coatings

Editorial

Special Issue: Functional Nanoparticles for Environmental Contaminants Removal and Agricultural Application

Ran Tao [1,2], Mengmeng Kong [3], Yinlong Zhang [1] and Yu Shen [1,2,*]

1 Co-Innovation Center for Sustainable Forestry in Southern China, College of Biology and the Environment, Nanjing Forestry University, Nanjing 210037, China; nature19980626@gmail.com (R.T.); ecoenvylz@163.com (Y.Z.)
2 National Positioning Observation Station of Hung-tse Lake Wetland Ecosystem in Jiangsu Province, Nanjing 210037, China
3 School of Biological Science and Technology, University of Jinan, Jinan 250022, China; bio_kongmm@ujn.edu.cn
* Correspondence: yushen@njfu.edu.cn or sheyttmax@hotmail.com

Currently, increasing demands are being placed on agricultural production, presented with the challenge of finding sustainable ways to meet the needs of the world's growing population [1]. Global warming and climate change have become a "wifi" contributing to agricultural and environmental issues, with rising global temperatures and extreme weather events leading to crop failures and impacting food security [2]. Furthermore, intensive agricultural practices and unsustainable land use are causing soil erosion, a loss of fertility, and reduced productivity [3]. Limited access to water, over-extraction, and pollution pose major challenges to agriculture, particularly in arid and semi-arid regions [4]. Additionally, the spread of pests and diseases has become increasingly challenging to control due to factors such as global trade and climate change [5].

Nanotechnology, and particularly the field of nanomaterials, holds the potential to revolutionize agriculture and the environment [6]. It can be utilized to enhance crop production efficiency [7], reduce the use of pesticides and fertilizers [8], and improve food quality [9]. Nanotechnology can also contribute to the development of novel materials that enhance irrigation efficiency, crop storage, and various other aspects of farming [10]. Moreover, nanotechnology has the potential to create sensors capable of detecting changes in soil quality, enabling farmers to make more informed decisions about land management [11]. Encouragingly, significant progress has been made in the field of nano-agriculture and environmental applications, as highlighted in our Special Issue "Functional Nanoparticles for Environmental Contaminants Removal and Agricultural Application" in *Coatings*.

Nanotechnology has played a positive role in agriculture. Guo et al. (2022) observed that silver nanoparticles outperformed other nanoparticles in terms of final crop seed germination percentages, and zinc nanoparticles were found to be the most effective in promoting root length growth during seed germination in a meta-analysis conducted between 1950 and 2021 [12]. Hexaconazole is a widely used, broad-spectrum, and highly efficient triazole fungicide, but its extensive use can lead to environmental disasters [13]. In response, Pan et al. (2021) applied azobenzene-modified bimodal mesoporous silica nanoparticles (BMMs-Azo) in conjunction with β-cyclodextrin to control the release of hexaconazole, reducing its environmental impact [14]. Biochar is known for its numerous surface functional groups and porous structure, which can reduce nutrient loss and enhance nutrient uptake by plants [15]. Combining Methylotrophic bacillus, colloidal biochar (containing dissolved nanoparticles), and organic fertilizer significantly increased the contents of lycopene, vitamin C, total sugar, and soluble sugar in tomato fruits by 58.40%, 46.53%, 29.45%, and 26.65%, respectively [16]. Additionally, Yang et al. (2022) demonstrated that biochar nanoparticles, acting as nanocarriers, substantially increased the fertilizer utilization of Chinese cabbage and promoted plant growth by over 50% [17]. Copper

Citation: Tao, R.; Kong, M.; Zhang, Y.; Shen, Y. Special Issue: Functional Nanoparticles for Environmental Contaminants Removal and Agricultural Application. *Coatings* **2023**, *13*, 1633. https://doi.org/10.3390/coatings13091633

