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Risk assessment of engineered nanoparticles and other contaminants in terrestrial plants

Wenchao Du, Yanwen Xu, Ying Yin, Rong Ji and Hongyan Guo

Abstract

Nanoparticles (NPs) will inevitably interact with co-existing contaminants after release to soil environment. There are potential routes affecting their interaction and consequent bioaccumulation and phytotoxicity. The joint effects of NPs and other contaminants on terrestrial plants are increasingly investigated but still limited. To provide a sound basis for risk assessment, more research should evaluate the joint effects under soil realistic conditions. This will promote the potential application of NPs in soil remediation, or as nano fertilizer/pesticide.

Addresses

State Key Laboratory of Pollution Control and Resource Reuse, School of Environment, Nanjing University, Nanjing 210046, China

Corresponding author: Guo, Hongyan (hyguo@nju.edu.cn)

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Co-existing contaminants, Plant, Soil, Joint toxicity, Bioaccumulation.

Introduction

Nanoparticle (NP) applications and accompanying risk assessment have attracted sufficient attention. There have been a large number of studies conducted on implications and impact of NPs in terrestrial plants [1]. These studies are important to elucidate nanotoxicity under single contaminant condition. However, in natural environment, nanoparticles always co-exist with other contaminants. Once released into the soil, they will inevitably interact with co-existing contaminants, and become important binding phases for both organic and inorganic contaminants [2]. And concomitant sorption and transformation have the potential to alter bioavailability and toxicity of both NPs and contaminants [3]. Especially, the application of NPs in remediating polluted soils and detoxifying stressed plants is gaining recognition [4]. Phytotests on joint toxicity aim to put together the nanoparticles, contaminants, and other external factors that could determine their phytotoxicity and plant uptake from soil and will bring us closer to a reliable estimate of their potential application in soil remediation.

Deng et al. (2017) gave a comprehensive review on the joint biological effects of NPs and co-existing contaminants [3]. Among the 119 isolated articles focusing on the joint effects on organisms, there are only 10 articles listed about plants. Here, we further bring together the existing research on the joint exposure of NPs and co-contaminants on terrestrial plants and discuss observed effects and internal mechanisms. Particular attention is paid to the balance between nanotoxicity and nano-applications. Existing research methods and results are evaluated and a perspective on future research is provided. This review will promote a better understanding of the risk of nanoparticles when they enter the soil.

Existing research

Studies on the joint toxicity, bioaccumulation of NPs and other contaminants on terrestrial plants are briefly summarized in Table 1.

NPs decrease the bioavailability and toxicity of other contaminants

Recently, there is a growing interest to overcome the phytotoxicity of heavy metals by using NPs as adsorbents in the medium [5]. A range of NPs are being studied for their potential remediation application in polluted soil. Magnetite NPs reduced the inhibition effects caused by Cd^{2+} and Cr^{6+} on the root length of *Triticum aestivum* [6]. TiO_2 NPs decreased the growth inhibition on plant height, biomass and root length of *Oryza sativa* caused by Cd^{2+} [7]. TiO_2 NPs and CeO_2 NPs alleviated the toxicity of Cu^{2+} showing on the root length of *O. sativa* by decreasing bioavailable soluble Cu^{2+} concentration [8]. Si NPs protected *Pisum sativum* seedlings against Cr^{6+} phytotoxicity in oxidative stress and nutrient element aspects [9]. In these studies, reduced bioaccumulation of related metal elements in plants was thought to contribute in the alleviation in phytotoxicity. Similarly, six different NPs (montmorillonite, hydroxyapatite, kaolin, a-Fe_2O_3, γ-Fe_2O_3 and Fe_3O_4) reduced the inhibition effect of Cd^{2+} on root growth of four seedlings (carrot, tomato, cucumber and lettuce), and further analysis showed that the precipitation associated with Cd^{2+} contributed to phytotoxicity reduction by the NPs [2]. In these studies, the adsorption capacity of NPs play a decisive role in altering bioavailability and toxicity of co-existing contaminants

Table 1

Summary of joint effects of nanoparticles (NPs) and contaminants on terrestrial plants.

