

Supplementary material

Soil Systems

Processing of municipal waste for phytostabilization of heavy metal polluted soils

S1. Data basis for the calculation of the decrease in NH_4NO_3 soluble heavy metal concentrations in soil caused by plant uptake; calculation was performed for the two treatments None (without amendment) and amendment with biochar from green waste produced at 700°C (GW_P700); means $\pm$ standard deviation ($n = 4$); plants absorbed the heavy metals from 470 g soil

Treatment	Shoot dry mass (g)			
None	0.89 ± 0.09			
GW_P700	1.76 ± 0.06			
	Root dry mass (g)			
None	0.17 ± 0.02			
GW_P700	0.30 ± 0.02			
	Shoot concentration (mg kg^{-1})			
	Cd	Cu	Ni	Zn
None	2.8 ± 0.07	17 ± 4.1	1.7 ± 0.9	89 ± 33
GW_P700	5.2 ± 1.25	18 ± 3.2	1.8 ± 0.3	71 ± 27
	Root concentration (mg kg^{-1})			
None	22 ± 3	1841 ± 47	81 ± 13	339 ± 41
GW_P700	13 ± 6	1352 ± 187	28 ± 7	107 ± 19
	Shoot accumulation (μg)			
None	2.5 ± 0.3	15 ± 3	1.5 ± 0.8	78 ± 26
GW_P700	9.1 ± 2.1	31 ± 6	3.2 ± 0.5	126 ± 49
	Root accumulation (μg)			
None	3.7 ± 5.2	320 ± 47	14.1 ± 3.0	58 ± 8
GW_P700	3.9 ± 2.1	404 ± 64	8.3 ± 2.3	32 ± 7
	Plant accumulation (μg)			
None	6.2 ± 0.7	334 ± 48	15.6 ± 2.7	136 ± 23
GW_P700	13.0 ± 0.3	435 ± 61	11.5 ± 2.8	158 ± 47
	Plant accumulation-induced decrease of soil concentration* (mg kg^{-1} soil)			
None	0.013 ± 0.001	0.71 ± 0.10	0.03 ± 0.006	0.29 ± 0.05
GW_P700	0.028 ± 0.001	0.93 ± 0.13	0.02 ± 0.006	0.34 ± 0.10
	Measured decrease of soil concentration in the rhizosphere (mg kg^{-1} soil)			
None	0.093 ± 0.004	2.19 ± 0.11	0.43 ± 0.01	4.70 ± 0.20
GW_P700	0.012 ± 0.002	0.56 ± 0.28	0.07 ± 0.02	0.21 ± 0.03

*assumptions: (i) plant heavy metal uptake is derived only from the NH_4NO_3 -soluble pool; (ii) no transfer of heavy metals from the non- NH_4NO_3 -soluble to the NH_4NO_3 -soluble pool

For soil without amendment (None), the measured differences of heavy metal concentrations between bulk soil and rhizosphere soil (measured decrease of soil concentrations in the rhizosphere) were larger than the differences which would be expected if lower rhizosphere concentrations would be only due to plant uptake (plant accumulation-induced decrease of soil concentration). This indicates a root-induced reduction of the mobile heavy metal pool in the rhizosphere via root exudates

In soil amended with biochar (GW_P700), the measured differences of Cu, Ni and Zn were similar to the expected differences. For Cd, the measured difference was smaller than the expected difference. This was

possibly due to Cd plant uptake from the non-NH₄NO₃ soluble pool or Cd transfer from the non-soluble to the NH₄NO₃ soluble pool.

