Supporting information

Uptake and bioaccumulation of nanoparticles by five higher plants using single-particle-inductively coupled plasma-mass spectrometry

Jing Wang[a,b], Le Yue[a,b], Jian Zhao[c], Xuesong Cao[a,b], Chuanxi Wang[a,b], Feiran Chen[a,b], Zhenggao Xiao[a,b], Yan Feng[a,b], Zhenyu Wang*[a,b]

[a] *Institute of Environmental Processes and Pollution Control, and School of Environment and Civil Engineering, Jiangnan University, Wuxi 214122, China.*

[b] *Jiangsu Engineering Laboratory for Biomass Energy and Carbon Reduction Technology, Jiangnan University, Wuxi 214122, China.*

[c] *Institute of Coastal Environmental Pollution Control, and Ministry of Education Key Laboratory of Marine Environment and Ecology, Ocean University of China, Qingdao 266100, China*

*Corresponding author:

Tel.: +86 0510 85911123; Fax: +86 0510 85197773

E-mail address: wang0628@jiangnan.edu.cn (Dr. Zhenyu Wang)

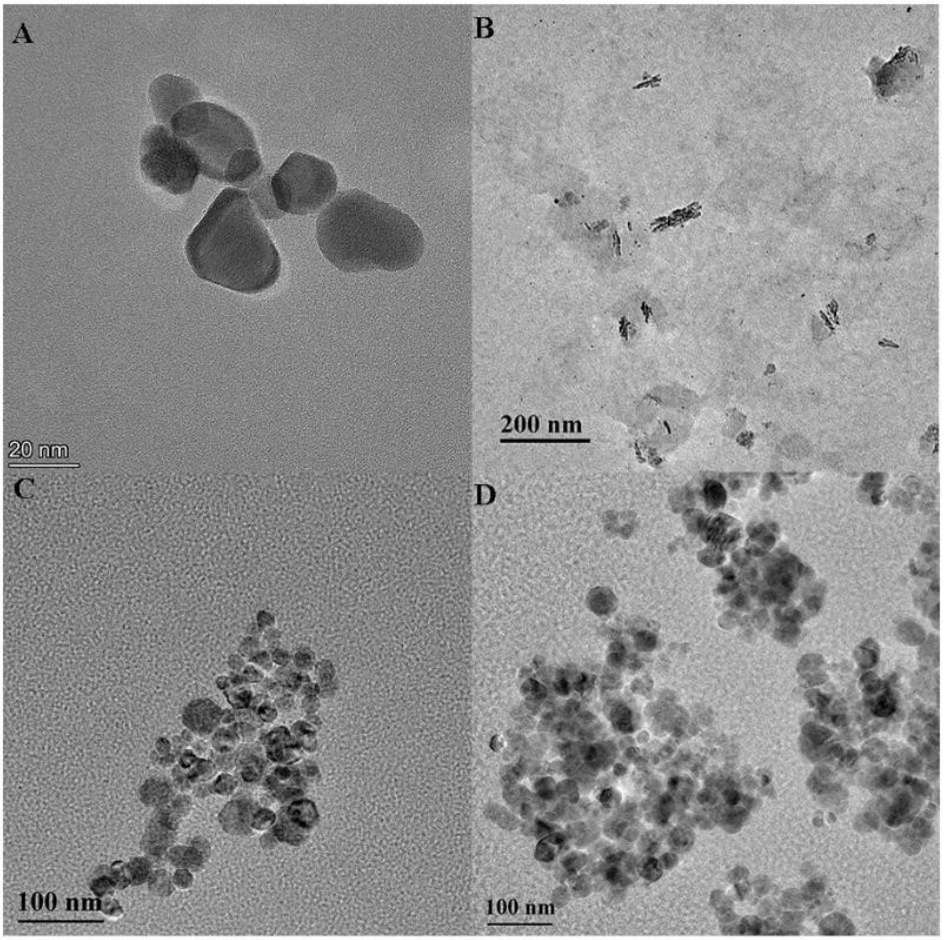


Fig. S1. TEM images of four NPs: (A) CeO_2; (B) La_2O_3; (C) Fe_3O_4; (D) $MnFe_2O_4$.

Fig.S2. Soil covered with plastic sheet to prevent the NPs entering soil.

