Electronic Supplementary Material (ESI) for Environmental Science: Nano.

Supplementary Information

Nutritional assessment of red kidney bean seeds harvested from plants exposed to coated/uncoated zinc oxide nanomaterials, bulk zinc oxide, and zinc chloride in two soil types

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Table S1. Experimental design for red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1, and $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}; with 4 replicates per treatment.

	Soil									
	NS					ES				
	Concentration (mg kg^{-1})									
Compound	0	62.5	125	250	500	0	62.5	125	250	500
Bulk ZnO	4	4	4	4	4	4	4	4	4	4
Z-COTE	4	4	4	4	4	4	4	4	4	4
Z-COTE HP1	4	4	4	4	4	4	4	4	4	4
$ZnCl_2$	4	4	4	4	4	4	4	4	4	4

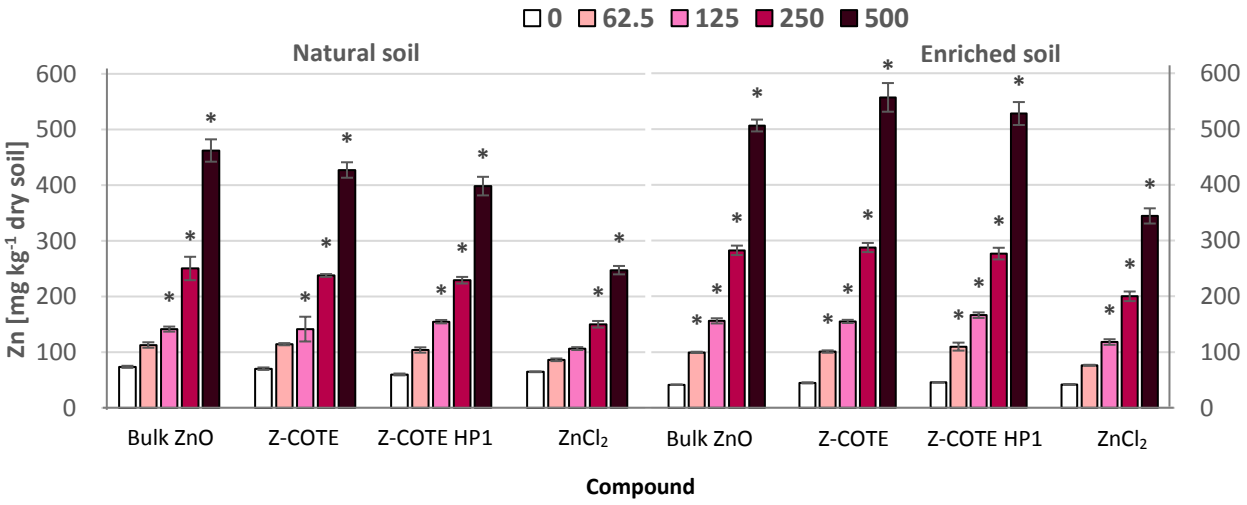

Fig. S1.Zinc content in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1, and $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1} after 45 days of growth of red kidney bean plants. Values are average ± standard deviation of 4 replicates. *Represents treatments different from their respective control.

Table S2. Number of days to harvest maturity for red kidney bean plants seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1, and $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Values are average ± standard deviation of 4 replicates. Letters represent differences between-compounds at the same concentration and within the same soil type, the symbol ^ represents differences between-soil within the same compound, at the same concentration; *stands for differences against the respective control

Parameter	Compound	Concentration (mg kg^{-1})	Natural soil $\bar{x}$ ± SD		Enriched Soil $\bar{x}$ ± SD	
Days to harvest maturity (#)	Bulk ZnO	Control	109.8 ± 2.9	^	92.0 ± 3.5	
		62.5	108.8 ± 4.5		99.0 ± 4.6	
		125	109.5 ± 6.1	^	86.5 ± 14.8	
		250	109.0 ± 4.5		95.0 ± 0.0	
		500	102.8 ± 10.3		91.5 ± 14.2	
	Z-COTE	Control	106.8 ± 3.9		94.8 ± 10.9	
		62.5	105.5 ± 4.1	^	88.3 ± 13.7	
		125	105.0 ± 8.0	^	82.8 ± 15.9	
		250	104.5 ± 1.7		92.3 ± 5.1	
		500	101.8 ± 10.1	^	81.3 ± 11.3	
	Z-COTE HP1	Control	122.3 ± 13.6	^	83.0 ± 8.0	
		62.5	110.5 ± 16.6	^	83.3 ± 15.9	
		125	116.8 ± 9.5	^	82.0 ± 17.1	
		250	121.8 ± 4.5	^	81.8 ± 11.0	
		500	115.5 ± 17.0	^	84.0 ± 18.6	
	$ZnCl_2$	Control	123.5 ± 5.7	^	87.5 ± 11.6	
		62.5	124.5 ± 9.1	^	85.3 ± 11.3	
		125	117.0 ± 12.8	^	86.8 ± 10.2	
		250	123.8 ± 9.0	^	87.5 ± 7.1	
		500	111.0 ± 0.0	^	81.3 ± 9.0	

Table S3. Three-way ANOVA summary for number of days to harvest maturity.

