Nanoscale elements suppress plant disease, enhance macronutrient use efficiency, and increase crop yield

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I. Abstract: The primary goal is to use nanoscale elements as an amendment strategy to suppress crop disease, improve nutritional content, and enhance yield. Soil pathogens significantly limit agricultural production, reducing crop yield by 10-20% and resulting in billions of dollars in annual losses. This shortfall in food production will worsen with a changing climate and an increasing population. Nanotechnology can play a critical role in maximizing global food production and achieving food security. Current approaches have focused on nano-enabled conventional agrichemicals, nanosensors, and waste treatment strategies. However, little is known about the effects of nanoparticle (NP) elements on disease suppression, macronutrient uptake, and crop growth. For example, micronutrients are pivotal in disease resistance through activation of defense barrier production and by affecting the systemic acquired resistance pathway. Unfortunately, element availability in soil is limited and foliarly applied micronutrients are not translocated to roots. Although NP intra plant translocation has been reported, there is no information on whether enhanced translocation of NP elements can deter root or shoot pathogens. Based on preliminary data, our central hypothesis is that NP nutrients can be used to strategically suppress disease, improve nutritional status and enhance crop growth and yield.

II. Background- In the US, plant pathogens reduce agricultural productivity by 20%, resulting in billions of dollars of annual losses. Crop diseases caused by pathogens such as viruses, bacteria, fungi and nematodes not only decrease yield but also compromise product quality and/or shelf life. Control efforts for fungal pathogens alone exceed $600 million per year; mycotoxin contamination impacts up to 25% of food crops globally. The additional stresses from a changing climate and an expanding population will further challenge agricultural productivity. Disease management options exist for many crops but all strategies have significant shortcomings. Novel and sustainable platforms for disease management are critically needed and will be the centerpiece of any long-term strategy for maintaining or increasing agricultural productivity. Elements such as Cu, Mn, and Zn are micronutrients that play pivotal roles in plant disease resistance through enzyme activation for defense barrier production. However, low availability in soil and poor translocation after foliar application limit the success of traditional amendment strategies.

Nanotechnology can play a critical role in maximizing global food production. Due to their small size, nanoparticles (NP) possess unique properties not evident in equivalent bulk materials. Current approaches have focused on nano-enabled formulations of conventional agrichemicals, nanosensors and nano-facilitated waste treatment. Little attention has been directed at the use of NPs to suppress pathogen infection, which could increase crop yield and nutritional quality. Notably, many of the NP elements are also required micronutrients, and may provide additional nutritional benefit. This project will demonstrate the potential for nanoscale nutrient oxides to suppress root/foliar disease, increase macronutrient use efficiency, and enhance crop yield.

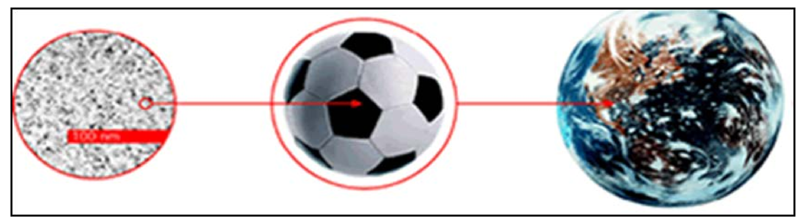


Figure 1. A NP is to a football as a football is to earth.