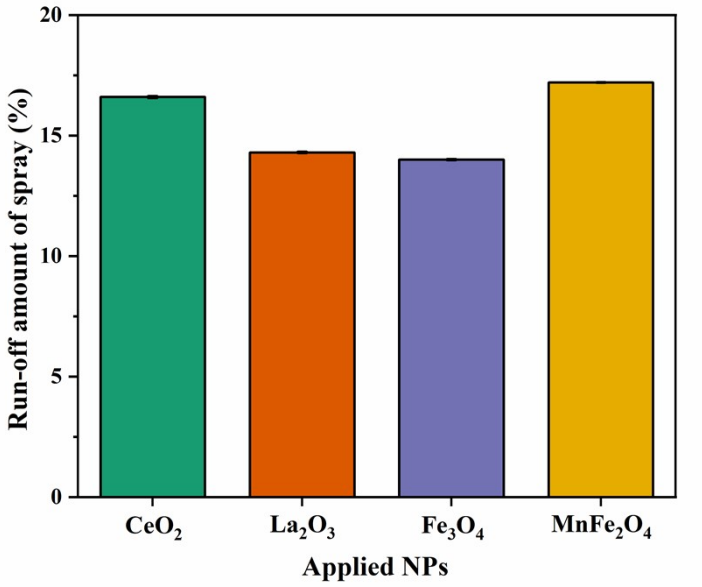


Fig. S3. The amount of CeO_2, La_2O_3, Fe_3O_4 and $MnFe_2O_4$ NPs ran off the leaf surface.

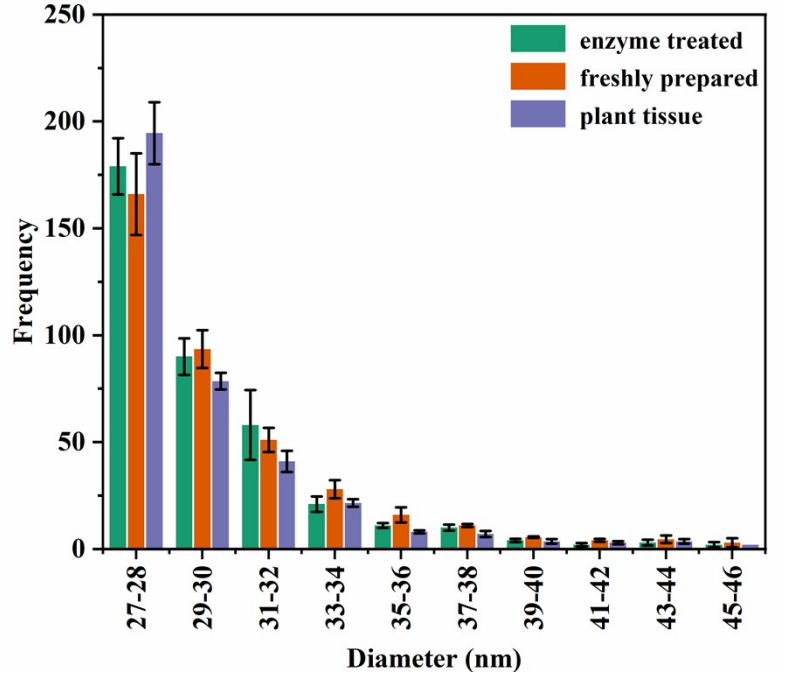


Fig. S4. The size distribution of Au NPs after 24-h digestion in enzyme solution, freshly prepared NPs suspensions and in plant tissue digestion solution (kidney bean) by SP-ICP-MS analysis. The final concentration of Au NPs was 2.4×10^4 particles mL^{-1} theoretically.

