Nanoscale Elements Suppress Plant Disease, Enhance Micronutrient Use Efficiency, and Increase Crop Yield

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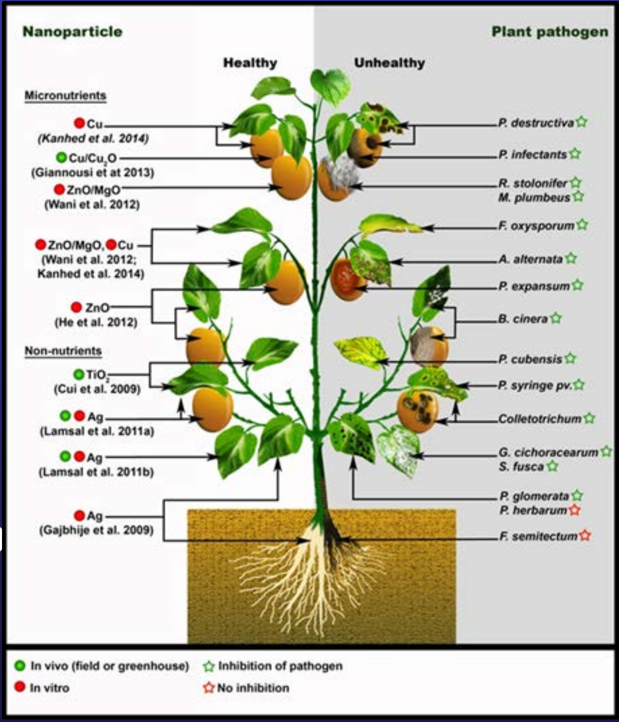
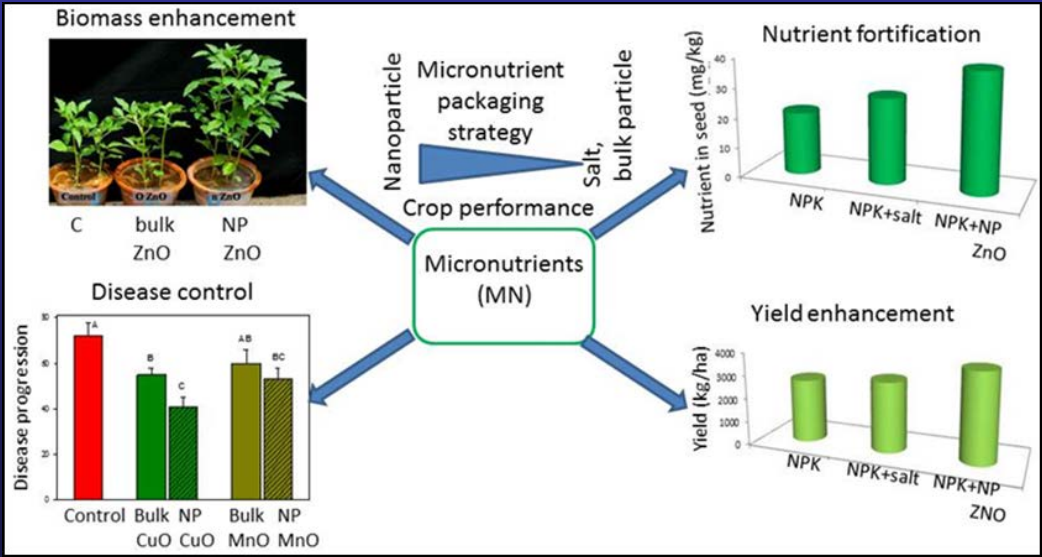
Project Goal and Rationale

- **Goal-** Use nanoscale elements to suppress crop disease, improve nutritional content, and enhance yield.
- Pathogens reduce yield by 10-20%, causing billions of dollars in losses. Control efforts (fungicides) exceed $600 million/year.
- Nutrient utilization is low due to inefficiencies and low availability.
- Shortfalls in food production will worsen with a changing climate and increasing population.
- Nanotechnology can play a critical role in maximizing food production and achieving food security.
- Current approaches have focused on nano-enabled conventional agrochemicals, nanosensors, and waste treatment.
- However, little is known about the effects of nanoscale micronutrients on disease suppressio macronutrient uptake, and crop growth.