Tests of Between-Subjects Effects

Dependent Variable: Number of days to harvest maturity

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
soil	25426.806	1	25426.806	233.216	0.000	*
compound	872.219	3	290.74	2.667	0.051	
concentration	895.525	4	223.881	2.053	0.091	
soil × compound	3409.569	3	1136.523	10.424	0.000	*
soil × concentration	111.975	4	27.994	0.257	0.905	
compound × concentration	463.125	12	38.594	0.354	0.976	
soil × compound × concentration	656.275	12	54.69	0.502	0.910	
Error	13083.25	120	109.027			
Total	1641121	160				
Corrected Total	44918.744	159				

Table S4. Three-way ANOVA summary for production of seeds and pods with seeds.

Tests of Between-Subjects Effects

Dependent Variable: Number of pods with seeds

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
soil	223.256	1	223.256	128.339	0.000	*
compound	27.819	3	9.273	5.331	0.002	*
concentration	8.65	4	2.162	1.243	0.296	
soil × compound	13.019	3	4.34	2.495	0.063	
soil × concentration	1.4	4	0.35	0.201	0.937	
compound × concentration	14.15	12	1.179	0.678	0.770	
soil × compound × concentration	36.2	12	3.017	1.734	0.068	
Error	208.75	120	1.74			
Total	7569	160				
Corrected Total	533.244	159				

Dependent Variable: Weight of pods with seeds

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
soil	1000.125	1	1000.125	939.428	0.000	*
compound	15.98	3	5.327	5.003	0.003	*
concentration	10.113	4	2.528	2.375	0.056	
soil × compound	2.438	3	0.813	0.763	0.517	
soil × concentration	5.996	4	1.499	1.408	0.235	
compound × concentration	13.565	12	1.13	1.062	0.398	
soil × compound × concentration	13.169	12	1.097	1.031	0.425	
Error	127.753	120	1.065			
Total	7254.929	160				
Corrected Total	1189.139	159				

Table S4. Three-way ANOVA summary for production of seeds and pods with seeds (continued).

Dependent Variable: Number of seeds

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
soil	1829.256	1	1829.256	421.933	0	*
compound	35.469	3	11.823	2.727	0.047	*
concentration	12.775	4	3.194	0.737	0.569	
soil × compound	8.769	3	2.923	0.674	0.569	
soil × concentration	26.275	4	6.569	1.515	0.202	
compound × concentration	21.125	12	1.76	0.406	0.959	
soil × compound × concentration	82.825	12	6.902	1.592	0.103	
Error	520.25	120	4.335			
Total	18919	160				
Corrected Total	2536.744	159				

Dependent Variable: Weight of seeds

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
soil	468.117	1	468.117	789.06	0.000	*
compound	9.213	3	3.071	5.177	0.002	*
concentration	3.736	4	0.934	1.574	0.185	
soil × compound	1.76	3	0.587	0.989	0.401	
soil × concentration	2.417	4	0.604	1.019	0.401	
compound × concentration	7.168	12	0.597	1.007	0.447	
soil × compound × concentration	5.909	12	0.492	0.83	0.619	
Error	71.191	120	0.593			
Total	3020.554	160				
Corrected Total	569.511	159				

Table S5. Protein content of red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1, and $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Values are average ± standard deviation of 4 replicates. Letters represent differences between-compounds at the same concentration and within the same soil type, the symbol ^ represents differences between-soil within the same compound, at the same concentration; *stands for differences against the respective control.

Nutrient	Compound	Concentration (mg kg^{-1})	Natural soil $\bar{x}$ ± SD		Enriched Soil $\bar{x}$ ± SD	
Protein (g/100g)	Bulk ZnO	Control	23.689 ± 1.752	a	23.419 ± 1.921	
		62.5	22.621 ± 0.779	a ^	24.518 ± 1.287	
		125	25.869 ± 2.168	^	23.530 ± 2.315	
		250	25.146 ± 1.983	ab	25.611 ± 2.035	a
		500	24.926 ± 1.966	^	22.623 ± 1.495	
	Z-COTE	Control	26.235 ± 0.906	b ^	23.919 ± 2.745	
		62.5	25.678 ± 1.642	b	24.494 ± 0.226	
		125	25.868 ± 2.281	^	22.944 ± 0.959	
		250	25.564 ± 1.603	ab	23.848 ± 0.856	ab
		500	23.981 ± 2.442		22.431 ± 0.698	
	Z-COTE HP1	Control	24.834 ± 2.578	ab	23.641 ± 1.865	
		62.5	24.670 ± 0.832	ab	24.736 ± 1.358	
		125	24.359 ± 0.574		24.100 ± 1.783	
		250	27.208 ± 1.772	a ^	23.143 ± 0.855	b
		500	25.778 ± 1.181		24.306 ± 2.521	
	$ZnCl_2$	Control	26.349 ± 1.181	b	25.526 ± 0.918	
		62.5	25.704 ± 2.747	b	24.586 ± 2.111	
		125	25.140 ± 1.614	^	***22.859 ± 2.518**	
		250	24.449 ± 1.516	b	24.533 ± 2.547	ab
		500	24.090 ± 1.931		23.360 ± 1.776	