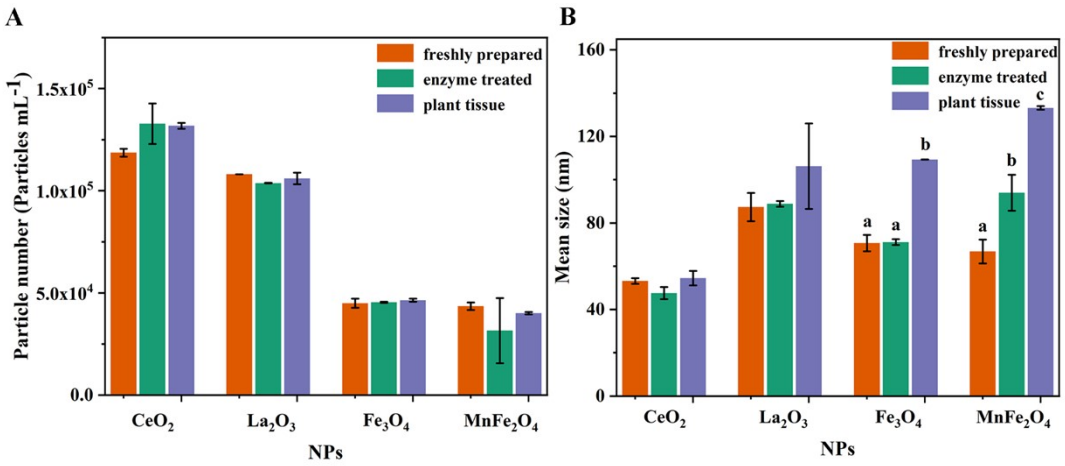
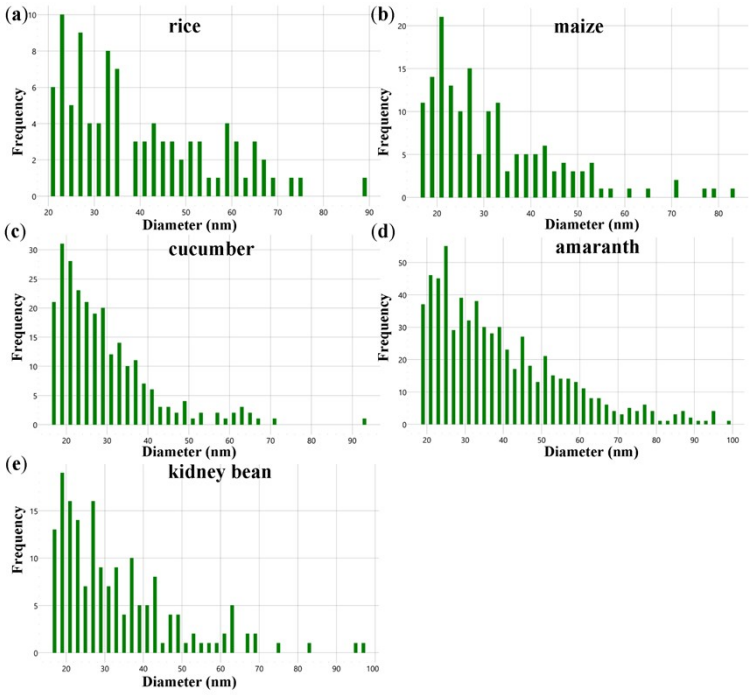
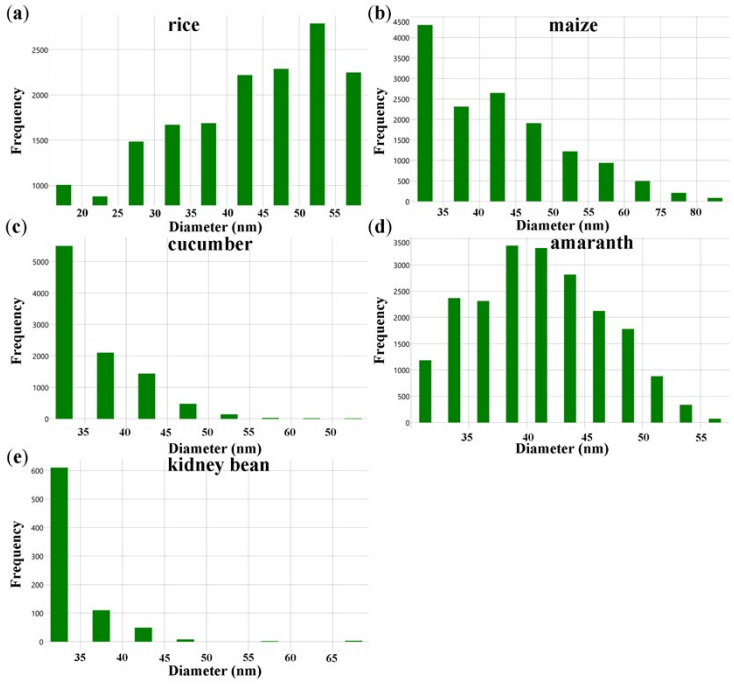


Fig. S5. Particle numbers (A) and mean sizes (B) of CeO_2, La_2O_3, Fe_3O_4 and $MnFe_2O_4$ NPs in the freshly prepared NPs suspensions, enzyme treated solution and plant tissue digestion solution. Plant tissue (kidney bean) sample spiked with NPs were digested by macerozyme R-10 enzyme. The values are presented as mean ± SD. The significance level between NPs are indicated by letters "a-c".