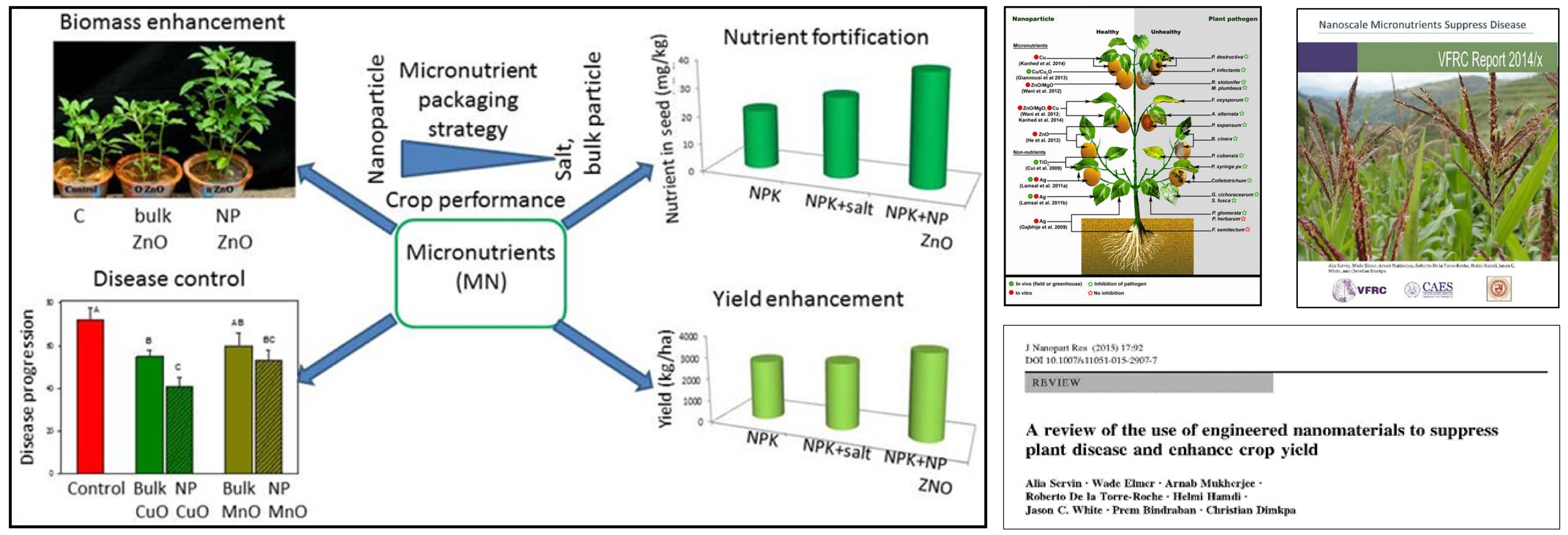


Figure 2. Conceptual representation of micronutrient use for enhancing crop productivity based on studies of crop performance indicators (biomass/yield, disease suppression, nutrient fortification) enhanced by NPs.

III. Objectives- This proposal was selected for funding in the FY2015 (start date of 3/1/16) USDA AFRI Foundational Program's Agriculture Systems and Technology Program Area; specifically: Program Area Priority Code A1511 "Nanotechnology for Agricultural and Food Systems." **Our central hypothesis is that nanoscale element oxides (CuO, MnO, ZnO, CeO_2) can be used to strategically suppress root/foliar disease, increase macronutrient use efficiency, and enhance crop yield.** This initial hypothesis is based on limited data in the literature but also on our preliminary data from our laboratories. Our four objectives are:

Obj. 1- Demonstrate NP efficacy upon foliar or root application at suppressing fungal pathogen infection in model vegetable and grain species.

Obj. 2- Determine the role of soil type and NP source in disease suppression and crop yield.

Obj. 3- Determine the impact of NP element treatment on macronutrient (NPK) utilization.

Obj. 4- Characterize NP absorption and translocation mechanisms in plant tissues by scanning/ transmission electron microscopy (S/TEM-EDS).

IV. Methods/Approach- Greenhouse and field trials will be conducted in CT, TX and AL to assess NP element efficacy for suppressing shoot or root disease for 4 crops. A determination of particle toxicity to the plants (biomass, yield) will also be made. Healthy transplants of eggplant, tomato, squash, watermelon and sorghum will be produced from seed in a greenhouse in soilless potting mix. These four crops are known to be susceptible to fungal pathogens. When seedlings are at the 2 or 4 leaf stage, plants will be removed from the potting mix and the roots will be washed free of soil prior to exposure and transplant. There will be trials with both foliar (spray) and root (drench) NP and equivalent salt exposures. Growth, disease progress and yield will be measured in all crops. At harvest, ICP-MS and electron microscopy will be used to characterize nutrient and nanoparticle content of key tissues. A range of soil types and amendment conentrations will also be included.