Project Objectives

1. Demonstrate nanoparticle (NP; Cu, Zn, Si, B, Mn, Ce) efficacy upon foliar or root application at suppressing fungal pathogen infection in model vegetable and grain species (tomato, eggplant, watermelon, sorghum).
2. Determine the role of soil type and NP source in disease suppression and crop yield.
3. Determine the impact of NP micronutrient treatment on macronutrient (NPK) utilization.
4. Characterize NP absorption and translocation mechanisms in plant tissues by scanning/ transmission electron microscopy (S/TEM-EDS).



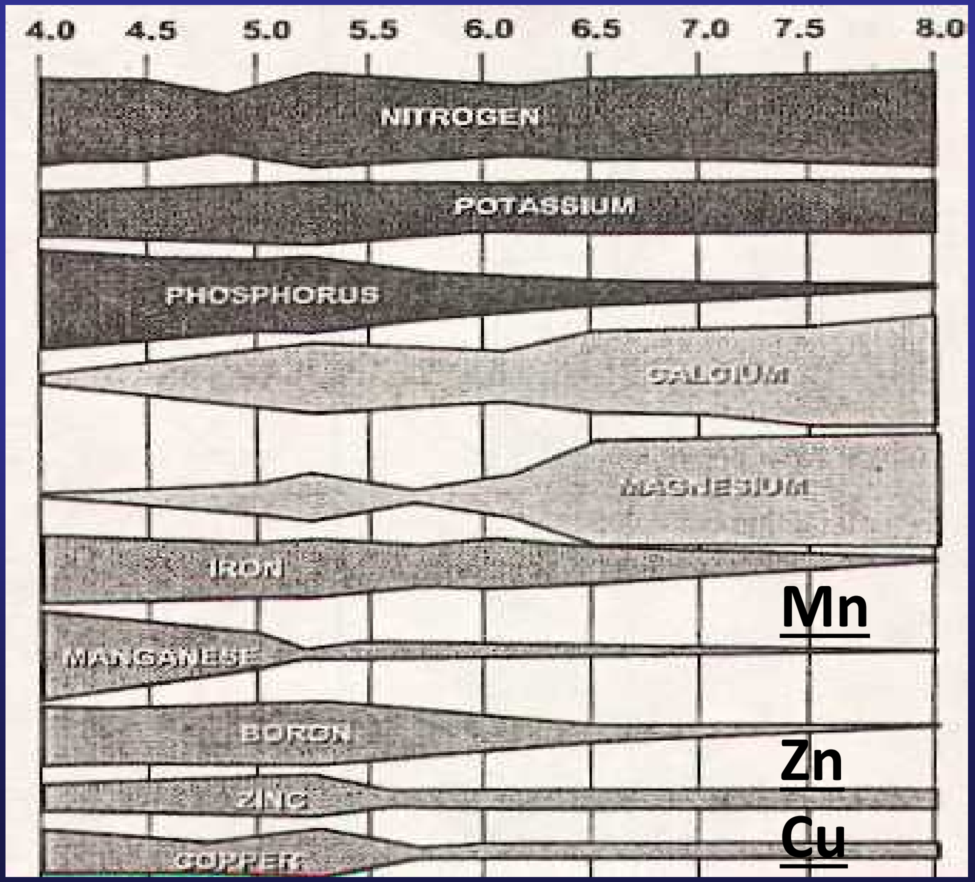
Why Micronutrients?

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

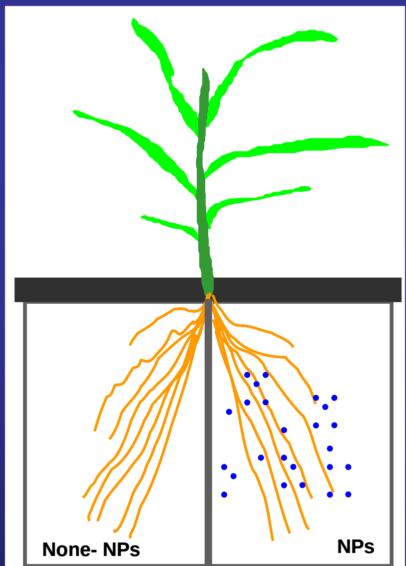
Micronutrient Availability?