S2. Effect of treatments on pH in bulk and rhizosphere soil (contaminated soil); means $\pm$ standard deviation, $n = 4$; GW green waste, BW biowaste

Treatment	Bulk soil	Rhizosphere soil
None	4.97 $\pm$ 0.05	5.09 $\pm$ 0.02
Non-processed GW	5.80 $\pm$ 0.03	5.69 $\pm$ 0.02
GW compost	5.38 $\pm$ 0.03	5.47 $\pm$ 0.05
GW biochar P350	5.81 $\pm$ 0.02	5.92 $\pm$ 0.05
GW biochar P450	5.86 $\pm$ 0.01	6.00 $\pm$ 0.03
GW biochar P700	6.45 $\pm$ 0.05	6.52 $\pm$ 0.06
GW biochar P700a	6.27 $\pm$ 0.04	6.35 $\pm$ 0.06
Non-processed BW	5.55 $\pm$ 0.01	5.67 $\pm$ 0.05
BW compost	5.45 $\pm$ 0.04	5.56 $\pm$ 0.11
BW biochar P350	5.61 $\pm$ 0.02	5.73 $\pm$ 0.03
BW biochar P450	5.81 $\pm$ 0.02	5.93 $\pm$ 0.06
BW biochar P700	6.23 $\pm$ 0.15	6.27 $\pm$ 0.18
BW biochar P700a	5.87 $\pm$ 0.03	5.99 $\pm$ 0.04
Fe-sludge	7.31 $\pm$ 0.05	7.26 $\pm$ 0.08
Ca (OH) ₂ 0.64 g/kg	5.62 $\pm$ 0.26	5.74 $\pm$ 0.19
Ca (OH) ₂ 1,28 g/kg	5.84 $\pm$ 0.22	6.09 $\pm$ 0.12

S3. Relationships between soil pH and mobile heavy metal concentrations in the bulk and rhizosphere soil for different sets of treatments; Org + Fe - soil amendment with organic material or Fe-sludge; Ca (OH)₂ - soil amendment with different amounts of Ca (OH)₂; HM - heavy metal; y = mobile heavy metal concentration; x = soil pH; R² - coefficient of determination

Soil	Treatment set	HM	Equation	R ²
Bulk	Org + Fe	Cd	$y = 90.036e^{-1.254x}$	0.95
Rhizosphere	Org + Fe	Cd	$y = 12.16e^{-1.025x}$	0.96
Bulk	Ca (OH) ₂	Cd	$y = 6.03e^{-0.724x}$	0.68
Rhizosphere	Ca (OH) ₂	Cd	$y = 1.21e^{-0.537x}$	0.73
Bulk	Org + Fe	Cu	$y = 1.77x^2 - 21.87x + 69.42$	0.80
Rhizosphere	Org + Fe	Cu	$y = 1.15x^2 - 140.35x + 44.13$	0.88
Bulk	Ca (OH) ₂	Cu	$y = 3.25x^2 - 37.74x + 112.42$	0.89
Rhizosphere	Ca (OH) ₂	Cu	$y = 0.97x^2 - 11.85x + 38.00$	0.85
Bulk	Org + Fe	Ni	$y = 71.04e^{-0.95x}$	0.90
Rhizosphere	Org + Fe	Ni	$y = 7.81e^{-0.67x}$	0.83
Bulk	Ca (OH) ₂	Ni	$y = 16.97e^{-0.60x}$	0.66
Rhizosphere	Ca (OH) ₂	Ni	$y = 5.46e^{-0.50x}$	0.73
Bulk	Org + Fe	Zn	$y = 420409e^{-2.13x}$	0.96
Rhizosphere	Org + Fe	Zn	$y = 188818e^{-2.11x}$	0.98
Bulk	Ca (OH) ₂	Zn	$y = 1426e^{-1.04x}$	0.63
Rhizosphere	Ca (OH) ₂	Zn	$y = 318e^{-0.88x}$	0.76

S4. Sources of variance for macro-nutrient concentrations in the shoot dry mass; ANOVAs were run separately for non-contaminated and contaminated soil; p-values. Treat Treatment, Fs Feedstock, Pr Processing, Pc Pyrolysis conditions