Table S6. Three-way ANOVA summary for protein content.

Tests of Between-Subjects Effects

Dependent Variable: Protein content

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
soil	115.488	1	115.488	36.413	0.000 *
compound	11.974	3	3.991	1.258	0.289
concentration	37.914	4	9.478	2.988	0.019 *
soil × compound	22.113	3	7.371	2.324	0.075
soil × concentration	30.719	4	7.68	2.421	0.049 *
compound × concentration	106.37	12	8.864	2.795	0.001 *
soil × compound × concentration	84.384	12	7.032	2.217	0.011 *
Error	888.06	280	3.172		
Total	193486.8	320			
Corrected Total	1297.022	319			

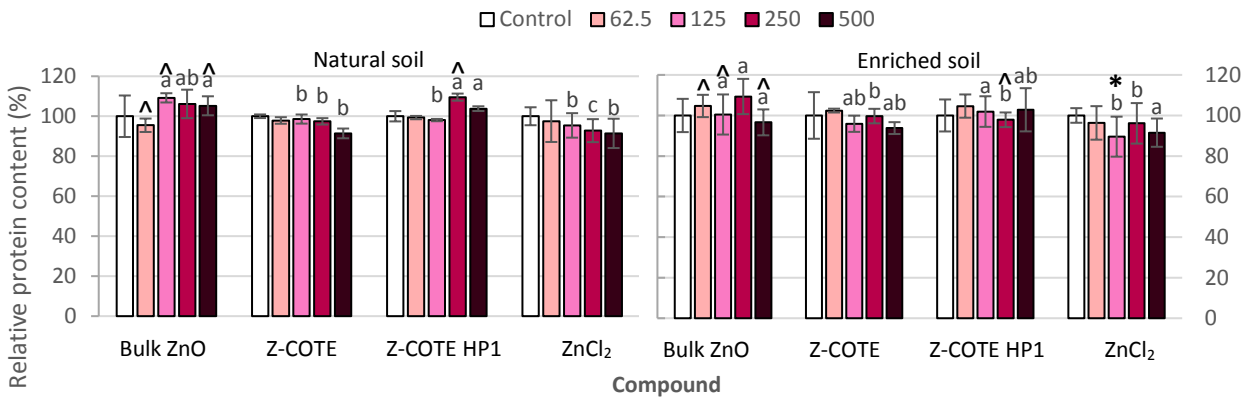

Figure S2. Relative protein content (%) of red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1, and $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Values are average ± standard deviation of 4 replicates. Letters represent differences between-compounds at the same concentration and within the same soil type, the symbol ^ represents differences between-soil within the same compound, at the same concentration; *stands for differences against the respective control.

Table S7. Three-way ANOVA summary for relative protein content.

Tests of Between-Subjects Effects

Dependent Variable: Relative protein content (%)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
soil	6.626	1	6.626	0.128	0.721
compound	3067.23	3	1022.41	19.687	0.000 *
concentration	604.667	4	151.167	2.911	0.022 *
soil × compound	67.793	3	22.598	0.435	0.728
soil × concentration	549.791	4	137.448	2.647	0.034 *
compound × concentration	1730.541	12	144.212	2.777	0.001 *
soil × compound × concentration	1421.223	12	118.435	2.281	0.009 *
Error	14541.026	280	51.932		
Total	3179045.9	320			
Corrected Total	21988.897	319			

Table S8. Sugar content of red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1, and $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Values are average ± standard deviation of 4 replicates. Letters represent differences between-compounds at the same concentration and within the same soil type, the symbol ^ represents differences between-soil within the same compound, at the same concentration; *stands for differences against the respective control