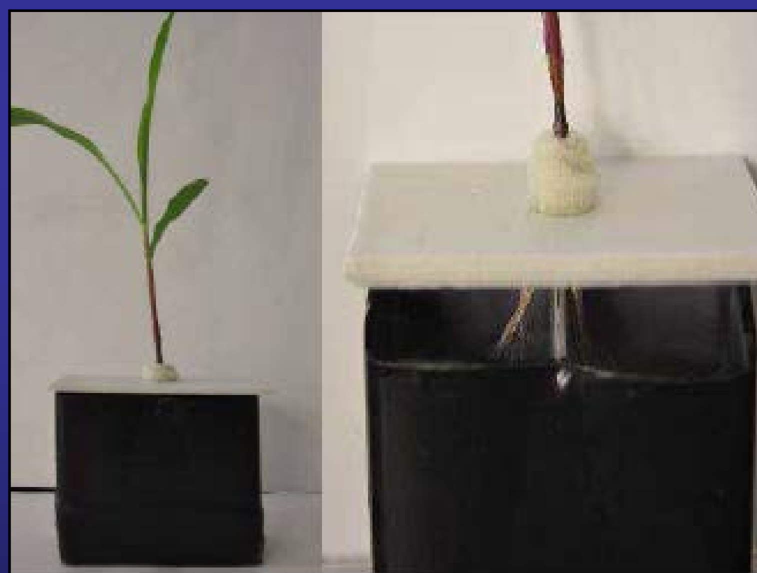
- Increasing micronutrient levels in roots is problematic in neutral soils.
- When applied to soil, they frequently precipitate and become unavailable to the plant.
- Micronutrients are not basipetally (shoot to root) translocated.
- Thus, options for preventing and treating root disease are rather limited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

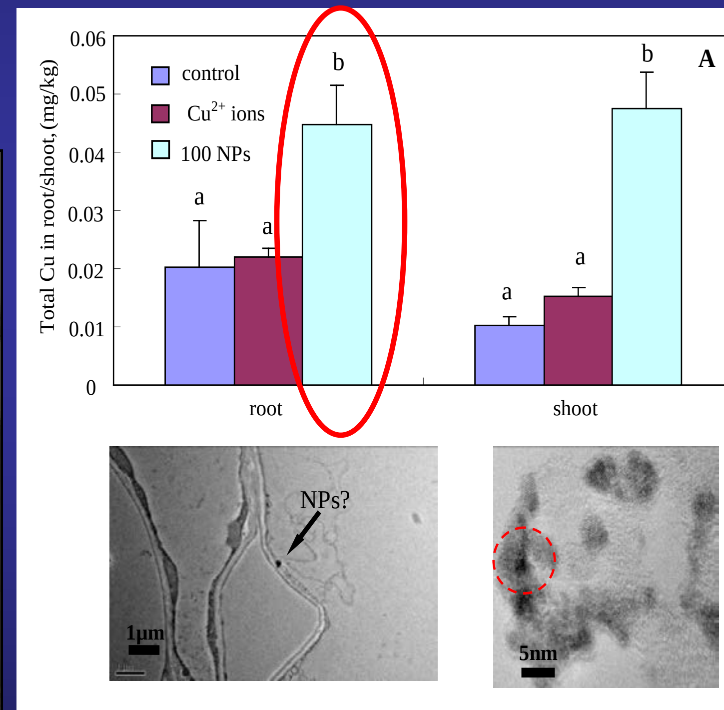


A Chemist and a Plant Pathologist Walk into a Bar…

- 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.

