Nanotechnology Use in Agriculture: Benefits and Potential Risks

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Raleigh, NC Tuesday June 4, 2013

What are Nanoparticles (NPs)?

- Nanoparticles are generated *naturally* by erosion, fires, volcanoes, and marine wave action
- **A key point**- People have been exposed to nanoparticles for as long as there have been people; in other words, “nano” isn’t inherently bad
- Nanoparticles are also produced by human activities such as coal combustion, vehicle exhaust, and weathering rubber tires

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What are Engineered Nanomaterials?

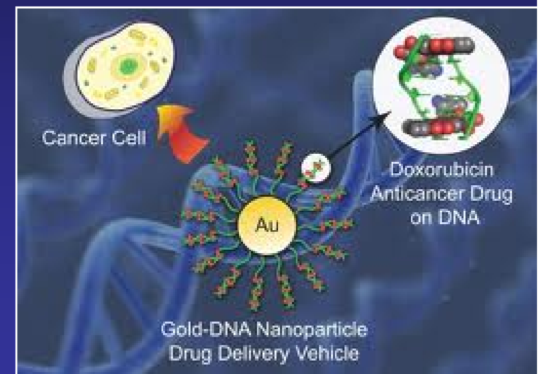
- Our ability to construct and manipulate materials at the nano-scale has increased dramatically in the last decade
- Why does this matter? Materials at the nano-scale behave *differently* than the same material at the bulk or non-nano scale
- Have higher surface area to volume; can engineer for surface reactivity or other desired characteristics
- Frequently, this unique behavior can be both useful and profitable
- Nanotechnology was a $1 billion industry in 2005; will be a $1 trillion industry in 2015

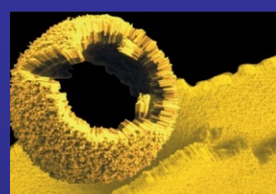
Different size gold NPs reflect different wavelengths of light

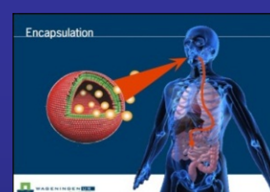
Changes in properties		
	Bulk-scale	**Nano-scale**
Si	Insulator	Conductive
Cu	Malleable and ductile	Stiff
TiO_2	White color	Colorless
Au	Chemically inert	Chemically active

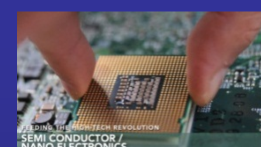
Nanotechnology-based Products- "The Good"

- As of March 2011, over 1300 commercially available products contain nanomaterials (The Project on Emerging Nanotechnologies)
- Used in medical devices, electronics, fuel cells, air filters, water treatment technologies, pharmaceuticals
- Single walled carbon nanotubes used for targeted cancer cell destruction via infrared radiation. Similar research with antibody-coated Au NPs that bind target cancer cells for laser destruction. Analogous advances for drug delivery.









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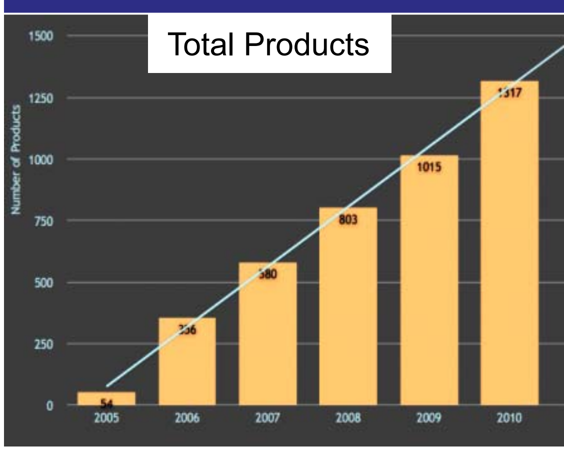

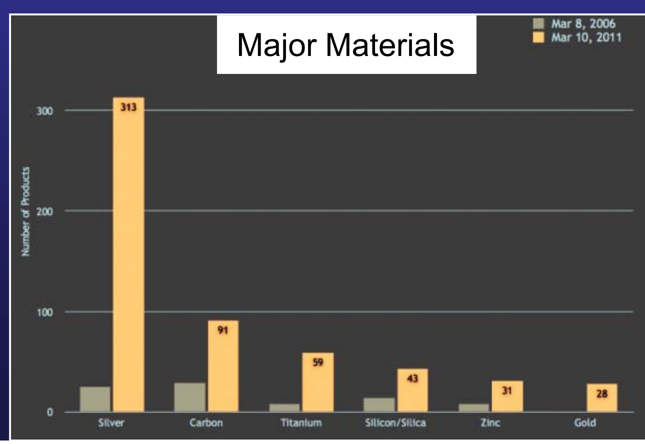

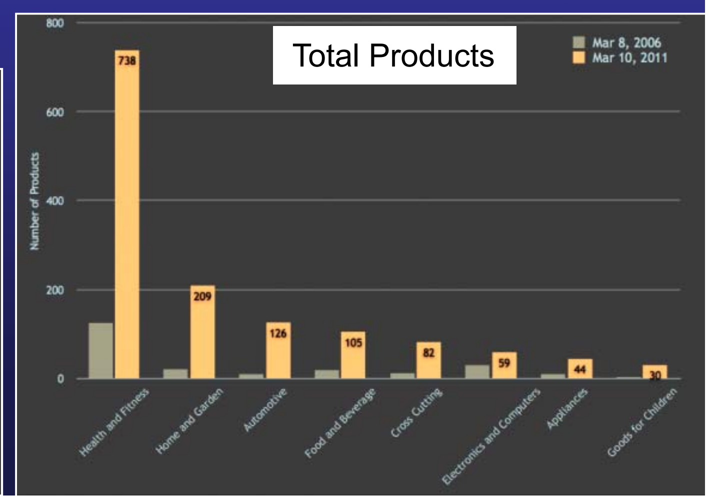

Nanomaterials and Agriculture

- 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

2012

IB IN DEPTH—Special Section on Nanobiotechnology, Part 1

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

Norman Scott[1] and Hongda Chen[2]

[1]Cornell University, Ithaca, NY
[2]USDA-National Institute of Food and Agriculture, Washington, DC

Nanotechnology has become a significant focus for federal investment in research and development (R&D). The National Nanotechnology Initiative (NNI), formed in 2001, is a crosscutting initiative now involving 26 federal departments and agencies, with 15 of these having an R&D budget for nanotechnology.[1] The National Institute for Food and Agriculture (NIFA, formerly Cooperative State Research, Education, and Extension Service) of the US Department of Agriculture (USDA), as a partner agency in the Federal NNI, sought to identify opportunities and define the potential for applying nanotechnology to revolutionize agriculture and food systems through a National Planning Workshop, Nanoscale Science and Engineering for Agriculture and Food Systems, held November 2002 in Washington DC.