NPs	Contaminants	Plants	Exposure			Results	Reference
			Growth Media	Time	Concentration		
Influence of NPs on the toxicity of contaminants							
CeO_2, TiO_2	Cu^{2+}, HA	*Oryza sativa*	petri dishes with test solutions	3 d	0, 2 mg/L Cu^{2+}; 0, 100, 1000 mg/L CeO_2, TiO_2 and HA-coated NPs; 0, 10, 20, 50, 100 mg/L HA	NPs and HA significantly alleviated Cu^{2+} phytotoxicity on root length.	[8]
Kaolin,montmorillonite, hydroxyapatite, Fe_3O_4, αFe_2O_3 γFe_2O_3	Cd^{2+}	*Lycopersicon esculentum, Cucumis sativus, Lactuca sativa, Daucus carota*	petri dishes with test solutions	4 d	0, 1, 2, 5, 10, 20, 50 and 100 mg/L Cd^{2+}; 0, 100, 500, 1000 and 2000 mg/L NPs	NPs reduced the root growth inhibition by Cd^{2+}.	[2]
Magnetite	Cd^{2+}, Cr^{6+}	*Triticum aestivum*	Quartz sadn	7 d	1, 10 mg/kg Cd^{2+}, Cr^{6+}; 1000 mg/kg magnetite NPs	Magnetite NPs reduced the root growth inhibition effects by Cd^{2+} and Cr^{6+}	[6]
Si	Cr^{6+}	*Pisum sativum* L.	1/2 strength Hoagland's solution	15 d	0, 100 µM Cr; 0, 10 µM Si NPs; 100 µM Cr+10 µM Si NPs	Si NPs protect pea seedlings against Cr(VI) phytotoxicity and oxidative stress, and up-regulating antioxidant defense system and nutrient elements.	[9]
TiO_2	Cd^{2+}	*Oryzasativa* L.	1/2 Kimura solution	20 d	0, 10, 20 mg/L $CdCl_2$; 0, 10, 100, 1000 mg/L TiO_2 NPs	TiO_2 reduced toxicity of Cd by increasing photosynthetic rate and chlorophyll content.	[7]
TiO_2	sodium nitroprusside	*Hordeum vulgare* L.	soil	40 d	100 µM SNP; 0, 500, 1000 and 2000 mg/kg TiO_2 NPs	TiO_2 NPs promoted growth and photosynthetic performance of barley plants under salt stress.	[30]
ZnO	Cd^{2+}, Pb^{2+}	*Leucaena leucocephala* L.	Hoagland's solution	15 d	25 mg/L ZnO NPs; 50, 100 mg/L Cd^{2+}/Pb^{2+}	ZnO NPs reduced toxicity of Cd or Pb on plant growth.	[5]
Ni/Fe	BDE209	Chinese cabbage	soil	14 d	0, 10 mg/kg BDE209; 0, 0.03 g/g Ni/Fe NPs	The Ni/Fe bimetallic nanoparticles decreased phytotoxicity of BDE209.	[10]
MWCNTs	contaminated sediment	*L. sativum*	sediment	7 d, 30 d, 60 d	0, 5% MWCNTs	MWCNTs reduced the inhibition effect of the contaminants on seed germination and root growth.	[24]
Influence of NPs on the accumulation of contaminants							
MWCNTs	carbamazepine	*Brassica oleracea*	hydroponic solutions; Soil	28 d, 42 d	0, 100 µg/L carbamazepine; 0, 50 mg/L and 500 mg/kg MWCNTs	MWCNTs suppressed carbamazepine accumulation.	[25]
MWCNTs	phenanthrene	wheat	hydroponic systems	28 d	100 µg/mL MWCNTs; 100 µg/L phenanthrene	MWCNTs could pierce wheat root cell walls and enhanced the transport of phenanthrene into living cells.	[12]