Source	Non-contaminated soil					Contaminated soil				
	K	Ca	Mg	P	S	K	Ca	Mg	P	S
<i>a) All treatments</i>										
Treat	0.016	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
<i>b) Fresh and composted green waste and biowaste and biochars</i>										
Pr	0.045	0.620	0.001	<0.001	0.837	<0.001	<0.001	<0.001	0.001	0.001
Fs	0.036	0.199	0.151	0.202	0.266	<0.001	0.001	<0.001	0.872	0.010
Fs × Pr	0.421	0.113	0.692	0.012	0.900	<0.001	0.247	0.002	0.665	0.005
<i>c) Only biochars produced under different pyrolysis conditions</i>										
Pc	0.015	0.519	0.436	0.022	0.995	0.412	0.448	0.110	0.301	0.001
Fs	0.041	0.092	0.047	0.007	0.264	<0.001	0.005	0.126	0.778	<0.001
Fs × Pc	0.082	0.212	0.719	0.199	0.849	0.022	0.166	0.346	0.215	0.014

S5. Effect of soil (non-con. non-contaminated; con. contaminated) and treatment on the shoot macro-nutrient concentrations;
means $\pm$ standard deviation, n = 4

Treatment	Shoot mineral concentration (% dry mass)									
	P		S		K		Ca		Mg	
	non-con.	con.	non-con.	con.	non-con.	con.	non-con.	con.	non-con.	con.
None	0.86 $\pm$ 0.11	0.60 $\pm$ 0.03	0.18 $\pm$ 0.01	0.27 $\pm$ 0.02	6.2 $\pm$ 0.85	6.7 $\pm$ 0.31	0.73 $\pm$ 0.08	0.94 $\pm$ 0.04	0.39 $\pm$ 0.03	0.38 $\pm$ 0.02
Non-processed GW	0.89 $\pm$ 0.05	0.65 $\pm$ 0.07	0.16 $\pm$ 0.01	0.25 $\pm$ 0.02	7.1 $\pm$ 0.32	6.9 $\pm$ 0.78	0.65 $\pm$ 0.03	0.50 $\pm$ 0.07	0.27 $\pm$ 0.05	0.19 $\pm$ 0.02
GW compost	0.80 $\pm$ 0.10	0.57 $\pm$ 0.07	0.17 $\pm$ 0.01	0.22 $\pm$ 0.01	6.8 $\pm$ 0.74	7.3 $\pm$ 0.48	0.59 $\pm$ 0.03	0.61 $\pm$ 0.05	0.33 $\pm$ 0.04	0.30 $\pm$ 0.02
GW biochar P350	0.68 $\pm$ 0.04	0.57 $\pm$ 0.04	0.17 $\pm$ 0.02	0.23 $\pm$ 0.02	6.9 $\pm$ 0.24	8.3 $\pm$ 0.34	0.64 $\pm$ 0.04	0.49 $\pm$ 0.02	0.33 $\pm$ 0.05	0.25 $\pm$ 0.01
GW biochar P450	0.70 $\pm$ 0.06	0.58 $\pm$ 0.01	0.17 $\pm$ 0.02	0.25 $\pm$ 0.01	6.8 $\pm$ 0.36	8.3 $\pm$ 0.11	0.65 $\pm$ 0.04	0.48 $\pm$ 0.05	0.32 $\pm$ 0.03	0.25 $\pm$ 0.01