			Natural soil					Enriched Soil				
Nutrient	**Compound**	**Concentration (mg kg^{-1})**	$\bar{x}$	±	*SD*			$\bar{x}$	±	*SD*		
Sugar (g/100g)	**Bulk ZnO**	Control	3.199	±	0.382	a	^	5.152	±	1.236	a	
		62.5	3.025	±	0.551	a	^	6.338	±	3.333	a	
		125	3.276	±	0.700			4.250	±	2.661		
		250	3.468	±	0.359	a		3.778	±	0.685		
		500	3.990	±	1.303			3.061	±	1.318		
	Z-COTE	Control	6.900	±	0.926	b	^	3.276	±	0.515	ab	
		62.5	5.876	±	1.681	b	^	2.910	±	1.114	b	
		125	4.548	±	1.739		^	1.884	±	0.571		
		250	6.683	±	0.761	b	^	2.574	±	0.498		
		500	5.624	±	0.962		^	1.777	±	0.476		
	Z-COTE HP1	Control	3.698	±	1.302	a		2.152	±	0.489	b	
		62.5	5.212	±	2.444	ab	^	2.457	±	0.466	b	
		125	4.594	±	1.504		^	2.256	±	1.296		
		250	5.774	±	0.937	ab	^	2.073	±	1.093		
		500	4.927	±	0.701		^	2.053	±	0.982		
	$ZnCl_2$	Control	5.376	±	1.281	ab	^	1.213	±	0.778	b	
		62.5	3.758	±	1.526	ab		2.581	±	0.976	b	
		125	4.705	±	2.049			3.004	±	1.508		
		250	4.580	±	1.875	ab	^	2.635	±	1.238		
		500	5.045	±	1.856		^	2.106	±	1.045		

Table S9. Three-way ANOVA summary for sugar content.

Tests of Between-Subjects Effects

Dependent Variable: Sugar content

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
soil	134.919	1	134.919	74.563	0.000	*
compound	14.244	3	4.748	2.624	0.054	
concentration	5.8	4	1.45	0.801	0.527	
soil × compound	122.95	3	40.983	22.649	0.000	*
soil × concentration	15.844	4	3.961	2.189	0.074	
compound × concentration	26.635	12	2.22	1.227	0.273	
soil × compound × concentration	23.995	12	2	1.105	0.362	
Error	217.135	120	1.809			
Total	2865.564	160				
Corrected Total	561.523	159				

Table S10. Relative sugar content (%) of red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1, and $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Values are average ± standard deviation of 4 replicates normalized to the control. Letters represent differences between-compounds at the same concentration and within the same soil type, the symbol ^ represents differences between-soil within the same compound, at the same concentration; *stands for differences against the respective control.

			Natural soil				Enriched Soil			
Nutrient	**Compound**	**Concentration (mg kg^{-1})**	$\bar{x}$	±	*SD*		$\bar{x}$	±	*SD*	
Relative sugar content (%)	**Bulk ZnO**	Control	100.00	±	11.95		100.00	±	24.00	
		62.5	94.55	±	17.20		123.01	±	64.69	a
		125	102.40	±	21.86		82.50	±	51.64	a
		250	108.38	±	11.23		73.34	±	13.29	a
		500	124.70	±	40.71	^	59.41	±	25.59	a
	Z-COTE	Control	100.00	±	13.42		100.00	±	15.74	
		62.5	85.16	±	24.37		88.86	±	34.00	a
		125	65.91	±	25.20		57.52	±	17.44	a
		250	96.86	±	11.03		78.58	±	15.21	a
		500	81.51	±	13.94		54.25	±	14.53	a
	Z-COTE HP1	Control	100.00	±	35.19		100.00	±	22.74	
		62.5	140.93	±	66.09		114.20	±	21.69	a
		125	124.25	±	40.67		104.84	±	60.23	a
		250	156.15	±	25.34		96.32	±	50.78	a
		500	133.24	±	18.94		95.42	±	45.63	ab
	$ZnCl_2$	Control	100.00	±	23.82	^	100.00	±	64.16	
		62.5	69.90	±	28.38	^	***212.78**	**±**	**80.45**	b
		125	87.51	±	38.12	^	***247.65**	**±**	**124.30**	b
		250	85.19	±	34.88	^	***217.27**	**±**	**102.03**	a
		500	93.85	±	34.52	^	173.62	±	86.19	b

Table S11. Three-way ANOVA summary for relative sugar content (%).

Tests of Between-Subjects Effects

Dependent Variable: Relative sugar content (%)

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	
soil	5247.961	1	5247.961	2.576	0.111	
compound	75237.33	3	25079.11	12.311	0.000	*
concentration	6520.795	4	1630.199	0.8	0.527	
soil × compound	113434.99	3	37811.663	18.562	0.000	*
soil × concentration	13530.09	4	3382.522	1.66	0.164	
compound × concentration	27360.147	12	2280.012	1.119	0.351	
soil × compound × concentration	35437.76	12	2953.147	1.45	0.153	
Error	244449.49	120	2037.079			
Total	2396168.8	160				
Corrected Total	521218.56	159				

Table S12. Zinc (Zn) content of red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1, and $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Values are average ± standard deviation of 4 replicates normalized to the control. Letters represent differences between-compounds at the same concentration and within the same soil type, the symbol ^ represents differences between-soil within the same compound, at the same concentration; *stands for differences against the respective control.

