CSIRO PUBLISHING

RESEARCH FRONT

Environ. Chem. **2019**, *16*, 375–376
https://doi.org/10.1071/ENv16n6_FO

Foreword

Foreword to the Research Front on 'Nanotechnology and Agriculture'

Jason C. White[A] *and Jason M. Unrine*[B,C]

[A]Connecticut Agricultural Experiment Station, Department of Analytical Chemistry, New Haven, CT 06511, USA.
[B]University of Kentucky, Department of Plant and Soil Sciences, Lexington, KY 40546, USA.
[C]Corresponding author. Email: Jason.Unrine@uky.edu

Food production must increase dramatically, while food (and other) waste must substantially decrease to meet the needs of a growing world population, which is expected to approach 10 billion by 2050 (McCouch et al. 2013). These needs have to be met despite a rapidly changing climate and increasingly unpredictable weather, as well as limited supplies of water, energy and arable land. Convergent technologies are being developed to increase agricultural efficiency and reduce environmental impacts and waste, including advances in robotics, sensing, genomic technologies, synthetic biology and enhanced-efficiency fertilisers and pesticides. Several of these technologies involve the use of engineered nanomaterials, and nanotechnology is considered to be a key component to resolving the food–water–energy nexus (Rodrigues et al. 2017). While research into the potential applications of nanotechnology and nanomaterials has been increasing for some time, considerably less effort has been directed towards the fate, transport and adverse effects of nanomaterials in the environment. At the same time, there is potential for nanomaterials to reduce the negative environmental impacts of agriculture. This Research Front brings together recent advances in our understanding of the environmental behaviour of nanomaterials, both from an agricultural applications perspective and that of environmental protection.

The direct use of nanomaterials as foliar-applied fungicides and fertilisers is one of the applications described in this Research Front (Kah et al. 2019; Li et al. 2019; Nath et al. 2019; Read et al. 2019). Enhancing the adhesion of agrochemicals using engineered nanomaterials not only increases their efficacy, but it could also reduce their environmental impact by reducing their presence in soil and runoff. Kah et al. (2019) investigated the rain-fastness of different nanoformulations of copper that are widely used as fungicides in citrus plants. The authors reported that particle size strongly affected attachment to leaf surfaces, but that other factors, such as solubility and morphology, also played a role. Li et al. (2019) investigated the trophic transfer of copper hydroxide materials in a plant–insect system and found that the rate of transfer along the food chain could be accurately predicted from particle solubility. Neves et al. (2019) found that the formulation of copper-based nanofungicides greatly influenced their toxicity to the soil invertebrate *Folsomia candida*, and that there was an interaction between the formulation and soil properties, such as pH and organic-matter content.

The use of nanocarriers for delivering conventional pesticides was investigated by Fojtová et al. (2019). Nanoscale particles of chlorpyrifos and tebuconazole as active ingredients were embedded in either lipid-based or polymeric nanocarriers. The authors found that the nanocarriers significantly influenced the bioavailability of the cargo, but that the interactions were complex and difficult to generalise.

Nanomaterials are also being actively investigated for use as targeted fertilisers. Zinc deficiency is a major human health issue from the perspectives of both crop yield and human nutrition. Read et al. (2019) compare tools (inductively coupled plasma mass spectrometry, radio-tracing and synchrotron-based X-ray spectroscopy) for investigating the foliar uptake and in-planta distribution of Zn after foliar application of Zn nanomaterials. Because Zn is physiologically regulated at high concentrations in tissues, they found that radio-tracing was a promising technique to be used in the development of enhanced efficiency of Zn nanofertilisers. Nath et al. (2019) also used isotopic tracing to investigate the uptake of nanomaterials from a toxicological perspective; the authors used stable-isotope techniques, focusing on soil and hydroponic exposures, to investigate Ag, Cu and ZnO nanomaterial uptake and translocation. While uptake from hydroponic exposure was much higher than that from soil, they found that the presence of plants enhanced the dissolution of Ag nanomaterials in hydroponic exposures, presumably owing to root exudation by the plants.

Some nanomaterials are unintentionally introduced to agroecosystems, such as through the land application of sewage sludge biosolids. Biosolids are expected to contain significant quantities of engineered nanomaterials, including carbonaceous nanomaterials such as carbon black, graphenes and fullerenes. Wang et al. (2019) found that there were combined effects of exposure to these three types of carbonaceous nanomaterials, biotic and abiotic stressors (insect and heat stress) in soybean. The overall effects of the different stressors, however, were additive in nature and had different endpoints.

Innovative applications of nanotechnology within agriculture are reported. For example, Liu et al. (2019) review applications of nanomaterials for augmenting photosynthesis in plants. Phenrat et al. (2019) describe how magnetic iron oxide nanomaterials can be used for removing Cd from contaminated rice-paddy soil. Gillispie et al. (2019) give an overview of the use of iron and manganese oxides in agriculture both for sequestering contaminants and for use as micronutrient fertilisers.