V. Preliminary findings- Greenhouse grown eggplants were treated with nanoscale metal oxides or their bulk equivalent and were transplanted into field soil infested with *Verticillium dahlia*. Foliar nanoscale CuO amendment significantly suppressed disease and resulted in greater Cu content in the roots of exposed plants when compared to controls and bulk treated plants. This suggests that a nanoscale-specific process of phloem based shoot-to-root translocation could activate inherent disease response pathways and enhance overall plant nutrition. Also, fruit yield upon nanoscale CuO and MnO amendment was significantly increased beyond control or bulk treated plants. In terms of economic impact, we treated an acre of eggplants with 23 g of CuO NPs at a cost of $44.00. Our results show a 43-58% increase fruit yield in comparison to control plants; a 17-31% increase over bulk CuO. If an eggplant produces 5 fruit, this equates to 17,500 fruit per acre. At market value, the $44 investment per acre for NP CuO could increase profit by $10,150 to $27,650 per acre.

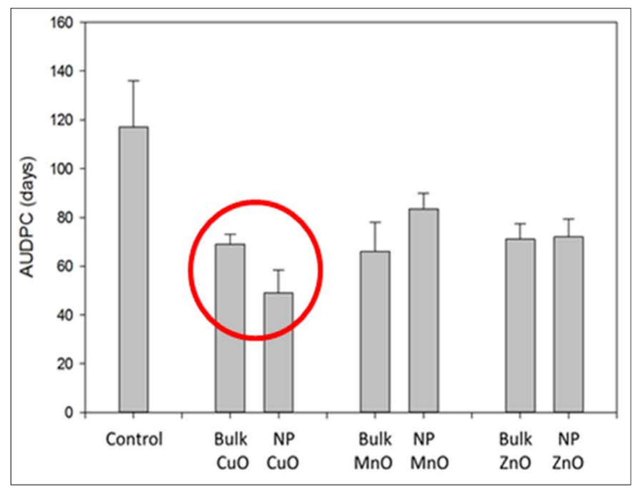
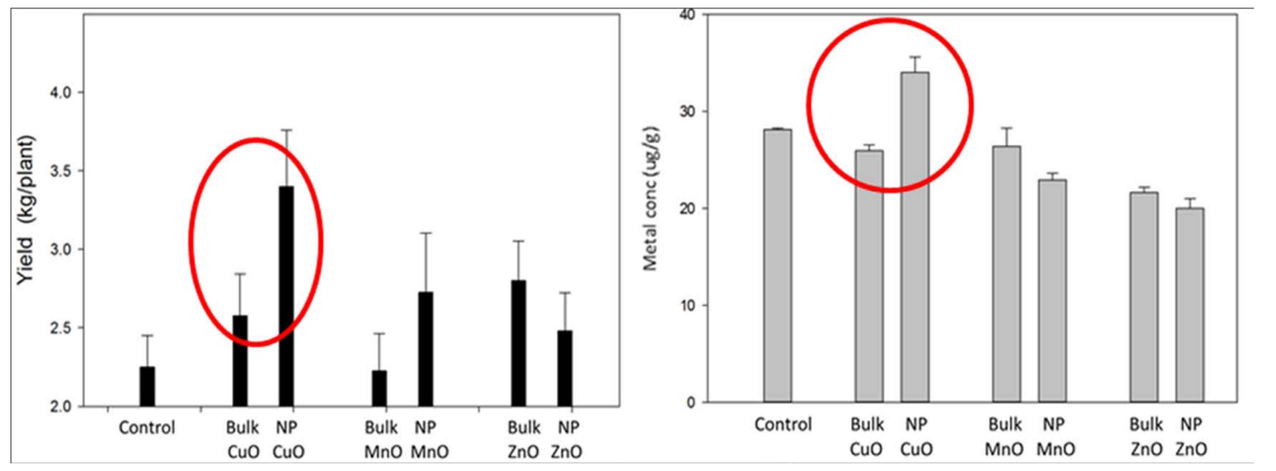


Figure 3. The Area-Under-the-Disease-Progress-Curve (AUDPC) for greenhouse grown eggplants treated with nanoscale metal oxides or their bulk equivalent and grown in soil infested with *Verticillium dahlia* (left); the metal content of the tissues (bottom right) and yield of plants (bottom left)



VI. Conclusions- Results in a paper currently under review at *Environmental Science: Nano* show that nanoscale micronutrients such as CuO can be applied foliarly to reduce root disease and increase yield. The current 3-year project will greatly expand on this work and characterize the key mechanisms of action.

We thank USDA NIFA- Program Area Code A4141 for Funding #2016-67021-24985