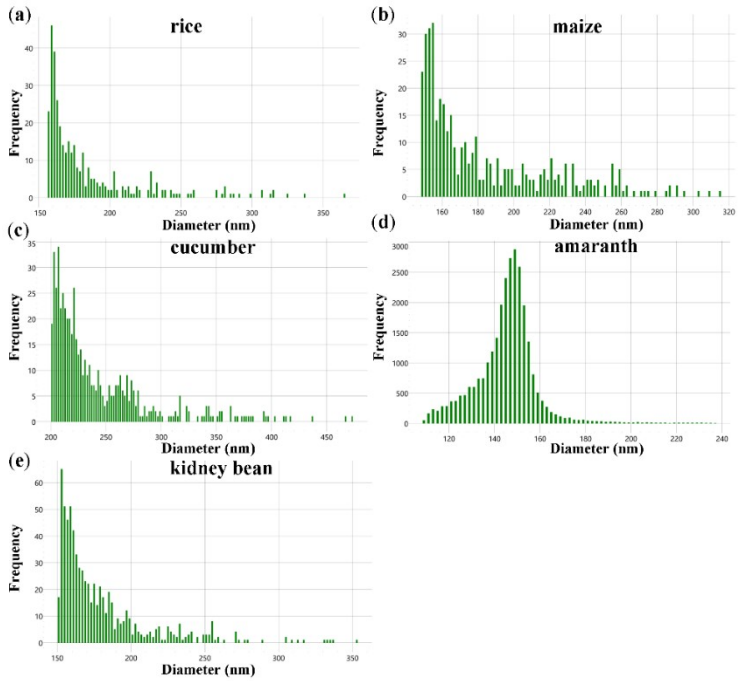
A: CeO_2 NPs



B: La_2O_3 NPs:



C: Fe_3O_4 NPs:



D: $MnFe_2O_4$ NPs:

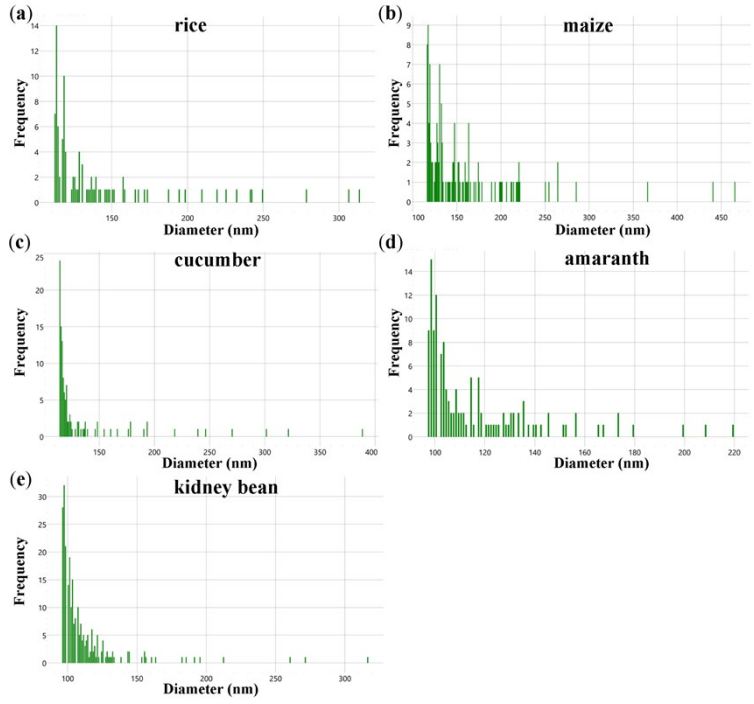
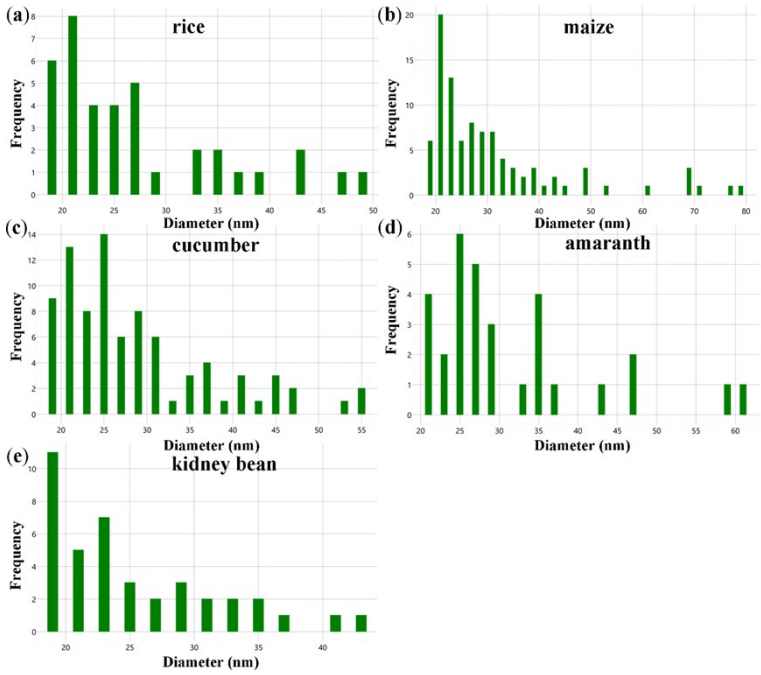
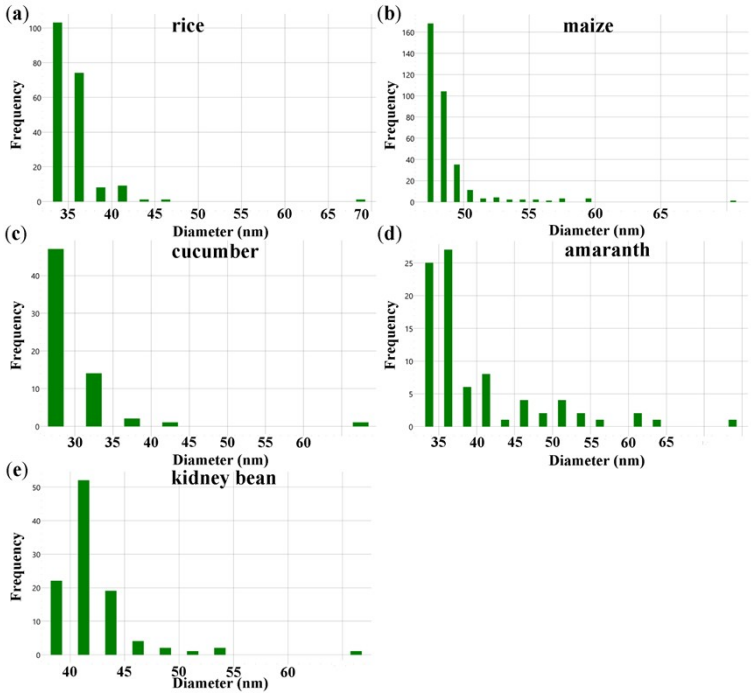