The objective of the planning workshop was to develop a science roadmap (strategic plan) with recommendations for implementation of a new program in nanotechnologies in the USDA for agriculture and food systems. Planning workshop participants were leading nanotechnology researchers and administrators from Land Grant Universities and nanotechnology program leaders from other federal agencies. In developing this strategic plan, the workshop participants heard nanotechnology leaders from National Science Foundation (NSF), Department of Defense, Department of Energy, National Institutes of Health, National Aeronautics and Space Administration, Department of Commerce/National Institute of Standards and Technology, Environmental Protection Agency (EPA), Food and Drug Administration (FDA), the National Nanotechnology Coordinating Office, and the National Science and Technology Council's (NSTC) subcommittee on Nanoscale Science, Engineering, and Technology.

NIFA has identified specific science priority areas in agriculture and food systems (global food security and hunger, climate change, sustainable energy, childhood obesity, and food safety), several of which can directly benefit from research in nanotechnology. A principal recommendation from the workshop stated that USDA/NIFA should significantly enhance support for research in nanoscale science and engineering in agriculture and food systems through strong participation in the NNI goals. Areas of specific benefit to agriculture and food systems were identified: pathogen and contaminant detection; identity preservation and tracking; smart treatment delivery systems; smart systems integration for agriculture and food processing; nanodevices for molecular and cellular biology; nanoscale materials science and engineering; environmental issues and agricultural waste; and education of the public and future workforce.[2]

The National Planning Workshop participants recommended a significant financial investment in research as an enabling technology for agriculture and food systems. The recommended budget was \$36.3 million/year for fundamental research (principal investigator-driven) and in theme challenge areas, for multidisciplinary grants; establishment of several centers of excellence; support for public education/outreach; research infrastructure (specialized instrumentation); and educational support of graduate fellowships and postdoctoral education.

The USDA, through NIFA, responded to the workshop recommendations by initiating a competitive grants program under its National Research Initiative (NRI) for nanoscale science and engineering in agriculture and food systems in the 2003 Federal Budget. Since 2003 the program, with some operational interruptions in 2007, 2009, and 2012, has received 425 applications to the program (*Fig. 1*). The program has been very competitive, with 64 grants awarded for a success ratio of 15%. Some of the

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Review

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

Christian O. Dimkpa,[1] Joan E. McLean,[2] David W. Britt,[3] and Anne J. Anderson[1]

[1]Department of Biology, [2]Utah Water Research Laboratory, and [3]Department of Biological Engineering, Utah State University, Logan, UT

a deeper understanding of the complex interactions and interplay between NPs, plants, and microbes relevant to the variability of different ecosystems.

Key words: atomic force microscopy, dynamic light scattering, extracellular polymeric substances, Fourier transform infrared, reduced glutathione, oxidized glutathione, indole-3-acetic acid, indole-3-acetamide, inductively coupled plasma mass

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

- 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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Biol Trace Elem Res (2007) 119:77–88
DOI 10.1007/s12011-007-0046-4

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

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

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†,⊥

2012

Carbon Nanotubes Induce Growth Enhancement of Tobacco Cells

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

†Department of Applied Science, ‡Nanotechnology Center, §Department of System Engineering, University of Arkansas at Little Rock, Arkansas 72204, United States

J Nanopart Res (2011) 13:4519–4528
DOI 10.1007/s11051-011-0406-z

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

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*

(Received October 21, 2010. Accepted February 16, 2011)

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

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**

In memory of Professor Victor S.-Y. Lin, deceased May 4, 2010

Microbiological Research 166 (2011) 207–215
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Available online at www.sciencedirect.com
ScienceDirect
Microbiological Research
www.elsevier.de/micres

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

- Finding out the status of some of this research is difficult.
- The existing regulatory framework does not require particle-size specific data; EPA exception for NP silver in pesticides (2011)
- At SETAC Europe in May 2013, there were over 150 abstracts on nanotoxicology; only 3 were on plants (2 were mine)
- A lecture entitled "State of knowledge on nano-pesticides and implications for environmental exposure assessment in the EU"
  - Over 3000 "nano-pesticide" patents have been filed globally
  - More than 100 peer-reviewed papers (most in the last 3 years)

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EPA Proposes Policy on Nanoscale Materials in Pesticide Products

Release date: 06/09/2011

Contact Information: Dale Kemery (News Media Only) kemery.dale@epa.gov 202-564-7839 202-564-4355

WASHINGTON – The U.S. Environmental Protection Agency announced today it plans to obtain information on nanoscale materials in pesticide products. Under the requirements of the law, EPA will gather information on what nanoscale materials are present in pesticide products to determine whether the registration of a pesticide may cause unreasonable adverse effects on the environment and human health. The proposed policy will be open for public comment.

"We want to obtain timely and accurate information on what nanoscale materials may be in pesticide products, "said Steve Owens assistant administrator for EPA's Office of Chemical Safety and Pollution Prevention. "This information is needed for EPA to meet its requirement under the law to protect public health and the environment."

A number of organizations, as well as government, academic and private sector scientists, have considered whether the small size of nanoscale materials or the unique or enhanced properties of nanoscale materials may, under specific conditions, pose new or increased hazards to humans and the environment.

EPA also recognizes that nanoscale materials have a range of potentially beneficial public and commercial applications, including pest control products. The agency will continue to encourage responsible and innovative development of products containing nanoscale materials to realize these benefits while also addressing health or environmental concerns.