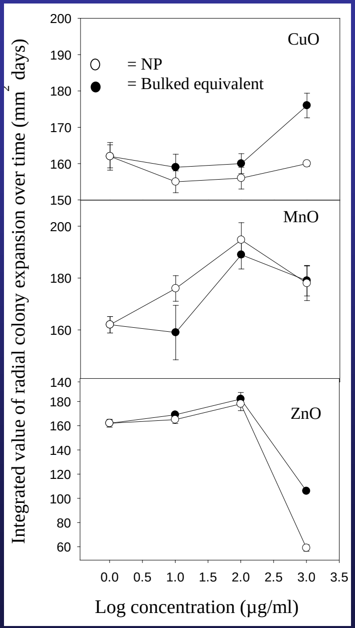
The Hypotheses?

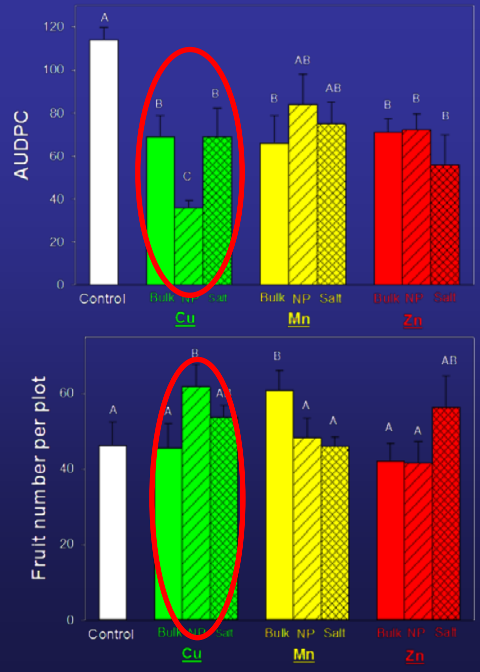
- Would applying nanoscale micronutrients to leaves affect growth?
- Would these metals be translocated to roots?
- Could these translocated nutrients stimulate plant defense and suppress root disease (mostly fungi, nematodes)?

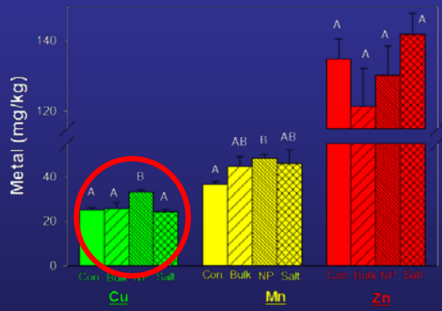
Nanoscale micronutrients (Cu, Zn, B, Si…)

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.

Foliar Application of Nanoscale Micronutrients to Watermelon

- In greenhouse/field studies, 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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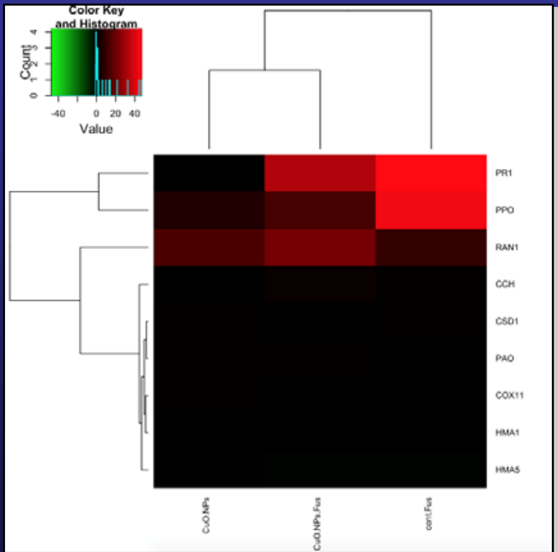