Fig. S6. The size distribution of CeO_2 (A), La_2O_3 (B), Fe_3O_4 (C) and $MnFe_2O_4$ (D) NPs in the dosed leaves of five plants (including (a) rice, (b) maize, (c) cucumber, (d) amaranth and (e) kidney bean) by SP-ICP-MS analysis.

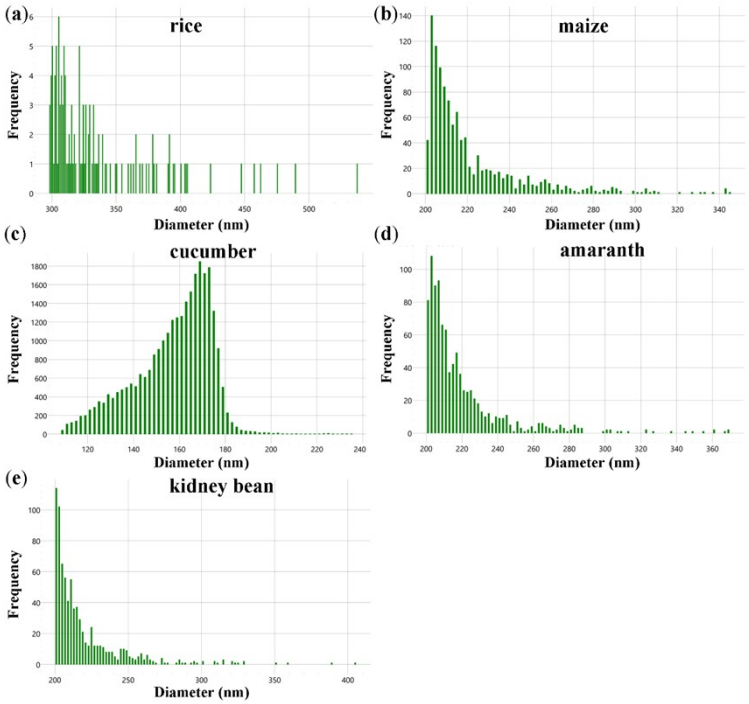
A: CeO_2 NPs:



B: La_2O_3 NPs:



C: Fe_3O_4 NPs:



D: $MnFe_2O_4$ NPs:

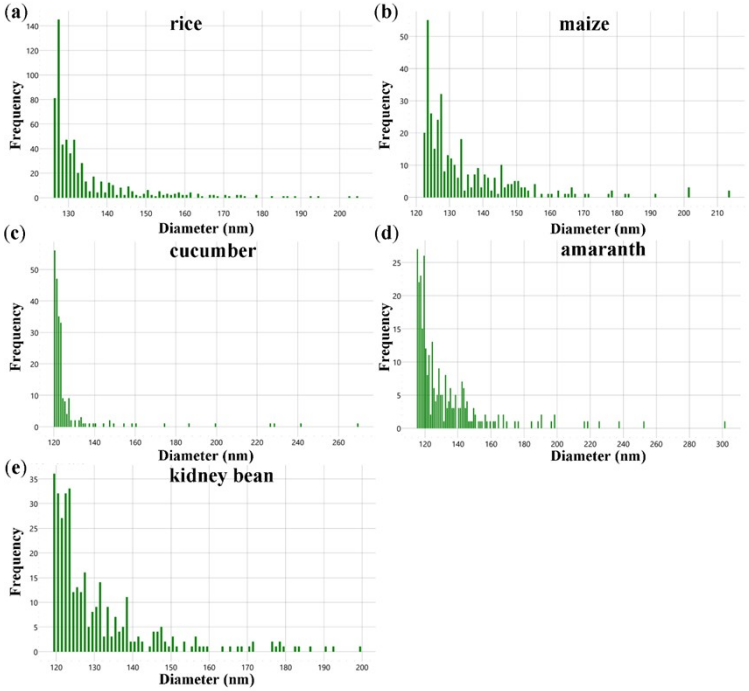
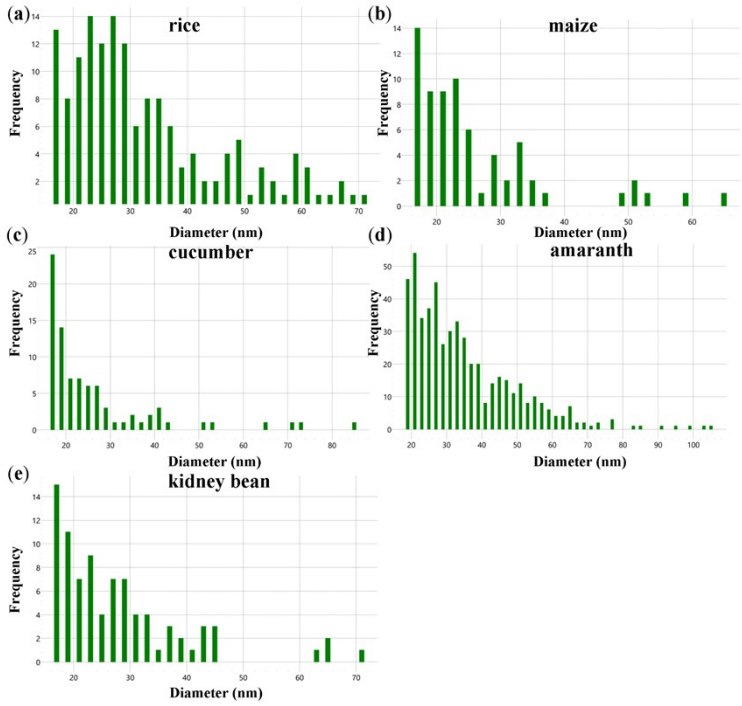
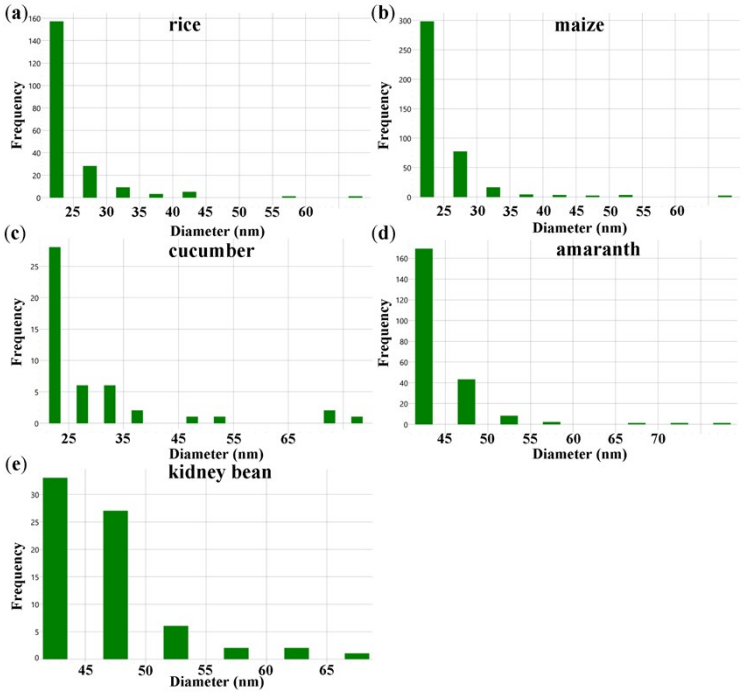


Fig. S7. The size distribution of CeO_2 (A), La_2O_3 (B), Fe_3O_4 (C) and $MnFe_2O_4$ (D) NPs in the roots of five plants (including (a) rice, (b) maize, (c) cucumber, (d) amaranth and (e) kidney bean) by SP-ICP-MS analysis.

