host resistance options limited
- Chemical control ineffective
- Trials with metal oxide NPs are underway

www.ct.gov/caes



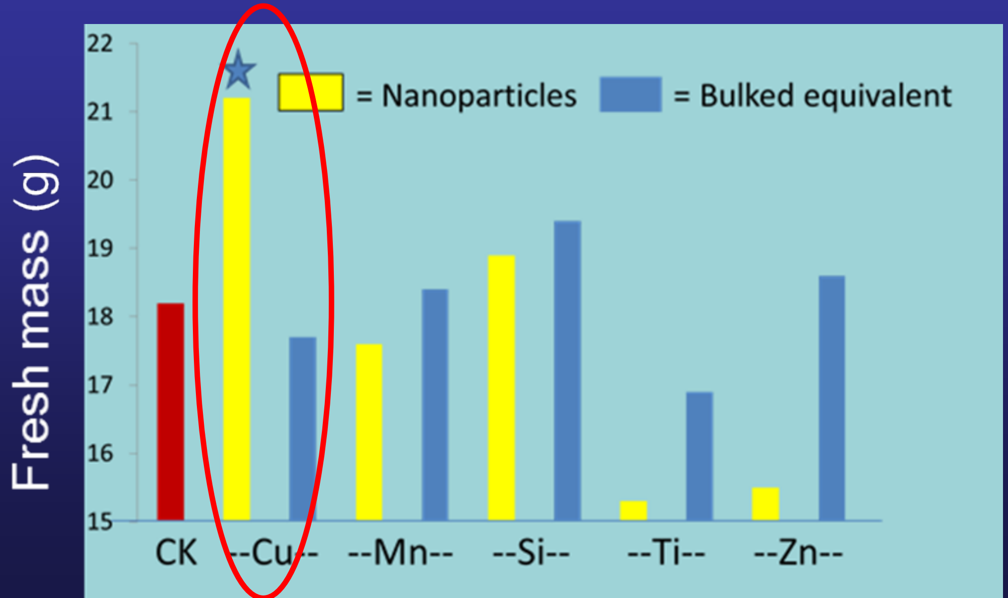


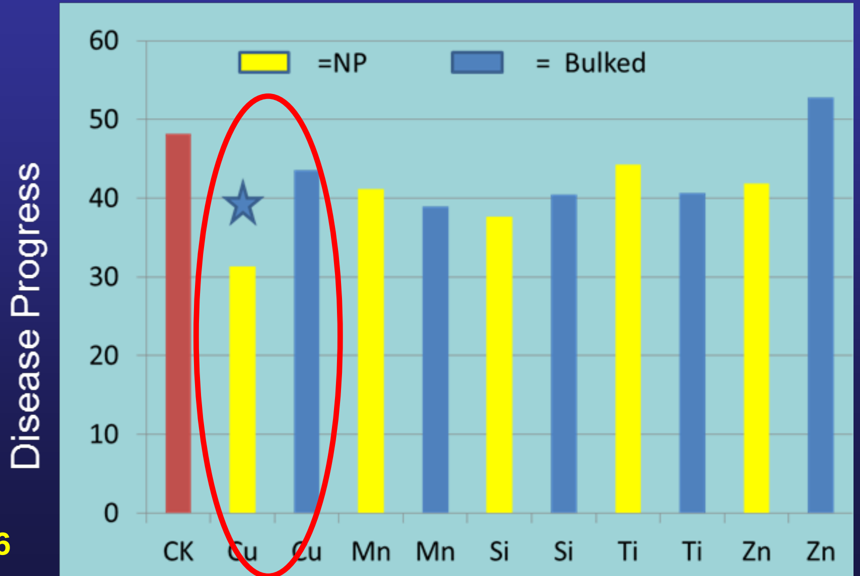
Control NP CuO

Fusarium Wilt of Watermelon-Greenhouse 2015-2016

- Greenhouse study with single foliar application of 1000 mg/L prior to growth in soil containing FON
- Again, NP CuO significant promoted plant growth (left) and significantly suppressed disease progress
- ICP-MS analysis of edible flesh found no differences in Cu levels among treatment