The new proposed policy options will be published in the Federal Register shortly. The notice will also propose a new approach for how EPA will determine whether a nanoscale ingredient is a "new" active or inert ingredient for purposes of scientific evaluation under the pesticide laws, when an identical, non-nanoscale form of the nanoscale ingredient is already registered under FIFRA. This approach will help ensure that EPA is informed about the presence of nanoscale ingredients in pesticide products and allows a more thorough review of the potential risks.

Comments on the Federal Register notice will be accepted until 30 days after publication. The notice will be available at www.regulations.gov in docket number EPA–HQ–OPP–2010-0197.

More information or to read the proposed notice:
http://www.epa.gov/pesticides/regulating/nanotechnology.html

Nanotechnology Products- “The Questionable?”

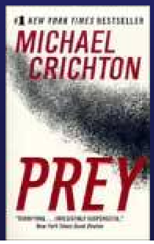
Table 2: Nanomaterials in food packaging

Product name	Manufacturer	Nano content	Claim	Web address or reference
Durethan® KU 2-2601	Bayer	Silica in a polymer-based nanocomposite	Nanoparticles of silica in the plastic prevent the penetration of oxygen and gas of the wrapping, extending the product’s shelf life.	http://www.research.bayer.com/edition_15/15_polyamides.pdfx
Hite Brewery beers: three-layer, 1.6L beer bottle	Honeywell	Honeywell’s Aegis OX nylon-based nano composite	• Oxygen and Carbon Dioxide Barrier • Clarity • Recyclability • Ease of Preform • Processability • Flavor/Odor/Aroma Barrier • Structural Integrity • Delamination Resistance • Aegis® barrier nylon resins can be found in a multitude of applications globally.	http://www.packaging-gateway.com/features/feature79/ http://www51.honeywell.com/sm/aegis/
Miller Beers: **• Lite** **• Genuine Draft** **• Ice House**	Nanocor	Imperm nylon/nano-composite barrier technology produced by Nanocor	Imperm is a plastic imbued with clay nano-particles that make bottles less likely to shatter and increases shelf life to up to six-month	http://www.nanocor.com/applications.asp http://www.forbes.com/investmentnewsletters/2005/08/09/nanotechnology-kraft-hershey-cz_jw_0810soapbox_inl.html?partner=rss
Nano Plastic Wrap	SongSing nanotechnology	Nano zinc light catalyst	Antibacterial, anti-uv, temperature resistant, fire proof	http://www.ssnano.net/ehtml/detail1.php?productid=73
Cadbury Schweppes: **• Cadbury® Dairy Milk™ Milk Tray™** **• Cadbury® Eden chocolate boxes** **• Shelf-ready packaging for the Cadbury® Fun Filled Freddo**	Plantic Technologies	Thermoformed Plantic® R1 trays (nano-composite biopolymer)	• Biodegradable after use • Compostable to European standards EN13432 • Made from renewable and sustainable resources (non-GM corn starch) • water dispersible, won’t pollute local groundwater systems or waterways • In use since 2002.	http://www.plantic.com.au/docs/Plantic_Cadbury_CS.pdf

- NMs are also used in pesticides, fertilizers, food packaging, cosmetics, and toys
- Are the risks of nanotechnology fully appreciated?
- Current regulatory guidelines assume a nanoparticle is toxicologically equivalent to the corresponding bulk material

- A valid assumption? If a substance at the nano-scale behaves chemically and physically different, what about biologically/toxicologically?

- Concerns have been raised from the beginning that the same attributes of NPs that make them useful, may lead to novel risks to human health and the environment. Those concerns are now becoming more mainstream.



Nanotoxicology and Agriculture

- Data on NM toxicity to plants is not abundant. Most early studies (2007-2010) looked only at NPs with no bulk material/ion comparison.
  - This is a key point. It is somewhat 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 nanomaterials 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 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.

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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 they “behave” differently?
- USDA NIFA Grant 1- 3/15/11 “Addressing Critical and Emerging Food Safety Issues.” A 5-year $1.5 million grant entitled “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

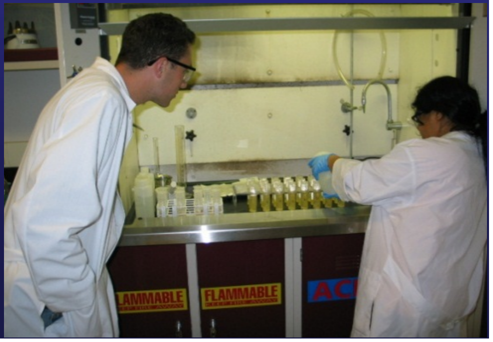
USDA
National Institute of Food and Agriculture