Received: 5 September 2023
Accepted: 13 September 2023
Published: 18 September 2023

nanoparticles have widespread applications in various industries, but their effects in agriculture and the environment vary. Yang et al. (2022) observed that 5 ppm copper nanoparticles caused the slight swelling of epithelial cells in the epididymal duct of Chinese soft-shelled turtles, while higher copper ion concentrations severely damaged the epithelial structure of the epididymal tube [18]. Faraz et al. (2022) reported on the foliar application of 2–16 ppm copper oxide nanoparticles (CuO NPs) on Brassica juncea 25 days after sowing, whereby 8 ppm resulted in optimal chlorophyll content, net photosynthetic rate, leaf proline content, and antioxidant enzyme activity [19]. However, the effectiveness of this concentration may vary for other plants. Surface coating is another factor affecting the interaction of CuO NPs with plants. Deng et al. (2022) found that the foliar spraying of 300 ppm bare NPs yielded similar results to 75 ppm citric-acid-coated NPs, with Cu NPs increasing the yield by approximately 170% compared to the control [20]. Interestingly, soil amendment with both bare and coated NPs did not significantly impact the plant mass relative to untreated plants. The use of manufactured nano-objects (MNOs), including carbon nanotubes (CNTs), nanoparticles (NPs), and nanopesticides, raises concerns, as these substances can impact the life cycle and not only accumulate in soils but also in other environmental components, negatively affecting the soil biota and processes. MNOs can interfere with soil physicochemical properties and microbial metabolic activity in rhizospheric soils [21]. Notably, negatively charged CuO NPs were found to significantly reduce disease progression and increase biomass, whereas positively charged NPs and a CuSO4 salt control had little impact on plants [22]. Based on element characteristics, it has been reported that magnesium nanoparticles (Mg-NPs) are more effective in enhancing the development of 'Superior Seedless' berries during various growth stages (flowering, fruit set, version, and harvest) compared to sulfate magnesium ($MgSO_4 \cdot 7H_2O$) and magnesium disodium EDTA (Mg-EDTA) [23]. As we move forward in the realm of coated nanoparticles for environmental remediation and agricultural use, recent studies have shown promise. It has been reported that β-carotene-coated chitosan nanoparticles (CNPs) have the potential to block polycyclic aromatic hydrocarbons (PAHs) and protect crops in PAH-contaminated soil. Under specific conditions of 20 °C, pH 6, and 10 mg/mL TPP, spinach biomass significantly increased, and the transfer of PAHs from the soil to the roots was reduced [24]. In agricultural activities, insecticides and pesticides can have unintended effects, and the nanofeature of higher efficiency is utilized to reduce ecotoxicity. Alginate CNPs have been employed in combination with DMT to reduce insecticide toxicity in zebrafish larvae while reducing the required dose [25]. Furthermore, CNPs can serve as a core for novel SnS_2 quantum dots with Azadirachta indica leaf extract, with coated CNPs exhibiting an enhanced removal of crystal violet dye [26]. Overall, our Special Issue reflects the cutting-edge trends in nanotechnology applications in agriculture and the environment.

Environmental catalysis has garnered significant attention for its clean methods of producing useful chemicals and facilitating various chemical processes. This approach can decompose and eliminate organic pollutants from aqueous environments while enabling the production of valuable chemicals [27]. Liu et al. (2023) synthesized novel N-doped biochar nanoparticles through the one-step pyrolysis of algal sludge without external nitrogen sources, yielding a highly active and cost-effective carbon-based catalyst capable of activating new oxidants for contaminant removal [28]. Additionally, Liu et al. (2022) found that Sedum plumbizincicola nanoparticles can effectively remove Bisphenol A (BPA) from complex wastewater, demonstrating stable and efficient reactions [29]. Nanoscale schwertmannite (nano-SWT) was prepared using an indoor temperature synthesis method with the assistance of polyvinylpyrrolidone, and nano-SWT was found to be effective in reducing sulfamethoxazole in the presence of Fenton-like catalysts using hydrogen peroxide (H_2O_2) [30]. Currently, Fenton catalysts are widely employed in conjunction with nanoparticles for environmental contaminant removal. Manganese tetroxide (Mn3O4) nanoparticles have been reported to simultaneously degrade estriol and 17α-ethinylestradiol (E3/EE2) with removal efficiencies of 97.5% and 96.4% for E3 and EE2, respectively, using Fenton-like catalysts [31]. Copper–iron peroxide nanoparticles (CFp

NPs) have been designed for tumor-microenvironment-mediated synergistic therapy in a heterogeneous chemodynamic therapy system. CFp NPs generate oxygen during catalysis and exhibit a tumor-microenvironment-responsive T1 magnetic resonance imaging contrast enhancement, aiding in tumor oxygenation and in vivo tumor monitoring [32]. Furthermore, it has been reported that S-doped carbon and Fe7S8 nanoparticles interact effectively for the high-efficiency removal of antibiotics through a Fenton-like degradation process. Within 40 min under neutral pH conditions, amoxicillin, norfloxacin, and tetracycline hydrochloride were removed at rates of 98.9%, 97.8%, and 99.3%, respectively, with the catalyst demonstrating excellent cycle stability [33]. At the same time, with the oxygen atoms in the sulfonic acid group cooperating with Ag+ to form a synergistic complexation, a novel magnetic fluorescent nanoprobe (Fe_3O_4@ZnS@MPS(MFNPs)) was designed for Ag+ detection in aquatic media [34]. These findings underscore the significant progress made in leveraging nanomaterials and catalytic processes for cleaner and more efficient environmental solutions, offering promise for a sustainable future.