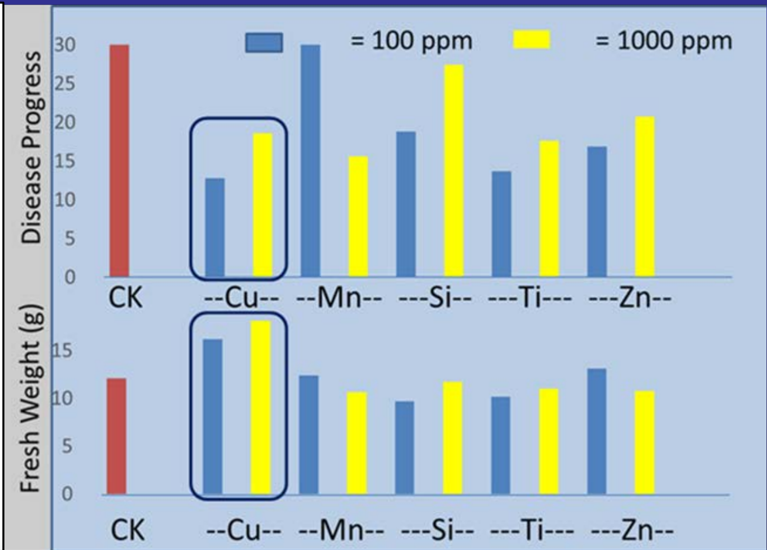

Elmer, White et al. 2017. *Plant Disease In prep.*

Root and foliar applied NP CeO_2 suppresses tomato root disease and increases biomass