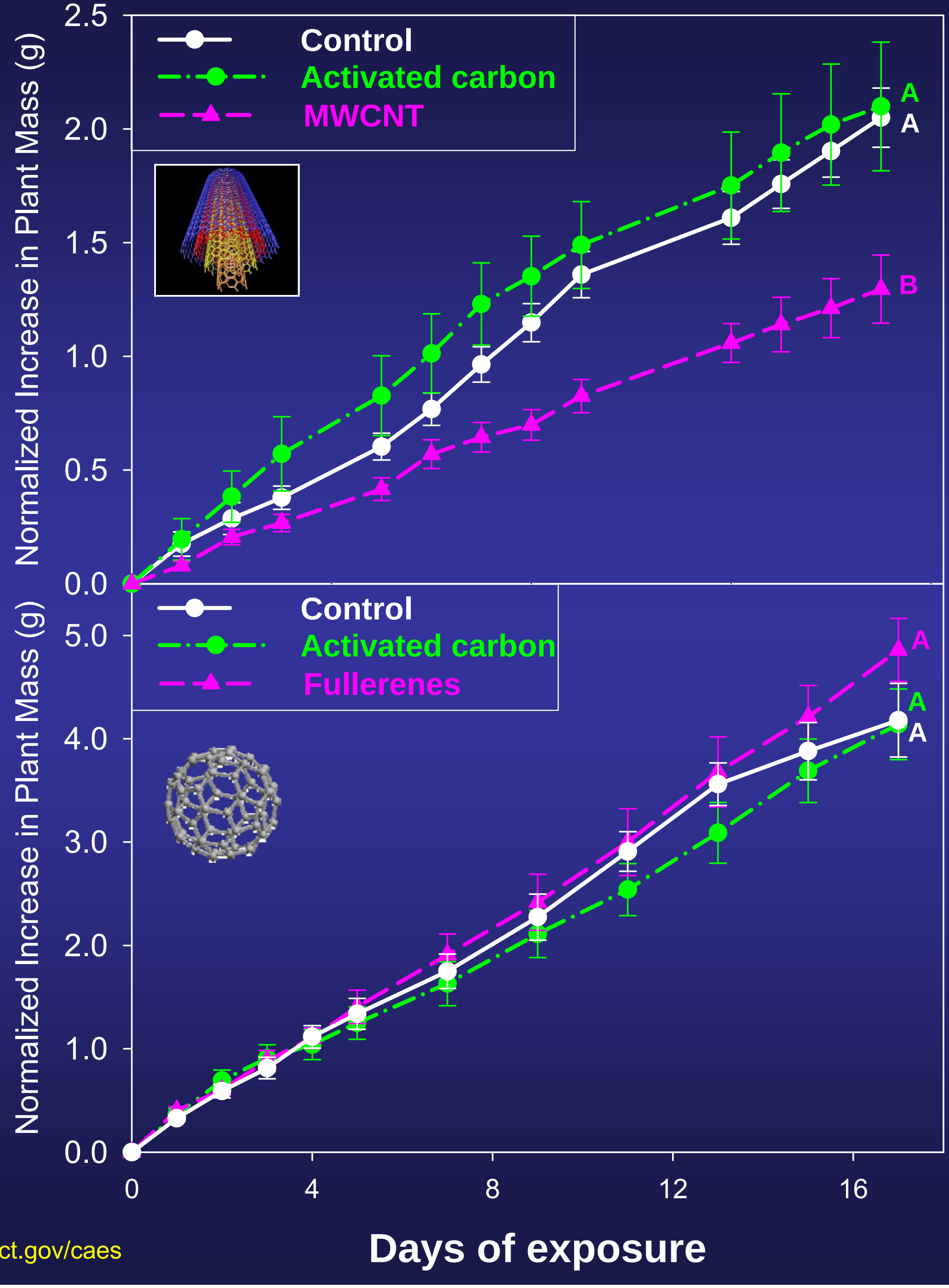
Southern Illinois University Carbondale

ESF
State University of New York College of Environmental Science and Forestry

Objective 1- Determine the uptake, translocation, and toxicity of NM to crops

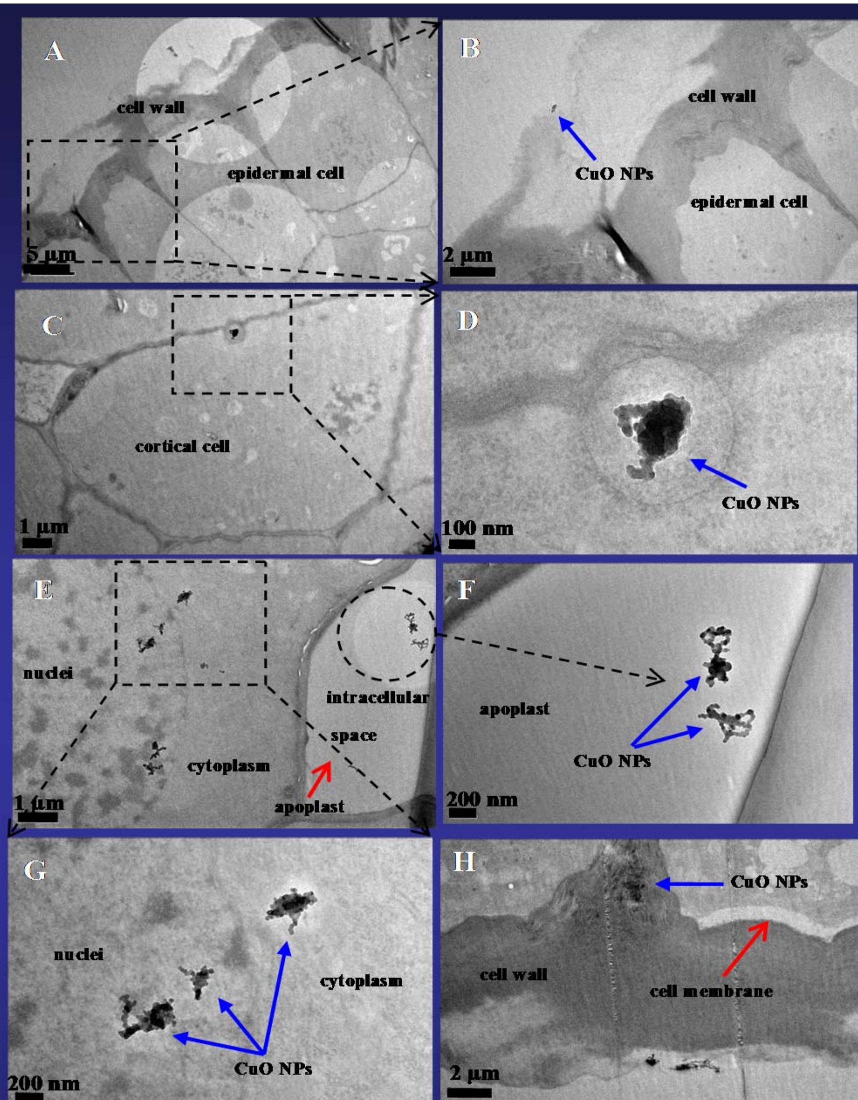
- 12 plant species- corn, soybean, wheat, alfalfa, rye, rice, pea, bean, zucchini, spinach, lettuce, tomato
- 12 particles- S/MW CNTs, fullerenes, Ag, CuO, Si, ZnO, Au, TiO_2, CeO_2, SiO_2, Al_2O_3
- Batch hydroponic screen with 10 day exposure to 0, 50, or 500 mg/L bulk, ion, and NP/NM. Measure biomass, transpiration, particle content. Select assays on others.
- 12 plants have been exposed to Ag; 11 to CeO_2; 11 to CuO; 6 to TiO_2; 4 to ZnO; 4 to MWCNT or C_{60} fullerenes; 3 to Al_2O_3; 3 to SiO_2
- Toxicity and accumulation potential are species-, particle-type-, and concentration-specific. **Most importantly, lots of particle size-specific toxicity/accumulation**.
- Not the most exciting of experiments to run but critical to isolating sensitive plant-nanoparticle combinations for more detailed study. Thorough evaluation of the screen will only be possible when full data set is available.