In conclusion, the advancements in nano-agriculture and environmental applications are evident from the research covered in the Special Issue "Functional Nanoparticles for Environmental Contaminants Removal and Agricultural Application" in *Coatings*. Noteworthy examples include the use of silver nanoparticles to enhance crop seed germination and the application of azobenzene-modified bimodal mesoporous silica nanoparticles to control the release of the fungicide hexaconazole, thereby reducing environmental impacts. While nanotechnology presents exciting prospects, it is crucial to consider its potential ecological effects and develop responsible applications. Overall, the progress in nanotechnology applications in agriculture and the environment underscores the field's potential to contribute to a more sustainable future.

Funding: This research was funded by the National Science Foundation, grant number 31872415.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Duarte, C.M.; Bruhn, A.; Krause-Jensen, D. A seaweed aquaculture imperative to meet global sustainability targets. *Nat. Sustain.* **2021**, *5*, 185–193. [CrossRef]
2. Kazemi Garajeh, M.; Salmani, B.; Zare Naghadehi, S.; Valipoori Goodarzi, H.; Khasraei, A. An integrated approach of remote sensing and geospatial analysis for modeling and predicting the impacts of climate change on food security. *Sci. Rep.* **2023**, *13*, 1057. [CrossRef] [PubMed]
3. Wang, X. Managing Land Carrying Capacity: Key to Achieving Sustainable Production Systems for Food Security. *Land* **2022**, *11*, 484. [CrossRef]
4. Mahlknecht, J.; Aguilar-Barajas, I.; Farias, P.; Knappett, P.S.K.; Torres-Martinez, J.A.; Hoogesteger, J.; Lara, R.H.; Ramirez-Mendoza, R.A.; Mora, A. Hydrochemical controls on arsenic contamination and its health risks in the Comarca Lagunera region (Mexico): Implications of the scientific evidence for public health policy. *Sci. Total Environ.* **2023**, *857*, 159347. [CrossRef]
5. Brennan, F.P.; Alsanius, B.W.; Allende, A.; Burgess, C.M.; Moreira, H.; Johannessen, G.S.; Castro, P.M.L.; Uyttendaele, M.; Truchado, P.; Holden, N.J. Harnessing agricultural microbiomes for human pathogen control. *ISME Commun.* **2022**, *2*, 44. [CrossRef]
6. Fu, X.; Zheng, Z.; Sha, Z.; Cao, H.; Yuan, Q.; Yu, H.; Li, Q. Biorefining waste into nanobiotechnologies can revolutionize sustainable agriculture. *Trends Biotechnol.* **2022**, *40*, 1503–1518. [CrossRef]
7. Guleria, G.; Thakur, S.; Shandilya, M.; Sharma, S.; Thakur, S.; Kalia, S. Nanotechnology for sustainable agro-food systems: The need and role of nanoparticles in protecting plants and improving crop productivity. *Plant Physiol. Biochem.* **2023**, *194*, 533–549. [CrossRef]
8. Beig, B.; Niazi, M.B.K.; Sher, F.; Jahan, Z.; Malik, U.S.; Khan, M.D.; Américo-Pinheiro, J.H.P.; Vo, D.-V.N. Nanotechnology-based controlled release of sustainable fertilizers. A review. *Environ. Chem. Lett.* **2022**, *20*, 2709–2726. [CrossRef]