www.ct.gov/caes



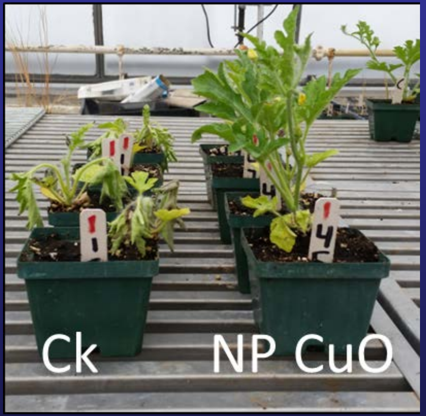


Fusarium Wilt of Watermelon-Greenhouse 2015-2016

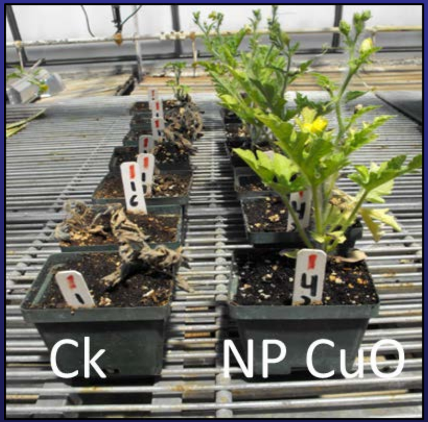
- A follow up greenhouse study with single foliar application of 100 or 1000 mg/L prior to growth in soil containing FON
- NP CuO significant promoted plant growth and significantly suppressed disease progress at both treatment levels
- Others affected disease only