Effect of activated carbon, MWCNTs (top) or Fullerenes (bottom) on zucchini biomass under hydroponic conditions. All present at 1000 mg/L.

Stampoulis et al. 2009. *Environ. Sci. Technol.* 43:9473-9479.



TEM-EDX of corn roots and stems exposed to NP and bulk CuO

Root epidermal cell walls entrapped CuO NPs (A, B) and translocation of CuO NPs across epidermal cell walls (H).

Magnified view (B) of the square in (A). CuO NPs near the interface between the plant cell wall and the plasma membrane (H).

Endocytosis-like structure in the cells (C,D). CuO NPs in cell and intracellular space of cortical cells (E-G). Magnified views (F,G) of the circled region and squared region in (E).

Energy-dispersive spectroscopy (EDS) spectra of dark regions confirm Cu.

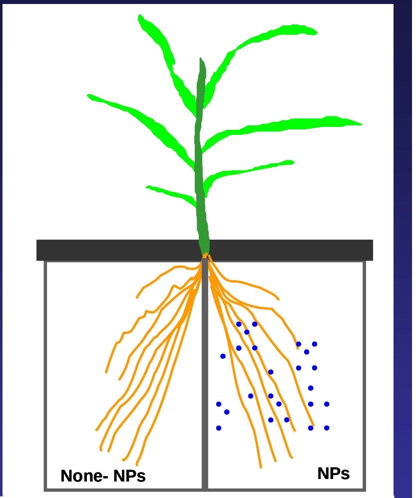
Wang et al. 2012. *Environ. Sci. Technol.* 46:4434-4441.

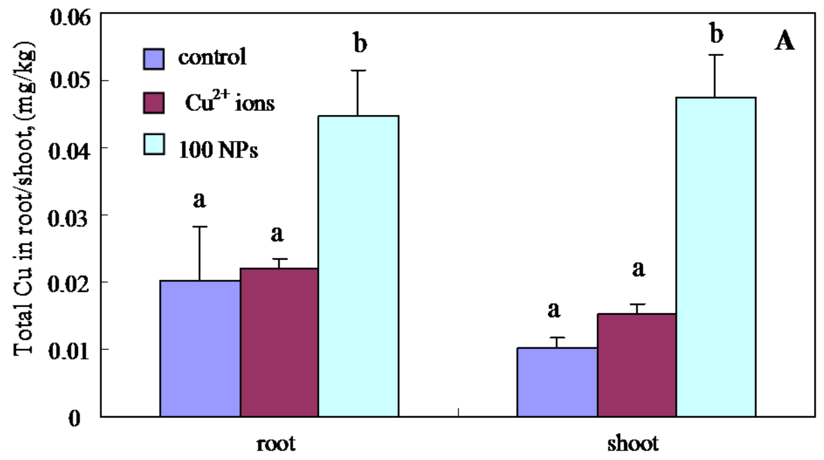
	control	Cu^{2+} ions	10 NPs	100 NPs	100 BPs
Length/cm	818 ± 158 b	806 ± 133 b	291 ± 24.2 a	121 ± 8.2 a	970 ± 45.0 b
SurfArea/cm^2	103 ± 16.9 b	91.5 ± 18.6 b	39.6 ± 6.4 a	23.5 ± 4.7 a	99.6 ± 10.9 b
AvgDiam/mm	0.36 ± 0.04 ab	0.37 ± 0.01 ab	0.45 ± 0.04 b	0.62 ± 0.10 c	0.34 ± 0.02 a
Tips/No	2271±50e	1314±246c	618±11b	211±7a	1817±178d

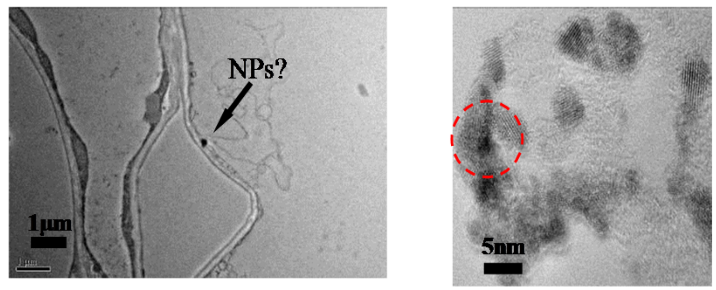
Effects of 0-100 mg L^{-1} CuO NPs, 0.15 mg L^{-1} Cu^{2+} ions and 100 mg L^{-1} CuO BPs on root morphology after 15 days exposure.

Split-root experiments with maize seedlings exposed to NP CuO or ions

- CuO NPs present in shoots
- Presence of CuO NPs in non-exposed roots suggests phloem transport from shoot to root
- During phloem transport to roots, CuO reduction to Cu_2O and Cu_2S is evident by interplanar crystal spacing as calculated by fast Fourier transformation (FFT)



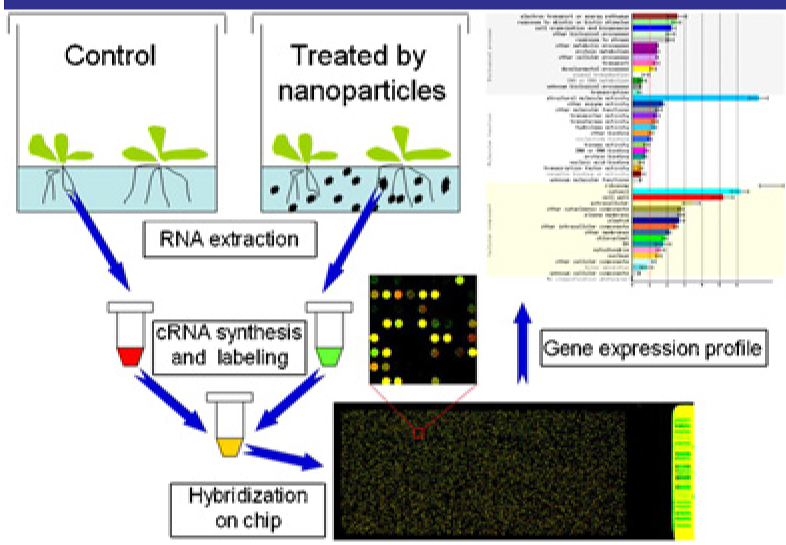




Wang et al. 2012. *Environ. Sci. Technol.* 46:4434-4441.