9. Sompura, Y.; Sangwan, D.; Barupal, T. Impact of nanotechnology on environment and their applica-tion in agronomy and food stuffs production: An Overview. *Biomater. J.* **2022**, *1*, 1–4.
10. Oladosu, Y.; Rafii, M.Y.; Arolu, F.; Chukwu, S.C.; Salisu, M.A.; Fagbohun, I.K.; Muftaudeen, T.K.; Swaray, S.; Haliru, B.S. Superabsorbent Polymer Hydrogels for Sustainable Agriculture: A Review. *Horticulturae* **2022**, *8*, 605. [CrossRef]
11. Silva, L.; Rodriguez-Sedano, F.; Baptista, P.; Coelho, J.P. The Digital Twin Paradigm Applied to Soil Quality Assessment: A Systematic Literature Review. *Sensors* **2023**, *23*, 1007. [CrossRef] [PubMed]
12. Guo, H.; Liu, Y.; Chen, J.; Zhu, Y.; Zhang, Z. The Effects of Several Metal Nanoparticles on Seed Germination and Seedling Growth: A Meta-Analysis. *Coatings* **2022**, *12*, 183. [CrossRef]
13. Syrgabek, Y.; Alimzhanova, M. Modern Analytical Methods for the Analysis of Pesticides in Grapes: A Review. *Foods* **2022**, *11*, 1623. [CrossRef] [PubMed]
14. Pan, H.; Li, W.; Wu, L.; Huang, W.; Zhang, F. β-Cyclodextrin-Modified Mesoporous Silica Nanoparticles with Photo-Responsive Gatekeepers for Controlled Release of Hexaconazole. *Coatings* **2021**, *11*, 1489. [CrossRef]
15. Rombel, A.; Krasucka, P.; Oleszczuk, P. Sustainable biochar-based soil fertilizers and amendments as a new trend in biochar research. *Sci. Total Environ.* **2022**, *816*, 151588. [CrossRef]
16. Gu, S.; Lian, F.; Yang, H.; Han, Y.; Zhang, W.; Yang, F.; Gao, J. Synergic Effect of Microorganism and Colloidal Biochar-Based Organic Fertilizer on the Growth and Fruit Quality of Tomato. *Coatings* **2021**, *11*, 1453. [CrossRef]
17. Yang, R.; Shen, J.; Zhang, Y.; Jiang, L.; Sun, X.; Wang, Z.; Tang, B.; Shen, Y. The Role of Biochar Nanoparticles Performing as Nanocarriers for Fertilizers on the Growth Promotion of Chinese Cabbage (*Brassica rapa* (Pekinensis Group)). *Coatings* **2022**, *12*, 1984. [CrossRef]
18. Yang, L.; Wei, Y.; Gao, S.; Wang, Q.; Chen, J.; Tang, B.; Bian, X. Effect of Copper Nanoparticles and Ions on Epididymis and Spermatozoa Viability of Chinese Soft-Shelled Turtles *Pelodiscus sinensis*. *Coatings* **2022**, *12*, 110. [CrossRef]
19. Faraz, A.; Faizan, M.; Hayat, S.; Alam, P.; Shahzadi, I. Foliar Application of Copper Oxide Nanoparticles Increases the Photosynthetic Efficiency and Antioxidant Activity in *Brassica juncea*. *J. Food Qual.* **2022**, *2022*, 5535100. [CrossRef]
20. Deng, C.; Wang, Y.; Cantu, J.M.; Valdes, C.; Navarro, G.; Cota-Ruiz, K.; Hernandez-Viezcas, J.A.; Li, C.; Elmer, W.H.; Dimkpa, C.O.; et al. Soil and foliar exposure of soybean (*Glycine max*) to Cu: Nanoparticle coating-dependent plant responses. *NanoImpact* **2022**, *26*, 100406. [CrossRef]
21. Mubeen, B.; Hasnain, A.; Wang, J.; Zheng, H.; Naqvi, S.A.H.; Prasad, R.; Rehman, A.U.; Sohail, M.A.; Hassan, M.Z.; Farhan, M.; et al. Current Progress and Open Challenges for Combined Toxic Effects of Manufactured Nano-Sized Objects (MNO's) on Soil Biota and Microbial Community. *Coatings* **2023**, *13*, 212. [CrossRef]
22. Borgatta, J.; Shen, Y.; Tamez, C.; Green, C.; Hedlund Orbeck, J.K.; Cahill, M.S.; Protter, C.; Deng, C.; Wang, Y.; Elmer, W.; et al. Influence of CuO Nanoparticle Aspect Ratio and Surface Charge on Disease Suppression in Tomato (*Solanum lycopersicum*). *J. Agric. Food Chem.* **2023**, *71*, 9644–9655. [CrossRef] [PubMed]