A B C

A = Control Infested

B = 50 mg/kg Root application: Infested

C = 50 mg/kg Root application: Non-infested

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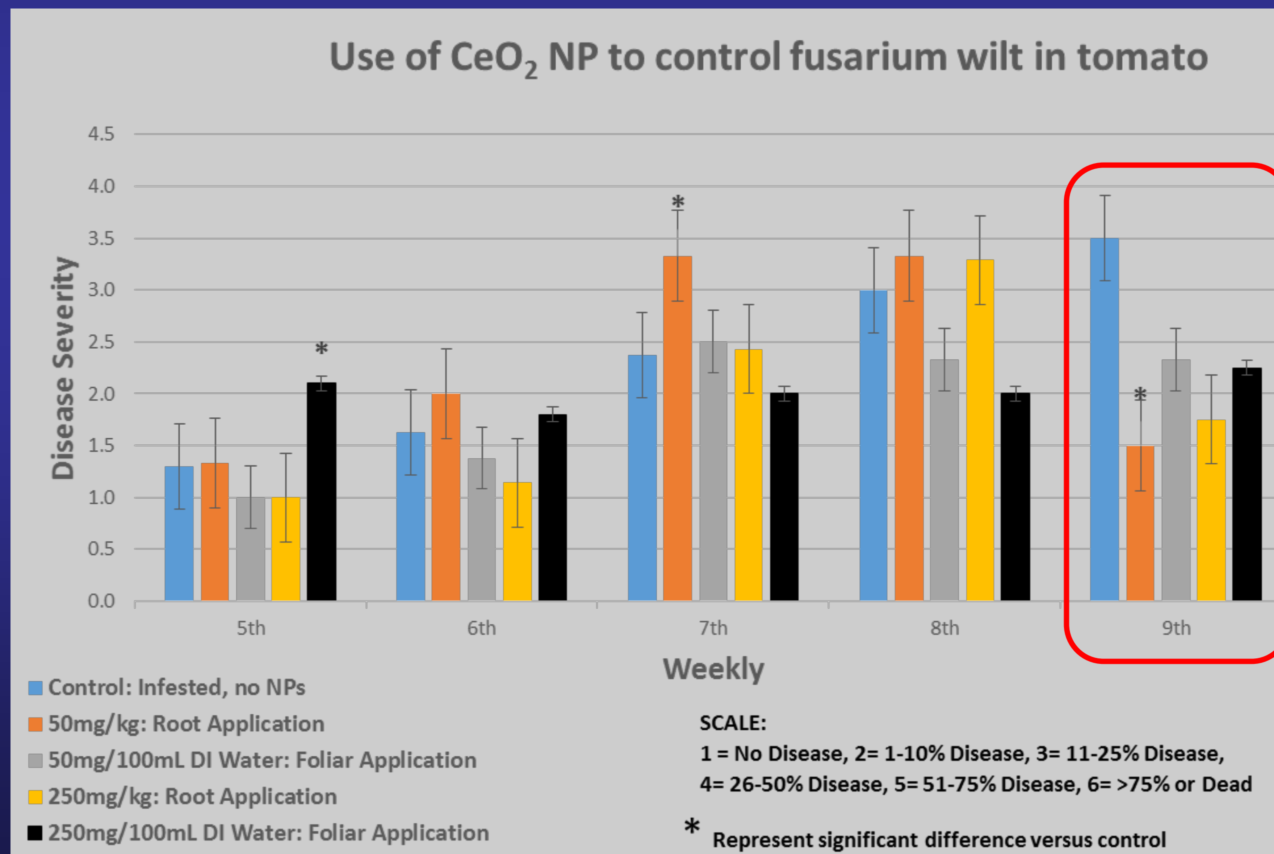
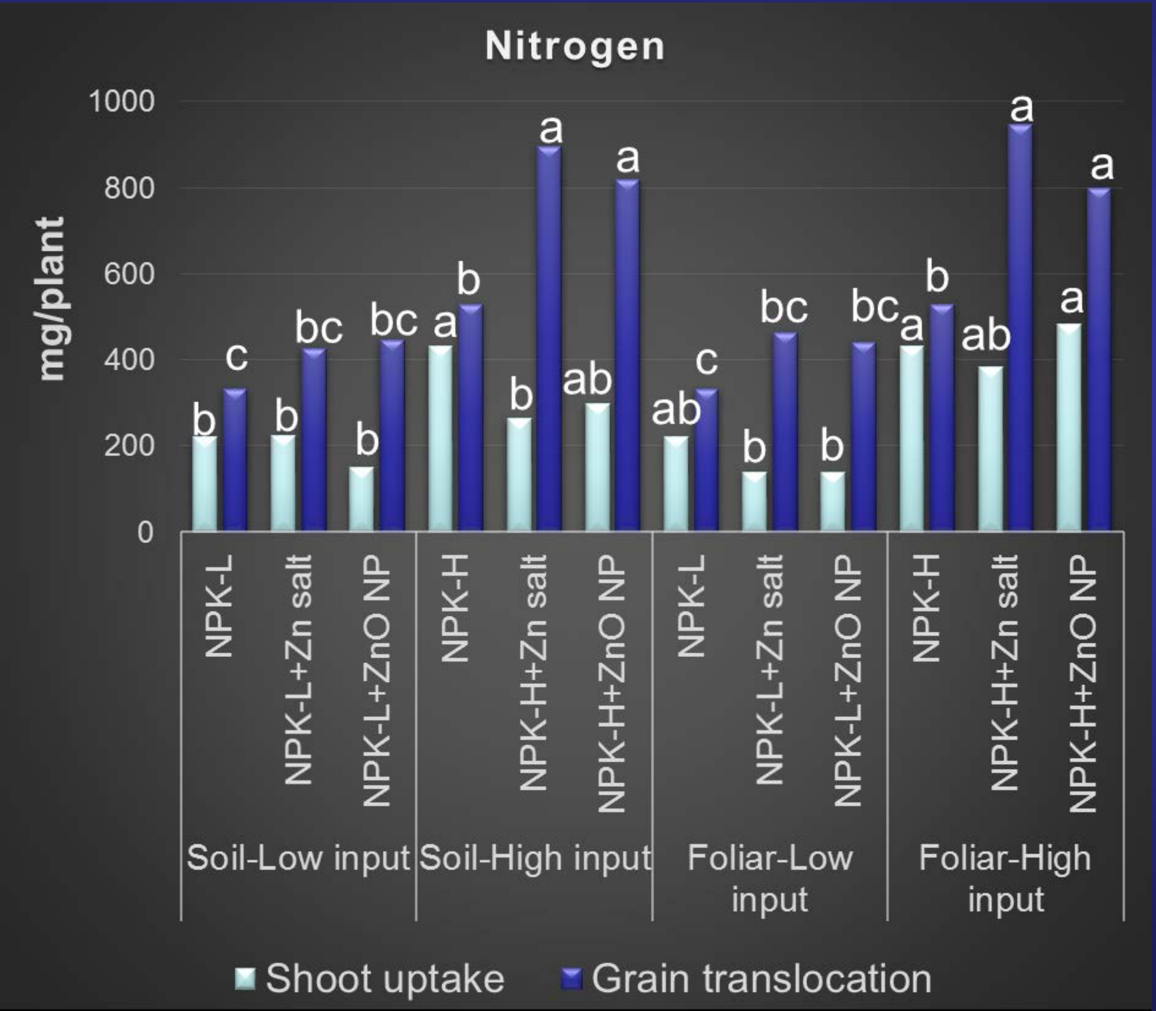