Collaborative experiments with the Institute of Experimental Botany, Czech Republic

- Focus is on changes in *Arabidopsis thaliana* gene expression after exposure metal oxide NPs and fullerene soot
- Specifically, microarrays were used to study the effect of 7-day exposure to 100 mg/L ZnO, TiO_2, or Fullerenes (FS) NPs on gene expression in *A. thaliana* roots
- Subsequent up/down regulated gene expression monitored; functionality mapped



Landa et al., 2012 *J. Hazard. Mat.* 241/242:55-62

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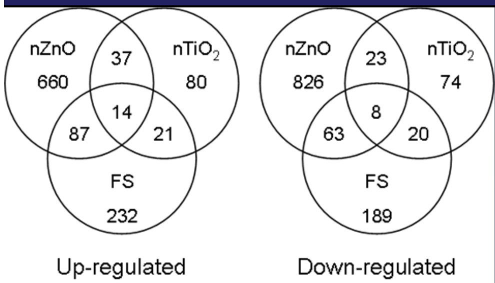
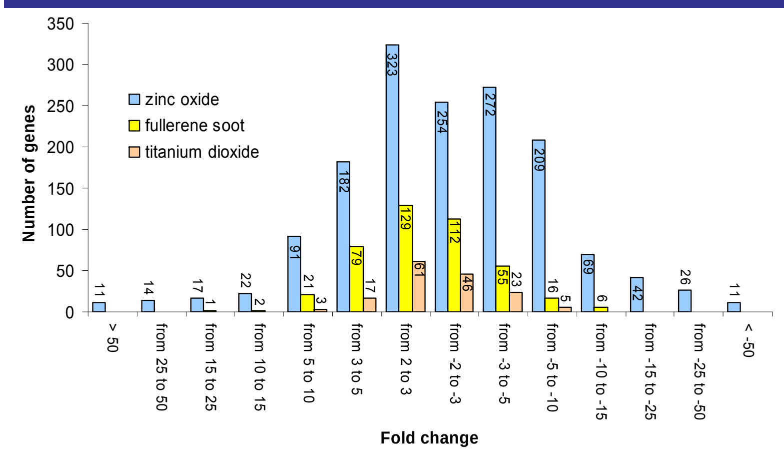
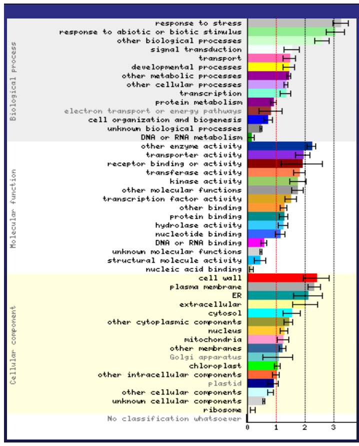
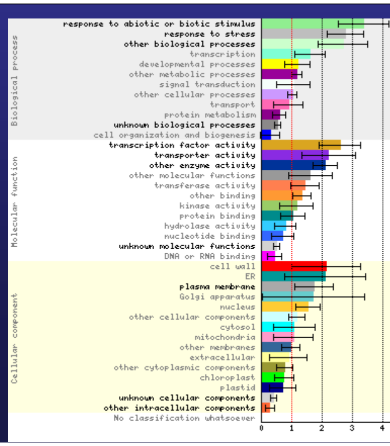
Total numbers of up/down regulated genes, the fold change in expression, and functionality



Landa et al., *J. Hazard. Mat.* 2012, 241/242:55-62







- ZnO NPs induced most change in gene expression
- Changes in gene expression upon TiO2 exposure were mild
- Some overlap but clear particle-specific changes in gene expression is evident
- Relatively more stress responsive genes induced for ZnO NPs and fullerene soot
- Relevance of these findings to agricultural crops is unknown

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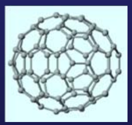
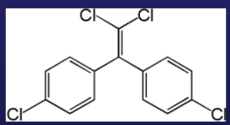
Obj. 4: Nanomaterial interactions with co-existing organic chemicals

- Nanomaterials may represent a novel class of contaminants entering agricultural systems directly (pesticide/fertilizers) or indirectly (biosolids)
- Agricultural systems contain a number of other organic chemicals
- Interactions between nanomaterials and these co-existing contaminants/ chemicals are unknown
  - Could bioavailability of legacy pesticides be affected? A food safety issue?
  - Could efficacy of intentional pesticides be affected? An economic issue?
- Several sets of experiments to date
  - Impact of C_{60} fullerenes and Ag on DDE accumulation by crops in a model system (vermiculite)
  - Impact of C_{60} fullerenes on weathered DDE/chlordane accumulation from soil by crop and worm species