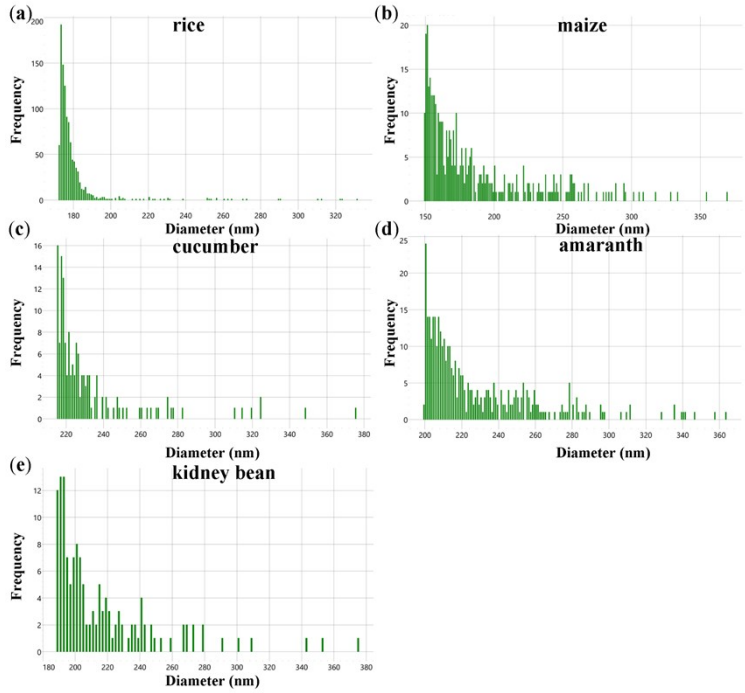
A: CeO_2 NPs:



B: La_2O_3 NPs:



C: Fe_3O_4 NPs:



D: $MnFe_2O_4$ NPs:

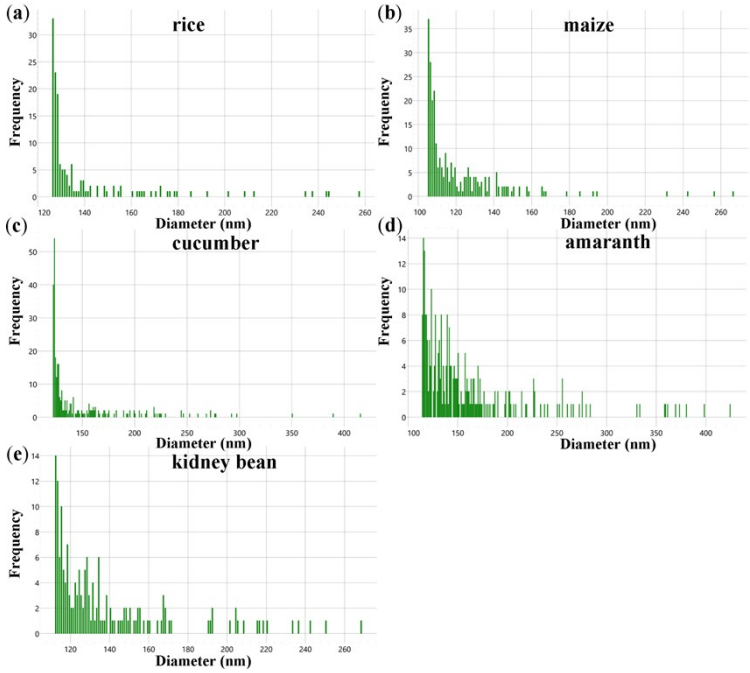


Fig. S8. The size distribution of CeO_2 (A), La_2O_3 (B), Fe_3O_4 (C) and $MnFe_2O_4$ (D) NPs in the new leaves of five plants (including (a) rice, (b) maize, (c) cucumber, (d) amaranth and (e) kidney bean) by SP-ICP-MS analysis.

Table S1. Size, hydrodynamic diameter and zeta potential of four NPs in ultrapure water (pH= 7.09)

Particle	Size (nm)	Hydraulic diameter (nm)	Zeta potential (mV)
CeO_2	23.40-41.16	556.77±31.61	24.13±1.86
La_2O_3	Width: 14.55 ± 5.98 Length: 58.01 ± 28.53	855.38±48.22	12.92±1.25
Fe_3O_4	22.39-43.47	230.65±16.93	-9.98±4.29
$MnFe_2O_4$	25.22-59.87	460.27±7.39	-8.83±0.44

Table S2. Instrumental parameters for SP-ICP-MS data acquisition.

Optimized ICP-MS operating condition					
Analyte	Ce^{140}	La^{139}	Fe^{56} (Fe_3O_4)		Fe^{56} ($MnFe_2O_4$)
Mass fraction (%)	0.81	0.85	0.72	0.19	
Density (g cm^{-3})	7.30	6.51	5.18	5.18	
Ionization (%)	100				
Dwell time (ms)	3				
Analysis (scan) time (s)	90				
Sample flow rate (mL min^{-1})	0.37				
Wash time (s)	45				
Mode	Standard	Standard	KED	KED	
Transport efficiency (%)	3.8				

Table S3. Typical sensitivity, detection limits and R^2 for element detection by ICP-MS.