GW biochar P700	0.67 $\pm$ 0.03	0.54 $\pm$ 0.04	0.18 $\pm$ 0.02	0.30 $\pm$ 0.01	7.2 $\pm$ 0.37	8.8 $\pm$ 0.41	0.64 $\pm$ 0.05	0.43 $\pm$ 0.05	0.31 $\pm$ 0.03	0.24 $\pm$ 0.02
GW biochar P700a	0.65 $\pm$ 0.04	0.58 $\pm$ 0.05	0.17 $\pm$ 0.02	0.22 $\pm$ 0.02	6.9 $\pm$ 0.43	9.5 $\pm$ 1.32	0.63 $\pm$ 0.03	0.41 $\pm$ 0.05	0.33 $\pm$ 0.01	0.25 $\pm$ 0.04
Non-processed BW	0.78 $\pm$ 0.04	0.65 $\pm$ 0.07	0.16 $\pm$ 0.01	0.25 $\pm$ 0.03	7.4 $\pm$ 0.18	7.6 $\pm$ 0.19	0.61 $\pm$ 0.06	0.54 $\pm$ 0.04	0.28 $\pm$ 0.01	0.28 $\pm$ 0.01
BW compost	0.83 $\pm$ 0.06	0.58 $\pm$ 0.07	0.17 $\pm$ 0.01	0.23 $\pm$ 0.03	7.0 $\pm$ 0.46	7.2 $\pm$ 0.43	0.63 $\pm$ 0.04	0.65 $\pm$ 0.02	0.34 $\pm$ 0.01	0.33 $\pm$ 0.01
BW biochar P350	0.76 $\pm$ 0.04	0.61 $\pm$ 0.07	0.17 $\pm$ 0.01	0.23 $\pm$ 0.03	7.2 $\pm$ 0.31	7.7 $\pm$ 0.24	0.58 $\pm$ 0.05	0.54 $\pm$ 0.04	0.30 $\pm$ 0.02	0.27 $\pm$ 0.02
BW biochar P450	0.79 $\pm$ 0.05	0.53 $\pm$ 0.02	0.16 $\pm$ 0.01	0.21 $\pm$ 0.01	7.5 $\pm$ 0.25	7.5 $\pm$ 0.27	0.60 $\pm$ 0.04	0.49 $\pm$ 0.02	0.30 $\pm$ 0.01	0.25 $\pm$ 0.01
BW biochar P700	0.66 $\pm$ 0.07	0.56 $\pm$ 0.07	0.16 $\pm$ 0.01	0.23 $\pm$ 0.02	7.4 $\pm$ 0.24	7.7 $\pm$ 0.20	0.62 $\pm$ 0.02	0.50 $\pm$ 0.07	0.29 $\pm$ 0.01	0.24 $\pm$ 0.01
BW biochar P700a	0.71 $\pm$ 0.06	0.56 $\pm$ 0.02	0.17 $\pm$ 0.02	0.20 $\pm$ 0.02	6.7 $\pm$ 0.10	7.2 $\pm$ 0.19	0.65 $\pm$ 0.05	0.56 $\pm$ 0.12	0.32 $\pm$ 0.05	0.29 $\pm$ 0.05
Fe-sludge	0.41 $\pm$ 0.01	0.32 $\pm$ 0.02	0.18 $\pm$ 0.01	0.21 $\pm$ 0.01	6.8 $\pm$ 0.22	6.9 $\pm$ 0.30	0.75 $\pm$ 0.04	0.56 $\pm$ 0.05	0.42 $\pm$ 0.01	0.34 $\pm$ 0.01
Ca (OH) ₂ 0.64 g/kg	0.97 $\pm$ 0.04	0.52 $\pm$ 0.05	0.19 $\pm$ 0.01	0.21 $\pm$ 0.01	6.6 $\pm$ 0.43	6.6 $\pm$ 0.39	0.74 $\pm$ 0.05	0.77 $\pm$ 0.11	0.36 $\pm$ 0.01	0.39 $\pm$ 0.04
Ca (OH) ₂ 1.28 g/kg	0.91 $\pm$ 0.02	0.54 $\pm$ 0.03	0.18 $\pm$ 0.03	0.21 $\pm$ 0.01	6.7 $\pm$ 0.81	6.9 $\pm$ 0.16	0.72 $\pm$ 0.02	0.75 $\pm$ 0.06	0.39 $\pm$ 0.10	0.38 $\pm$ 0.03