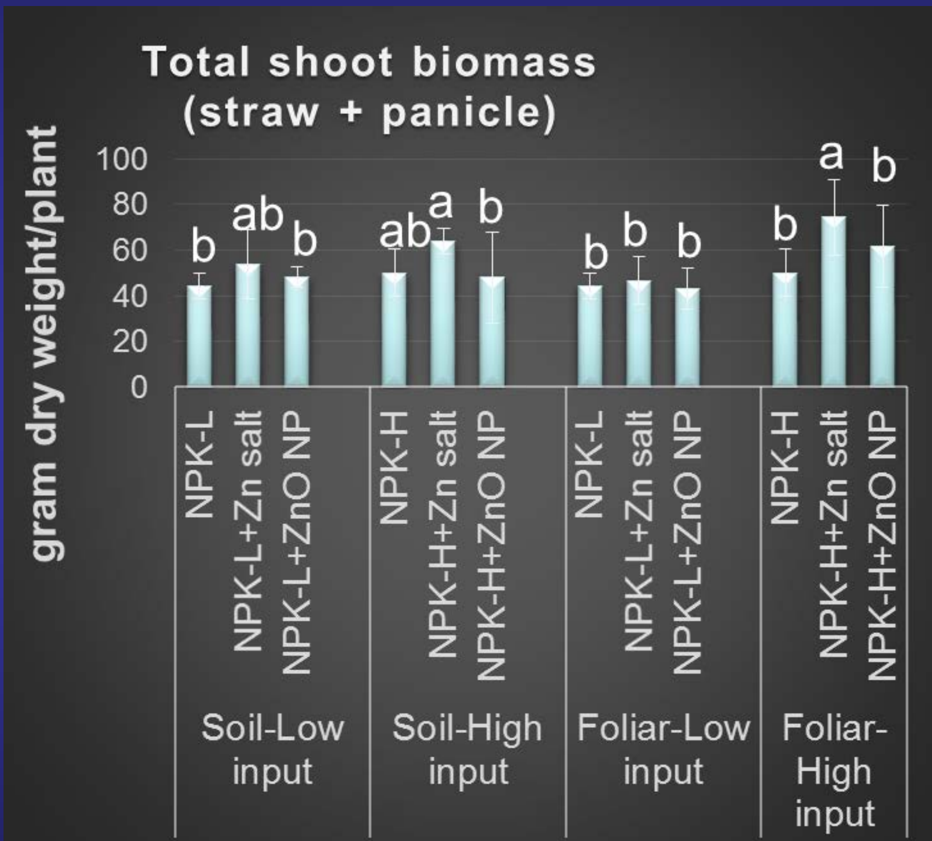
Nitrogen accumulation by Sorghum is Enhanced by Zn NP and Salts