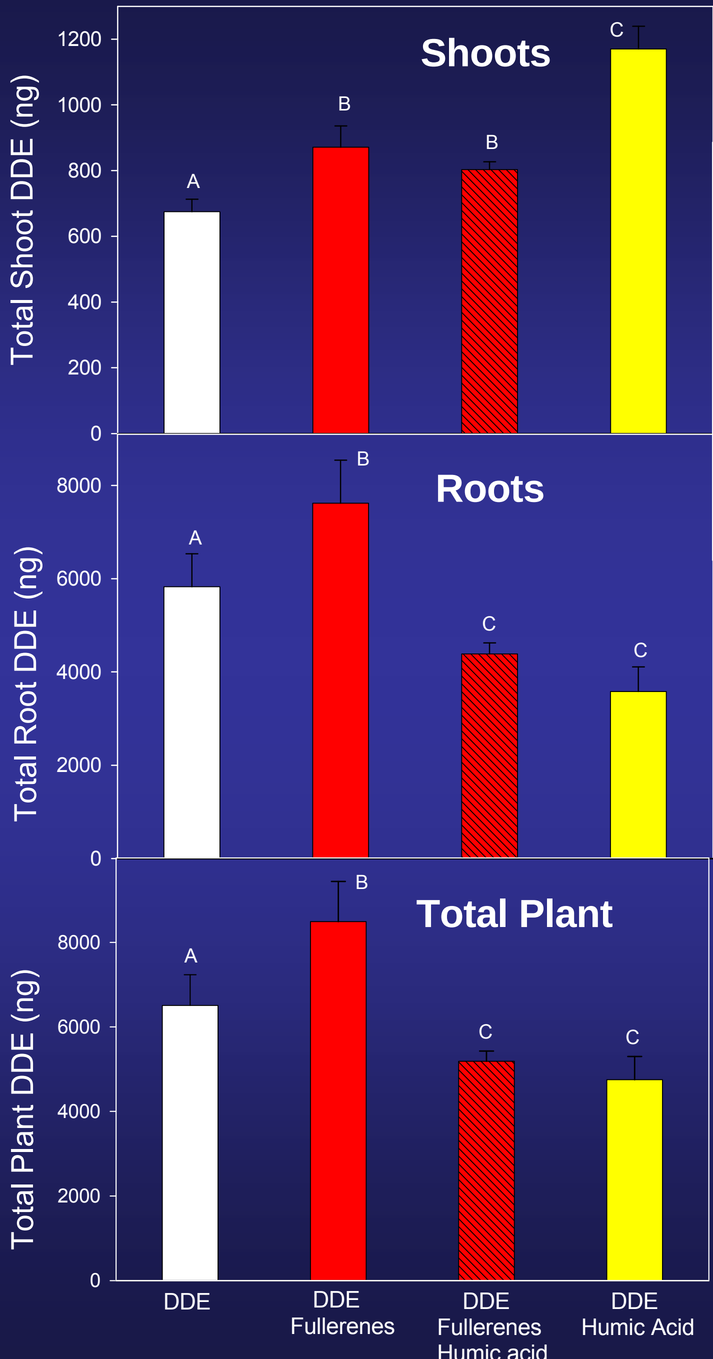


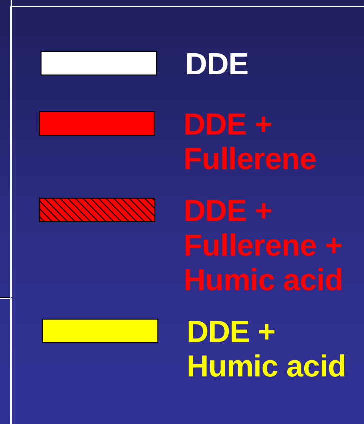


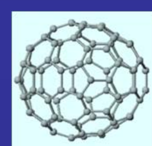
Obj. 4: Quantify the facilitated uptake of pesticides through NM-chemical interactions

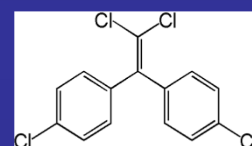
- Initial experiment using zucchini, tomato, and soybean grown in C_{60}-amended vermiculite
- Watered with DDE-containing solution (100 ng/mL)
- Measuring DDE root and shoot (GC-ECD or GC-MS) content upon co-exposure with C_{60} fullerenes
- LC-UV and LC-MS/MS method for fullerene detection in plants

Zucchini









De La Torre Roche et al. 2012.
Environ. Sci. Technol.
46, 9315−9323

Quantify the facilitated uptake of pesticides through NM-chemical interactions

- Zucchini shoot, root, and total plant content of DDE
- Fullerenes enhance DDE accumulation in both roots and shoots.
- Suggests interaction between DDE-fullerenes
- Fullerenes clearly present in and on roots; shoots?