			Natural soil				Enriched Soil			
Nutrient	**Compound**	**Concentration (mg kg^{-1})**	$\bar{x}$	±	*SD*		$\bar{x}$	±	*SD*	
Zn (mg kg^{-1})	Bulk ZnO	Control	48.930	±	6.879		57.531	±	5.223	
		62.5	68.328	±	5.410	^	***89.382**	**±**	**18.721**	
		125	63.483	±	6.338	^	***102.007**	**±**	**15.073**	a
		250	***77.846**	**±**	**9.763**	^	***115.29**	**±**	**5.598**	a
		500	***71.728**	**±**	**8.184**	^	***130.195**	**±**	**6.174**	a
	Z-COTE	Control	48.744	±	1.293		51.632	±	10.119	
		62.5	62.235	±	8.220	^	***80.348**	**±**	**6.004**	
		125	***75.831**	**±**	**20.037**	^	***93.316**	**±**	**20.659**	ab
		250	***72.085**	**±**	**4.112**	^	***111.807**	**±**	**16.902**	ab
		500	***77.773**	**±**	**13.880**	^	***125.273**	**±**	**7.931**	ab
	Z-COTE HP1	Control	54.584	±	3.627		43.226	±	4.579	
		62.5	57.707	±	5.123		***71.764**	**±**	**8.954**	
		125	64.491	±	8.837		***73.746**	**±**	**8.479**	b
		250	76.136	±	12.281	^	***93.7**	**±**	**14.851**	b
		500	***83.876**	**±**	**9.941**	^	***106.812**	**±**	**19.200**	b
	$ZnCl_2$	Control	45.636	±	7.260		55.630	±	7.317	
		62.5	65.672	±	7.761	^	***87.739**	**±**	**11.261**	
		125	64.845	±	0.557	^	***106.12**	**±**	**13.770**	a
		250	62.607	±	5.261	^	***107.814**	**±**	**5.892**	ab
		500	***87.384**	**±**	**21.696**	^	***128.232**	**±**	**5.734**	a

Table S13. Three-way ANOVA summary for Zn content.

Tests of Between-Subjects Effects

Dependent Variable: Zn

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	
soil	25164.863	1	25164.863	212.984	0.000	*
compound	2338.916	3	779.639	6.599	0.000	*
concentration	46525.561	4	11631.39	98.443	0.000	*
soil × compound	3189.618	3	1063.206	8.998	0.000	*
soil × concentration	7595.155	4	1898.789	16.07	0.000	*
compound × concentration	1487.121	12	123.927	1.049	0.410	
soil × compound × concentration	1145.957	12	95.496	0.808	0.641	
Error	14178.446	120	118.154			
Total	1101126.72	160				
Corrected Total	101625.637	159				

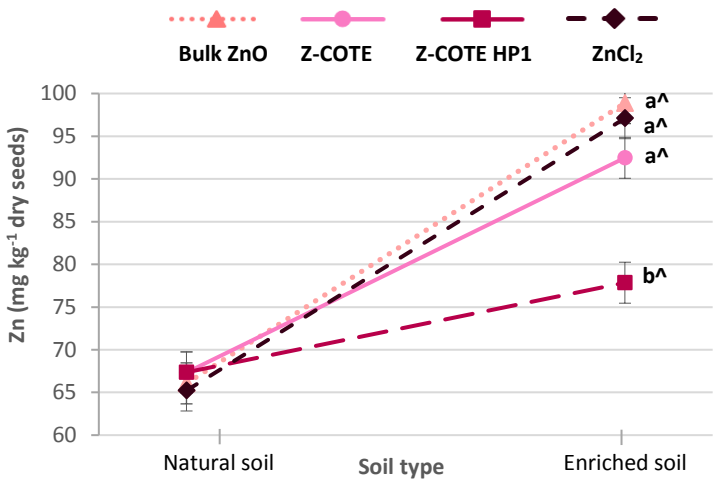

Fig. S3. Soil × compound interaction plot of Zn content of red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1 or $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Data are average of 20 replicates (concentration effect is not considered); and SE= 2.431. Letters represent differences between-compounds within the same soil type and the symbol ^ represents differences between-soil types within the same compound.