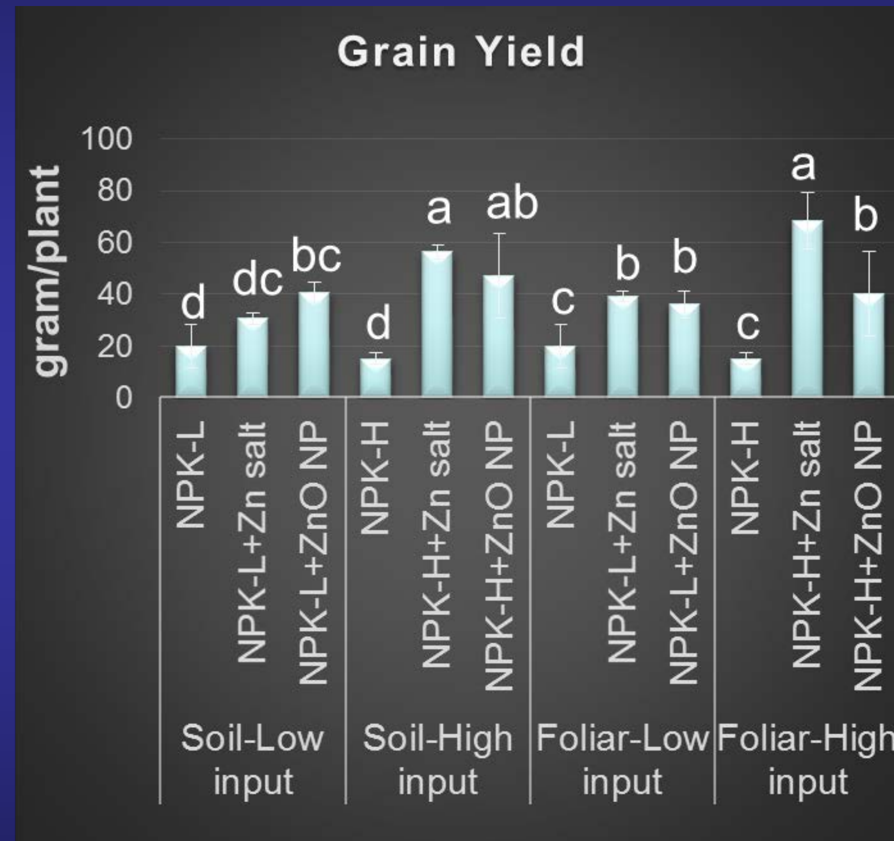


Accumulation = uptake + translocation

- 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 at high NPK more efficient with Zn salt than with NP.

Zn has Some Impact on Biomass but Consistently Stimulates Grain Yield





- Zn (salt) enhanced biomass in soil and foliar treatment at high NPK.
- Zn promoted yield; NP more effective at low NPK; salt more effective at high NPK.

Media and Next Steps

- http://www.scientia.global/dr-wade-h-elmer-improving-plant-disease-resistance-can-nanoparticles-deliver
- https://www.chemistryworld.com/news/metal-micronutrients-get-to-the-root-of-antifungal-defence/1017334.article
- http://www.ozy.com/fast-forward/could-nanotechnology-end-hunger/70771
- http://www.nhregister.com/health/20161226/connecticut-scientists-studying-nanoparticles-to-help-grow-disease-resistant-food

- **Center of Excellence**- http://www.ct.gov/caes/cwp/view.asp?a=4898&q=585400

Picture from the New Haven Register

- Field and greenhouse studies with different treatment regimes (concentrations, timing, combinations, foliar vs root) and mechanistic endpoints.
- Collaborations have started with the Center for Sustainable Nanotechnology, Washington University of St. Louis, and the University of Houston.
- These collaborators will specifically design and construct nanoscale micronutrient particles to maximize disease suppression, plant nutrition and overall crop yield.

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Conclusions and Impact

- Overcoming global food insecurity is a grand challenge.
- Current shortcomings in food production will be further stressed by a changing climate and an increasing population.

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- Inefficiencies along the farm-to-fork food chain are large (40-70%).
- Nanotechnology and precision agriculture can play a critical role here.
- Nanoscale micronutrient delivery systems for plant nutrition, disease suppression and enhanced yield appear to be inexpensive and highly effective.

Acknowledgements

- **<u>Gardea-Torresdey et al.</u>**- UTEP
- **<u>Dimkpa et al.</u>**- IFDC
- **<u>Isch</u>**- CT DPH
- **<u>Marmiroli et al.</u>**- Univ. of Parma, Italy
- **<u>At CAES</u>**- Elmer, De la Torre-Roche, Servin, Mukherjee, Zuverza-Mena, Ma, Majumdar, Pagano (Univ. of Parma), Musante, Thiel
- **<u>Jung et al.</u>**- Wuhan Univ. of Technology
- **<u>Center for Sustainable Nanotechnology</u>**
- **<u>Saleh</u>**- University of Houston
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