23. El-Ezz, S.F.A.; Lo'ay, A.; Al-Harbi, N.A.; Al-Qahtani, S.M.; Allam, H.M.; Abdein, M.A.; Abdelgawad, Z.A. A Comparison of the Effects of Several Foliar Forms of Magnesium Fertilization on 'Superior Seedless' (*Vitis vinifera* L.) in Saline Soils. *Coatings* **2022**, *12*, 201. [CrossRef]
24. Zhang, J.; Cui, M.; Tao, R.; Yao, Y.; Han, J.; Shen, Y. The Application of Carotenoid-Coated Chitosan Nanoparticles to Reduce the PAHs Stress on Spinach Growth. *Coatings* **2023**, *13*, 1404. [CrossRef]
25. Vallim, J.H.; Clemente, Z.; Castanha, R.F.; Pereira, A.d.E.S.; Campos, E.V.R.; Assalin, M.R.; Maurer-Morelli, C.V.; Fraceto, L.F.; Castro, V.L.S.S.d. Chitosan nanoparticles containing the insecticide dimethoate: A new approach in the reduction of harmful ecotoxicological effects. *NanoImpact* **2022**, *27*, 100408. [CrossRef] [PubMed]
26. Gadore, V.; Mishra, S.R.; Ahmaruzzaman, M. Green and environmentally sustainable fabrication of SnS_2 quantum dots/chitosan nanocomposite for enhanced photocatalytic performance: Effect of process variables, and water matrices. *J. Hazard. Mater.* **2023**, *444*, 130301. [CrossRef]
27. Yang, Y.; Wu, M.; Zhu, X.; Xu, H.; Ma, S.; Zhi, Y.; Xia, H.; Liu, X.; Pan, J.; Tang, J.-Y.; et al. 2020 Roadmap on two-dimensional nanomaterials for environmental catalysis. *Chin. Chem. Lett.* **2019**, *30*, 2065–2088. [CrossRef]
28. Liu, C.; Chen, Z.; Kang, R.; Wang, J.; Lu, Q.; Wang, T.; Tian, D.; Xu, Y.; Wang, Z.; Ding, H. N-Rich Algal Sludge Biochar for Peroxymonosulfate Activation toward Sulfadiazine Removal. *Coatings* **2023**, *13*, 431. [CrossRef]
29. Liu, C.; Chen, Z.; Kang, R.; Niu, Y.; Su, W.; Wang, X.; Tian, D.; Xu, Y. Sedum Plumbizincicola Derived Functional Carbon for Activation of Peroxymonosulfate to Eliminate Bisphenol A: Performance and Reaction Mechanisms. *Coatings* **2022**, *12*, 1892. [CrossRef]
30. Meng, X.; Wang, L.; Yang, Y.; Song, Y.; Yuan, C. Heterogeneous Fenton-like Catalyzation of Nanoscale Schwertmannite for Sulfamethoxazole Degradation. *Coatings* **2023**, *13*, 1097. [CrossRef]
31. Liu, M.; Lin, M.; Owens, G.; Chen, Z. Fenton-like oxidation mechanism for simultaneous removal of estriol and ethinyl estradiol by green synthesized Mn_3O_4 NPs. *Sep. Purif. Technol.* **2022**, *301*, 121978. [CrossRef]
32. Koo, S.; Park, O.K.; Kim, J.; Han, S.I.; Yoo, T.Y.; Lee, N.; Kim, Y.G.; Kim, H.; Lim, C.; Bae, J.-S.; et al. Enhanced Chemodynamic Therapy by Cu–Fe Peroxide Nanoparticles: Tumor Microenvironment-Mediated Synergistic Fenton Reaction. *ACS Nano* **2022**, *16*, 2535–2545. [CrossRef] [PubMed]

33. Zhang, X.; Wang, J.; Wang, Y.; Yao, Z.; Guo, W.; Xu, H.; Jiang, Z. Boosting electron transport process over multiple channels induced by S-doped carbon and Fe_7S_8 NPs interface toward high-efficiency antibiotics removal. *J. Hazard. Mater.* **2023**, *442*, 130115. [CrossRef] [PubMed]
34. Gao, Y.; Chen, X.; Xu, P.; Chen, J.; Yu, S.; Liu, Z.; Zeng, X. A Novel Magnetic Fluorescent Fe_3O_4@ZnS@MPS Nanosensor for Highly Sensitive Determination and Removal of Ag^+. *Coatings* **2023**, *13*, 1557. [CrossRef]