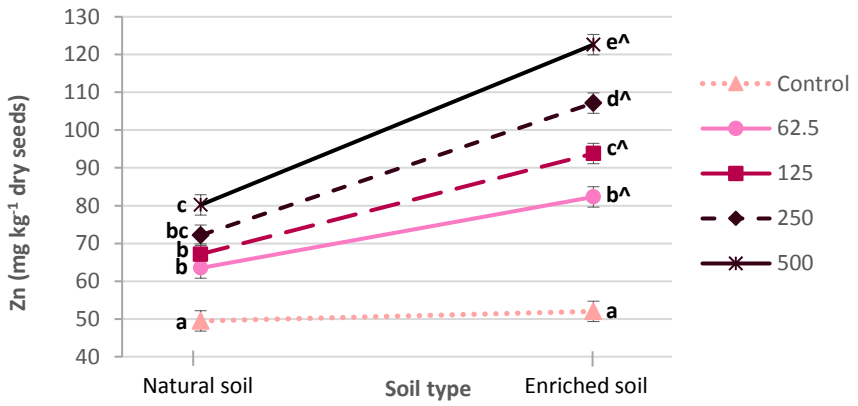

Fig. S4. Soil × concentration interaction plot of Zn content of red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1 or $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Data are average of 16 replicates (compound effect is not considered); and SE= 2.717. Letters represent differences between-concentrations within the same soil type and the symbol ^represents differences between-soil type within the same concentration.

Table S14. Three-way ANOVA summary for potassium (K), phosphorous (P), magnesium (Mg) and calcium (Ca) accumulation.

Tests of Between-Subjects Effects

Dependent Variable: K

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
soil	5781708997	1	5.782E+09	1971.622	0.000 *
compound	83586147.84	3	27862049	9.501	0.000 *
concentration	42650360.35	4	10662590	3.636	0.008 *
soil × compound	4267126.73	3	1422375.6	0.485	0.693
soil × concentration	3457320.844	4	864330.21	0.295	0.881
compound × concentration	89998392.35	12	7499866	2.558	0.005 *
soil × compound × concentration	28680575.43	12	2390048	0.815	0.635
Error	351895624.7	120	2932463.5		
Total	1.04172E+11	160			
Corrected Total	6386244545	159			

Dependent Variable: P

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
soil	1300421623	1	1.3E+09	523.327	0.000 *
compound	120703746.4	3	40234582	16.192	0.000 *
concentration	23185496.34	4	5796374.1	2.333	0.060
soil × compound	46439701.53	3	15479901	6.23	0.001 *
soil × concentration	3417510.675	4	854377.67	0.344	0.848
compound × concentration	33310404.36	12	2775867	1.117	0.353
soil × compound × concentration	46731231.92	12	3894269.3	1.567	0.110
Error	298189258.4	120	2484910.5		
Total	16999066235	160			
Corrected Total	1872398973	159			

Dependent Variable: Mg

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
soil	119437913.4	1	119437913	3396.386	0.000 *
compound	284202.381	3	94734.127	2.694	0.049 *
concentration	187734.77	4	46933.693	1.335	0.261
soil × compound	217522.549	3	72507.516	2.062	0.109
soil × concentration	13384.65	4	3346.162	0.095	0.984
compound × concentration	771654.358	12	64304.53	1.829	0.051
soil × compound × concentration	316534.797	12	26377.9	0.75	0.700
Error	4219941.922	120	35166.183		
Total	1446360275	160			
Corrected Total	125448888.8	159			

Table S14. Three-way ANOVA summary for potassium (K), phosphorous (P), magnesium (Mg) and calcium (Ca) accumulation (continued).

Dependent Variable: Ca

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
soil	26300549.49	1	26300549	183.672	0.000 *
compound	3315830.935	3	1105277	7.719	0.000 *
concentration	234185.133	4	58546.283	0.409	0.802
soil × compound	420305.052	3	140101.68	0.978	0.405
soil × concentration	730833.203	4	182708.3	1.276	0.283
compound × concentration	1571382.479	12	130948.54	0.914	0.535
soil × compound × concentration	1656538.106	12	138044.84	0.964	0.487
Error	17183131.51	120	143192.76		
Total	409293023.6	160			
Corrected Total	51412755.91	159			

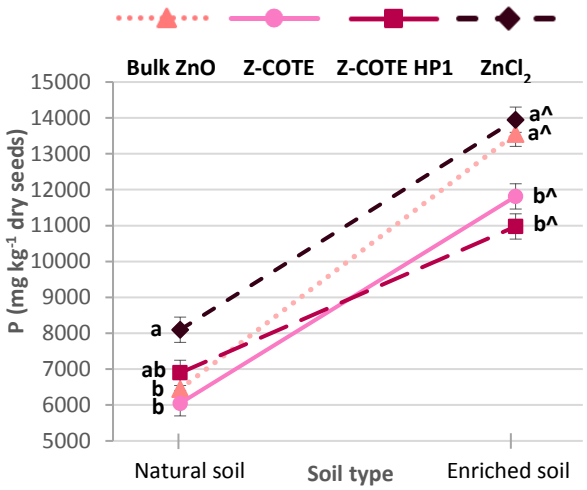

Fig. S5. Soil × compound interaction plot of P content of red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1 or $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Data are average of 20 replicates (concentration effect is not considered); and SE= 352.485. Letters represent differences between-compounds within the same soil type, and the symbol ^ represents differences between-soil type within the same compound.