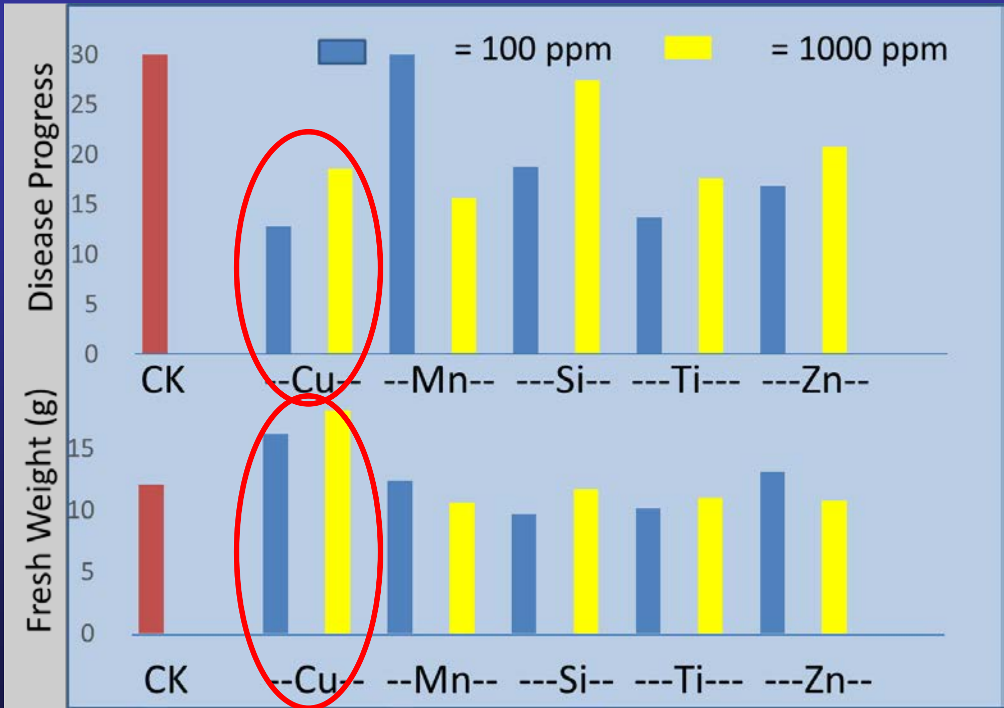
www.ct.gov/caes

7/13/16



7/21/16





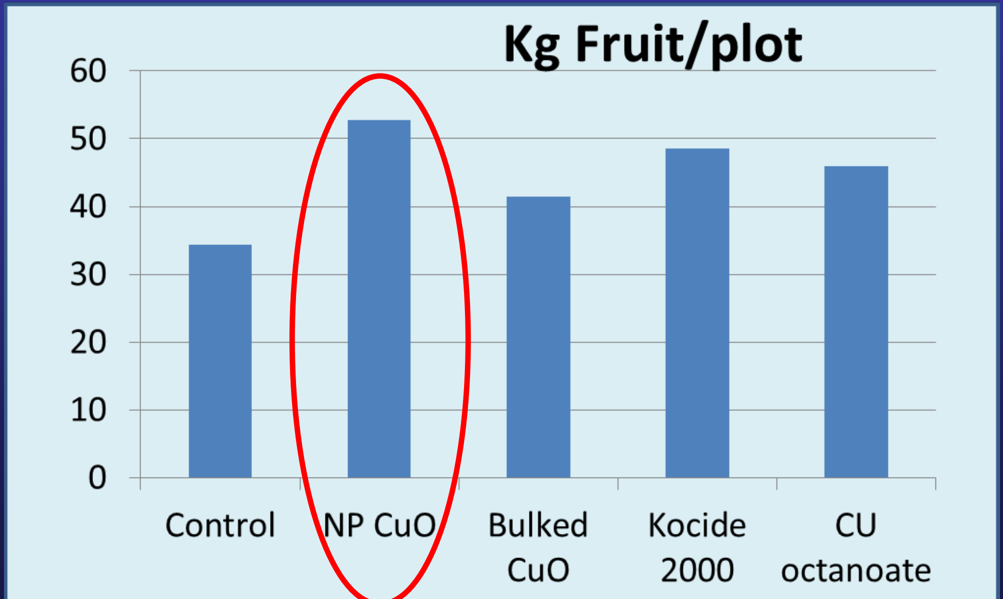
Fusarium Wilt of Watermelon- Field 2015

Treatments- Applied twice to seedlings in greenhouse

- Control, CuO NP, Bulk CuO, Kocide 2000, Organic Cu soap (Cu octanoate**)**

www.ct.gov/caes

- Fruit yield increased by NP
- No difference in fruit Cu content



Fusarium Wilt of Watermelon- Field 2016

Treatments- Multiple foliar applications made during growth at 2 farms

- Control
- B NP
- CeO NP
- CuO NP
- MnO NP
- ZnO NP

www.ct.gov/caes

Conclusions

- Treating seedlings with nanoscale CuO had positive effects on the growth and yield of
  - Tomato in the presence of *Fusarium* (greenhouse)
  - Eggplants in the presence of *Verticillium* (greenhouse, field)
  - Watermelons in the presence of *Verticillium* (greenhouse, field)
- Season long effects were observed following single or double applications to young transplants.
- Mechanism of action is either improved plant nutrition or stimulated disease response (or both); little direct NP activity on the pathogens.
- Future work will focus on characterizing the basis of plant response (transcriptomics), fully characterizing NP presence in the exposed plants (S/TEM-EDX, synchrotron), using different kinds of CuO NPs, and expanding the list of plant-pathogen systems investigated

Acknowledgements

- **Wade Elmer, Ph.D**- CAES
- **J. Gardea-Torresdey, Ph.D.**- UTEP
- **Christian Dimkpa, Ph.D.**- VFRC
- **At CAES**- R. De la Torre-Roche, P. Thiel, S. Majumdar, L. Pagano (Univ. of Parma), F. Pasquali (Univ. of Parma), S. Younas (SCSU)
- **Funding**- USDA AFRI Foundational Program Area A1511 “Nanotechnology for Agricultural and Food Systems;” Grant 2016-67021-2498 “Nanoscale elements suppress plant disease, enhance micronutrient use efficiency, and increase crop yield.” Also, USDA Hatch and FDA FERN

www.ct.gov/caes

VFRC Nourishing plants for healthy people in a green world

UTEP The University of Texas at El Paso

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

USDA National Institute of Food and Agriculture