Elements	Linearity range (mg/L)/R^2	Linearity equation	Detection limit (μg/L)	Bush branches and leaves (GBW07602) Standard value (μg/g)	Bush branches and leaves (GBW07602) ICP-MS measured value (μg/g, n = 3)
B	0-0.1/0.9983	y = 32.14x + 600.27	1.069	34 ± 7	34± 1
Na	0-10/0.9999	y = 556.08x - 11119	3.503	1.10 ± 0.001	1.13± 0.533
Mg	0-10/0.9999	y = 235.58x - 10577	0.904	2870 ± 180	2746± 238
S	0-10/1	y = 1338.6x - 12900	2.771	3200 ± 300	3081± 192
K	0-10/0.9999	y = 97.3x + 1674.4	4.701	8500 ± 500	8463± 258
Fe	0-10/1	y = 87.167x + 369.72	0.514	1020 ± 67	1043± 55
Mn	0-0.1/1	y = 1586.3x + 184.44	0.015	58 ± 6	60± 3
Zn	0-0.1/0.9997	y = 796.47x + 2066.6	0.247	20.3 ± 2.2	21± 0.9
La	0-0.1/1	y = 2851.6x - 683.65	0.001	1.23 ± 0.10	1.21± 0.10
Ce	0-0.1/0.9997	y = 65841x + 22753	0.001	2.4 ± 0.3	2.5± 0.3

Table S4. The particle concentration (particles mg^{-1}) and sizes of four NPs in the control plants without NPs exposure detected by SP-ICP-MS

A: rice

Particle	Category	Dosed leaves	New leaves	Roots
CeO_2	Number	3797±52	4604±63	3651±50
	Size (nm)	25.29±8.1	30.66±10.84	25.57±7.1
La_2O_3	Number	1679±23	1461±20	4948±68
	Length (nm)	93.35±15.24	261.68±35.52	51.49±14.15
Fe_3O_4	Number	1020±14	1751±24	3138±43
	Size (nm)	117.15±8.64	125.58±20.19	121.03±9.02
$MnFe_2O_4$	Number	5764±79	2552±35	7007±96
	Size (nm)	118.72±11.14	125.32±8.43	125.71±10.73

B: maize

Particle	Category	Dosed leaves	New leaves	Roots
CeO_2	Number	2627±36	3942±54	6191±85
	Size (nm)	22.18±3.71	25.02±5.99	29.14±6.44
La_2O_3	Number	2409±33	1386±19	1457±20
	Length (nm)	101.91±22.14	308.81±35.63	121.52±18.96
Fe_3O_4	Number	1459±20	2480±34	2043±28
	Size (nm)	126.65±15.44	118.99±16.32	123.54±9.12
$MnFe_2O_4$	Number	7632±105	2553±35	5694±78
	Size (nm)	110.83±16.32	125.15±10.78	125.36±10.28

C: cucumber

Particle	Category	Dosed	New leaves	Roots
CeO_2	Number	6199±85	5543±76	7153±98
	Size (nm)	26.42±8.21	27.11±9.28	32.7±6.66
La_2O_3	Number	3574±49	2409±33	5769±79
	Length (nm)	91.56±18.36	218.40±34.58	122.60±23.36
Fe_3O_4	Number	1240±17	3433±47	5037±69
	Size (nm)	121.07±12.43	132.06±12.28	127.59±4.47
$MnFe_2O_4$	Number	4593±63	3943±54	5980±82
	Size (nm)	125.61±9.8	125.64±9.19	144.4±6.8

D: amaranth

Particle	Category	Dosed leaves	New leaves	Roots
CeO_2	Number	2992±41	4597±63	6932±95
	Size (nm)	28.84±5.48	27.78±8.44	27.10±5.84
La_2O_3	Number	4524±62	1095±15	3719±51
	Length (nm)	115.70±19.39	292.66±37.45	84.19±13.66
Fe_3O_4	Number	3063±42	1315±18	4011±55
	Size (nm)	116.69±8.07	117.64±9.73	140.91±7.73
$MnFe_2O_4$	Number	3724±51	2994±41	6050±83
	Size (nm)	144.06±9.16	122.54±15.33	134.5±6.57

E: kidney bean

Particle	Category	Dosed leaves	New leaves	Roots
CeO_2	Number	2401±33	3719±51	3429±47
	Size (nm)	22.86±3.99	30.88±10.67	24.17±5.17
La_2O_3	Number	3675±52	949±13	3721±51
	Length (nm)	82.43±23.99	236.21±30.67	72.78±9.17
Fe_3O_4	Number	1533±21	2185±30	3502±48
	Size (nm)	124.36±11.34	113.04±14.78	126.57±9.61
$MnFe_2O_4$	Number	6640±91	2774±38	4088±56
	Size (nm)	110.41±10.54	125.93±7.18	124.61±11.03