Table S15. Copper (Cu) content of red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1, and $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Values are relative average ± standard deviation of 4 replicates. Letters represent differences between-compounds at the same concentration and within the same soil type, the symbol ^ represents differences between-soil within the same compound, at the same concentration; *stands for differences against the respective control.

Nutrient	Compound	Concentration (mg kg^{-1})	Natural soil				Enriched Soil			
			$\bar{x}$	±	SD		$\bar{x}$	±	SD	
Cu (mg kg^{-1})	Bulk ZnO	Control	8.63	±	1.20		9.11	±	0.97	^
		62.5	11.12	±	1.51		8.22	±	1.23	
		125	9.59	±	2.26		9.57	±	3.38	
		250	10.36	±	2.41		8.09	±	1.19	
		500	9.58	±	1.22	a	8.48	±	1.46	
	Z-COTE	Control	10.28	±	0.44		7.80	±	0.77	^
		62.5	9.53	±	1.31		7.37	±	0.38	
		125	11.26	±	2.16		8.19	±	2.36	^
		250	9.16	±	0.96		7.94	±	2.06	
		500	9.43	±	1.69	a	8.06	±	0.90	
	Z-COTE HP1	Control	11.19	±	1.18		7.07	±	0.83	^
		62.5	9.83	±	1.39		8.97	±	2.72	
		125	9.53	±	2.19		8.16	±	0.46	
		250	9.99	±	0.92		9.56	±	1.95	
		500	12.78	±	2.07	b	8.04	±	1.76	^
	$ZnCl_2$	Control	10.37	±	1.80		8.47	±	0.84	
		62.5	9.69	±	1.67		9.63	±	1.25	
		125	10.54	±	1.59		10.65	±	2.34	
		250	11.71	±	1.70		9.54	±	2.43	
		500	11.84	±	1.02	ab	9.46	±	0.74	^

Table S16. Three-way ANOVA summary for copper (Cu) accumulation.

Tests of Between-Subjects Effects

Dependent Variable: Cu

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
soil	115.827	1	115.827	41.959	0.000	*
compound	35.254	3	11.751	4.257	0.007	*
concentration	8.554	4	2.138	0.775	0.544	
soil × compound	9.609	3	3.203	1.16	0.328	
soil × concentration	8.195	4	2.049	0.742	0.565	
compound × concentration	26.99	12	2.249	0.815	0.635	
soil × compound × concentration	56.052	12	4.671	1.692	0.077	
Error	331.259	120	2.76			
Total	14937.57	160				
Corrected Total	591.74	159				

Table S17. Manganese (Mn), molybdenum (Mo), and nickel (Ni) content of red kidney bean seeds grown in natural soil (NS) or organic-matter enriched soil (ES) amended with bulk ZnO, Z-COTE, Z-COTE HP1, and $ZnCl_2$ at 0 (control), 62.5, 125, 250, and 500 mg kg^{-1}. Values are average ± standard deviation of 4 replicates. Letters represent differences between-compounds at the same concentration and within the same soil type, the symbol ^ represents differences between-soil within the same compound (also in red font), at the same concentration; *stands for differences against the respective control.