This Research Front highlights a wide diversity of applications and implications of nanomaterials in agriculture, as well as research approaches and tools. The overarching aim is to encourage environmental chemists, ecotoxicologists and health scientists to work together to develop tools to predict the environmental fate and impacts of nanomaterials in agroecosystems. The Research Front shows that information gained during technology development can inform environmental safety assessment and vice versa. For example, understanding how nanomaterial properties affect foliar adhesion in plants informs not only material efficacy, but trophic transfer, and soil runoff and leaching. Similarly, tools for tracking nanomaterials in organisms, such as isotopic tracking techniques, are critical for developing efficacious materials, but they are also critical for understanding their fate in ecosystems and organisms. Facilitating this reciprocal exchange of knowledge and techniques will be critical as nanotechnology becomes a key component of agricultural sustainability solutions.

Jason C. White and Jason M. Unrine
Guest Editor and Editor
Environmental Chemistry

Conflicts of interest

The authors declare no conflicts of interest.

References

Fojtová D, Vašícková J, Grillo R, Bílková Z, Šimek Z, Neuwirthová N, Kah M, Hofman J (2019). Nanoformulations can significantly affect pesticide degradation and uptake by earthworms and plants. *Environmental Chemistry* **16**, 470–481. doi:10.1071/EN19057

Gillispie E, Taylor S, Qafoku N, Hochella M (2019). Impact of iron and manganese nano-metal-oxides on contaminant interaction and fortification potential in agricultural systems – a review. *Environmental Chemistry* **16**, 377–390. doi:10.1071/EN19063

Kah M, Navarro D, Kookana RS, Kirby JK, Santra S, Ozcan A, Kabiri S (2019). Impact of (nano)formulations on the distribution and wash-off of copper pesticides and fertilisers applied on citrus leaves. *Environmental Chemistry* **16**, 401–410. doi:10.1071/EN18279

Li J, Rodrigues S, Tsyusko OV, Unrine JM (2019). Comparing plant–insect trophic transfer of Cu from lab-synthesised nano-$Cu(OH)_2$ with a commercial nano-$Cu(OH)_2$ fungicide formulation. *Environmental Chemistry* **16**, 411–418. doi:10.1071/EN19011

Liu Y, Yue L, Wang Z, Xing B (2019). Processes and mechanisms of photosynthesis augmented by engineered nanomaterials. *Environmental Chemistry* **16**, 430–445. doi:10.1071/EN19046

McCouch S, Baute GJ, Bradeen J, Bramel P, Bretting PK, Buckler E, Burke JM, Charest D, Cloutier S, Cole G, Dempewolf H, Dingkuhn M, Feuillet C, Gepts P, Grattapaglia D, Guarino L, Jackson S, Knapp S, Langridge P, Lawton-Rauh A, Lijua Q, Lusty C, Michael T, Myles S, Naito K, Nelson RL, Pontarollo R, Richards CM, Rieseberg L, Ross-Ibarra J, Rounsley S, Hamilton RS, Schurr U, Stein N, Tomooka N, Van Der Knaap E, Van Tassel D, Toll J, Valls J, Varshney RK, Ward J, Waugh R, Wenzl P, Zamir D (2013). Feeding the future. *Nature* **499**, 23–24. doi:10.1038/499023A

Nath J, Dror I, Landa P, Motkova K, Vanek T, Berkowitz B (2019). Isotopic labelling for sensitive detection of nanoparticle uptake and translocation in plants from hydroponic medium and soil. *Environmental Chemistry* **16**, 391–400. doi:10.1071/EN19064

Neves J, Cardoso DN, Malheiro C, Kah M, Soares AMVM, Wrona FJ, Loureiro S (2019). Copper toxicity to *Folsomia candida* in different soils: a comparison between nano and conventional formulations. *Environmental Chemistry* **16**, 419–429. doi:10.1071/EN19061

Phenrat T, Hongkumnerd P, Suk-In J, Khum-In V (2019). Nanoscale zerovalent iron particles for magnet-assisted soil washing of cadmium-contaminated paddy soil: proof of concept. *Environmental Chemistry* **16**, 446–458. doi:10.1071/EN19028

Read TL, Doolette CL, Cresswell T, Howell NR, Aughterson R, Karatchevtseva I, Donner E, Kopittke PM, Schjoerring JK, Lombi E (2019). Investigating the foliar uptake of zinc from conventional and nanoformulations: a methodological study. *Environmental Chemistry* **16**, 459–469. doi:10.1071/EN19019

Rodrigues SM, Demokritou P, Dokoozlian N, Hendren CO, Karn B, Mauter MS, Sadik OA, Safarpour M, Unrine JM, Viers J, Welle P, White JC, Wiesner MR, Lowry GV (2017). Nanotechnology for sustainable food production: promising opportunities and scientific challenges. *Environmental Science. Nano* **4**, 767–781. doi:10.1039/C6EN00573J

Wang Y, Welch ZS, Ramirez AR, Bouchard DC, Schimel JP, Gardea-Torresdey JL, Holden PA (2019). Effects of carbonaceous nanomaterials on soil-grown soybeans under combined heat and insect stresses. *Environmental Chemistry* **16**, 482–493. doi:10.1071/EN19047