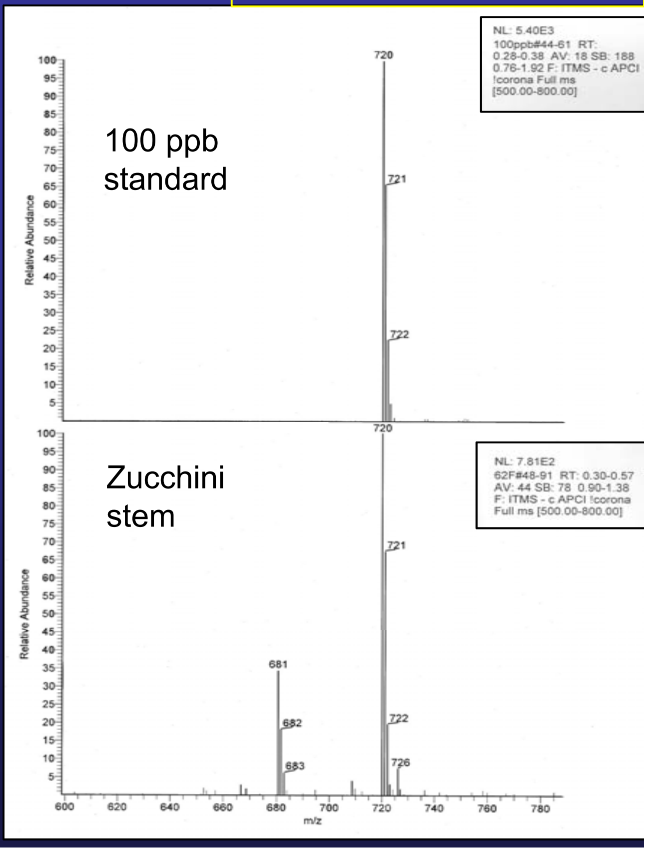
Membrane damage and fullerene uptake

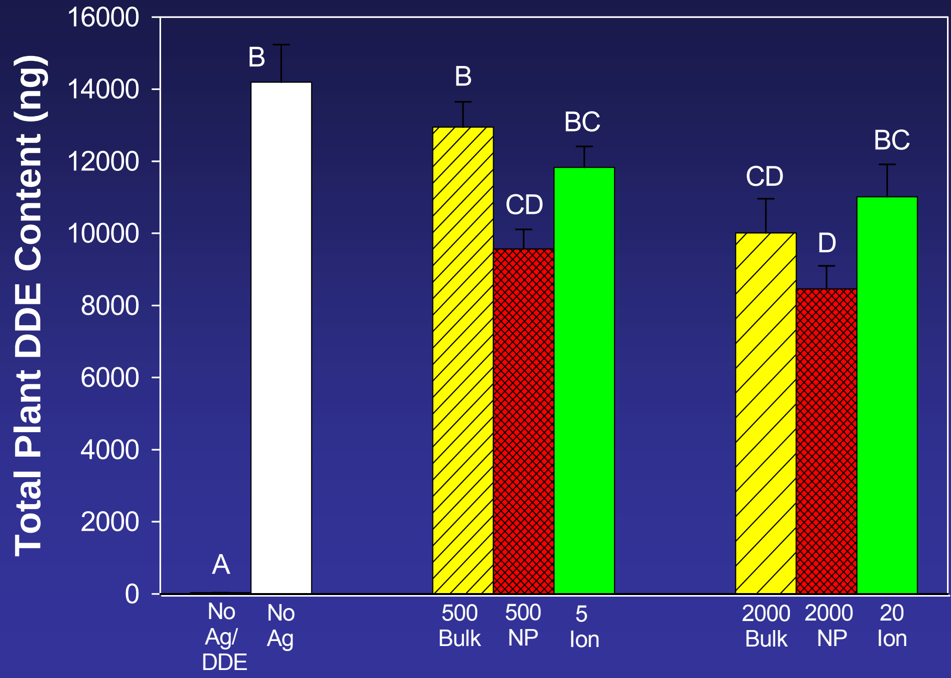
- Soybean and tomato had significantly greater MDA formation (lipid peroxidation) upon DDE and/or C_{60} exposure
- Zucchini had 60-4400 ppb C_{60} in over half the stem samples

De La Torre Roche et al. 2012. *Environ. Sci. Technol.* 46, 9315−9323

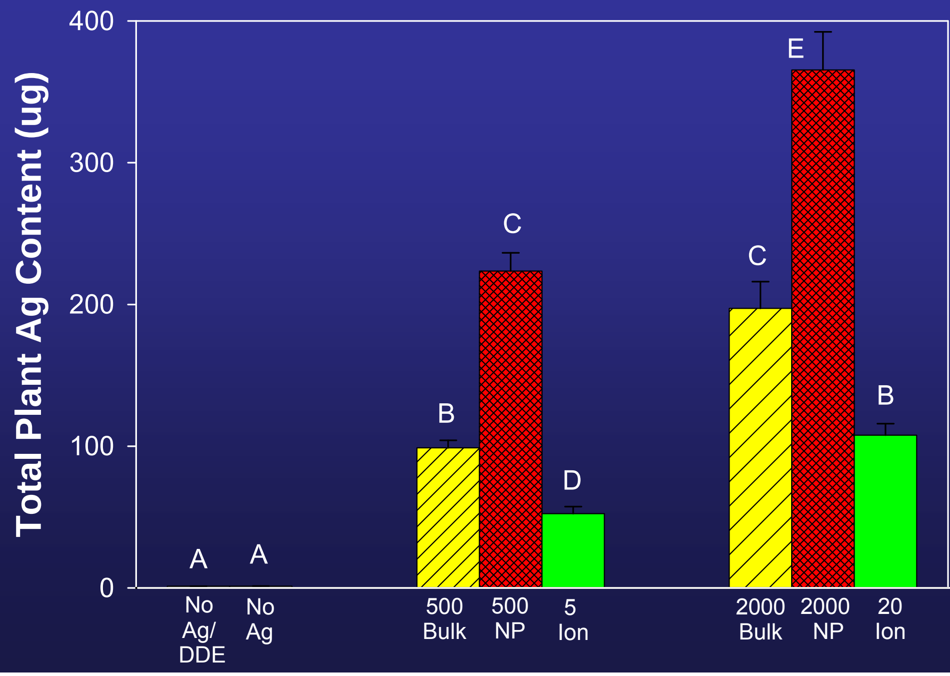
Concentration of malondialdehyde (μM MDA) produced by plant root and shoots upon exposure to DDE and C_{60} by the TBARS method. MDA is produced during the degradation of fatty acids

Plant	Control	DDE	C60	DDE + C60
Tomato				
Shoot	0.123 A	0.175 B	0.134 A	0.182 B
Root	0.132 A	0.139 A	0.170 B	0.168 B
Soybean				
Shoot	0.451 A	0.590 B	0.684 B	0.462 A
Root	0.489 A	0.755 B	0.924 B	0.674 AB
Zucchini				
Shoot	0.190 A	0.183 A	0.166 A	0.188 A
Root	1.03 A	0.909 A	0.956 A	1.19 A





- Soybean DDE Content in the presence of 500-2000 mg/L bulk or nanoparticle Ag. Ionic Ag was present at 5 and 20 mg/L.



- Soybean Ag Content in the presence of 100 ng/mL DDE

De La Torre Roche et al. 2013. *Environ. Sci. Technol.* 718–725

CAES Nanotoxicology Program

- USDA NIFA Grant 2- 3/1/12 "Nanotechnology for Agricultural and Food Systems." A 3-year $473,000 grant "Nanoscale Interactions between Engineered Nanomaterials and Black Carbon (Biochar) in Soil
  - **Obj. 1**: To quantify and mechanistically model the binding of NMs to biochar
  - **Obj. 2**: To determine the impact of biochar nanostructure and weathering on the effects of engineered nanomaterials on crop and earthworm species.

- Formal/informal collaborations with the National Institute of Standards and Technology (NIST), University of Texas El-Paso (UTEP), Institute of Experimental Botany (Czech Republic), University of Parma (Italy), Hasselt University (Belgium), and the Ocean University of China

Conclusions

- Nanotechnology clearly has the potential to dramatically impact and improve agriculture
- However, the current degree of understanding of nanomaterial fate and effects in agricultural systems is poor
- It is possible that engineered nanomaterials may represent an emerging class of contaminants
- Exposure on agricultural crops may occur directly through NM-containing pesticide/fertilizer formulations, as well as spills, or indirectly through the application of NM-containing biosolids
- Lots of particle size-specific toxicity; not really supposed to happen
- Very little known in the area of co-contaminant interactions but it appears that some nanoparticles may significantly alter co-contaminant fate.
- Soil may minimize many of these co-contaminant interactions; more work currently being done here.

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- **Wang et al**- Ocean University of China
- **J. W. Kelsey**- Muhlenberg College
- **T. Vanek**- Czech Republic
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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”