			Concentration (mg kg^{-1})																				
Nutrient	**Soil**	**Compound**	**Control**				**62.5 mg kg^{-1}**				**125 mg kg^{-1}**				**250 mg kg^{-1}**				**500 mg kg^{-1}**			
Mn	NS	Bulk ZnO	^18.02	±	1.47		^17.91	±	1.79		^18.69	±	1.66		^18.36	±	1.15		^18.67	±	2.30	ab
(mg kg^{-1})		Z-COTE	^19.07	±	1.37		^18.00	±	1.78		^20.02	±	5.09		^17.79	±	0.37		^16.29	±	2.11	a
		Z-COTE HP1	^18.81	±	2.18		^17.28	±	0.78		^17.47	±	1.00		^18.96	±	1.80		^18.07	±	1.89	ab
		$ZnCl_2$	^18.48	±	0.25		^16.08	±	4.66		^20.28	±	2.00		^15.93	±	2.33		^22.18	±	6.24	b
	ES	Bulk ZnO	34.30	±	1.99		33.51	±	1.98		34.25	±	2.81		34.55	±	2.09		37.69	±	1.75	
		Z-COTE	34.68	±	4.28		33.88	±	0.77		32.25	±	1.21		35.47	±	2.08		35.58	±	2.38	
		Z-COTE HP1	33.22	±	1.51		33.27	±	1.90		33.05	±	0.26		35.71	±	3.43		36.56	±	1.44	
		$ZnCl_2$	31.77	±	1.37		31.64	±	1.17		31.03	±	1.84		32.97	±	2.35		33.50	±	2.04	
Mo	NS	Bulk ZnO	4.63	±	2.07		7.61	±	4.37		5.41	±	6.85		8.41	±	7.83		6.49	±	3.24	a
(mg kg^{-1})		Z-COTE	4.07	±	3.47		3.68	±	2.14		8.75	±	3.91		6.05	±	2.47		9.29	±	3.07	ab
		Z-COTE HP1	7.93	±	4.50		5.88	±	2.73		7.30	±	3.70		8.39	±	4.69		**^*15.89**	**±**	**5.60**	b
		$ZnCl_2$	7.37	±	3.81		5.86	±	5.48		4.48	±	5.51		^11.06	±	3.13		8.21	±	5.67	a
	ES	Bulk ZnO	6.69	±	1.43		5.90	±	3.80		6.04	±	2.75		5.95	±	1.35		7.29	±	1.14	
		Z-COTE	4.38	±	1.01		1.82	±	1.37		5.65	±	4.38		5.15	±	3.64		5.50	±	1.61	
		Z-COTE HP1	3.53	±	2.28		2.52	±	1.02		2.22	±	1.28		4.32	±	3.61		6.49	±	4.08	
		$ZnCl_2$	3.81	±	0.16		5.60	±	3.18		6.37	±	2.84		3.76	±	3.70		5.95	±	0.85	
Ni	NS	Bulk ZnO	3.24	±	0.80		2.70	±	0.26	a	***1.93**	**±**	**0.81**	a	***1.98**	**±**	**0.51**		***1.63**	**±**	**0.68**	ab
(mg kg^{-1})		Z-COTE	^3.84	±	0.68		***1.78**	**±**	**0.50**	ab	***1.72**	**±**	**0.46**	a	***1.65**	**±**	**0.31**		***1.32**	**±**	**0.38**	a
		Z-COTE HP1	3.17	±	1.09		***1.56**	**±**	**0.57**	b	***1.81**	**±**	**0.66**	a	***1.19**	**±**	**0.35**		***1.81**	**±**	**0.48**	ab
		$ZnCl_2$	^3.95	±	0.39		^4.17	±	1.06	c	^4.15	±	1.48	b	***2.27**	**±**	**0.52**		***2.73**	**±**	**0.39**	b
	ES	Bulk ZnO	2.91	±	0.45		2.25	±	0.24		1.99	±	1.09		2.10	±	0.45		1.75	±	0.55	
		Z-COTE	2.79	±	0.56		1.70	±	0.41		***1.48**	**±**	**0.58**		***1.42**	**±**	**0.32**		1.65	±	0.55	
		Z-COTE HP1	2.66	±	0.60		2.14	±	0.29		***1.45**	**±**	**0.34**		1.61	±	0.46		***1.03**	**±**	**0.31**	
		$ZnCl_2$	2.82	±	0.43		2.83	±	0.36		2.33	±	0.35		2.21	±	0.46		1.98	±	0.38	

Table S18. Three-way ANOVA summary for manganese (Mn), molybdenum (Mo), and nickel (Ni) accumulation.

Tests of Between-Subjects Effects

Dependent Variable: Mn

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
soil	9766.619	1	9766.619	1750.29	0.000	*
compound	32.544	3	10.848	1.944	0.126	
concentration	75.431	4	18.858	3.38	0.012	*
soil × compound	55.966	3	18.655	3.343	0.022	*
soil × concentration	68.655	4	17.164	3.076	0.019	*
compound × concentration	67.767	12	5.647	1.012	0.442	
soil × compound × concentration	80.108	12	6.676	1.196	0.293	
Error	669.601	120	5.58			
Total	120077.58	160				
Corrected Total	10816.691	159				

Tests of Between-Subjects Effects

Dependent Variable: Mo

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
soil	228.843	1	228.843	17.059	0.000	*
compound	27.827	3	9.276	0.691	0.559	
concentration	215.103	4	53.776	4.009	0.004	*
soil × compound	136.111	3	45.37	3.382	0.021	*
soil × concentration	44.621	4	11.155	0.832	0.508	
compound × concentration	200.597	12	16.716	1.246	0.260	
soil × compound × concentration	148.254	12	12.355	0.921	0.529	
Error	1609.805	120	13.415			
Total	8649.012	160				
Corrected Total	2611.161	159				

Tests of Between-Subjects Effects

Dependent Variable: Ni

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	
soil	5.604	1	5.604	15.679	0.000	*
compound	29.817	3	9.939	27.809	0.000	*
concentration	43.444	4	10.861	30.389	0.000	*
soil × compound	5.689	3	1.896	5.306	0.002	*
soil × concentration	3.163	4	0.791	2.212	0.072	
compound × concentration	9.473	12	0.789	2.209	0.015	*
soil × compound × concentration	5.859	12	0.488	1.366	0.192	
Error	42.888	120	0.357			
Total	950.577	160				
Corrected Total	145.935	159				