Supplementary Materials

Poultry Litter Biochar as a Gentle Soil Amendment in Multi-Contaminated Soil: Quality Evaluation on Nutrient Preservation and Contaminant Immobilization

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Results

Thermal Analysis (TG/DTG) and IR Spectroscopy of PLBs

Figure 1a shows the thermal degradation behavior (TG and differential TG (DTG) of PLBs prepared at different temperature. The mass loss between 50 and 100 °C (150°C for P2) is due to the accumulated water in the sample. The major mass loss occurs for the sample P2 and P3 at 250–300 °C and 300–350 °C, for the sample P4 at 250–350 °C, sample P5 and P6 at 650–700 °C. Additional mass loss occurred in the wide range was due to the overlapping of degradation of different components. The final biochar residue yield of P2, P3, P4, P5, and P6 was 42.4%, 44.7%, 60.1%, 76.1%, and 86.3%, respectively. Thermal degradation profiles changed significantly at pyrolysis temperatures greater than 400°C. The degradation reactions occurred over a much broader temperature range between 400 and 700°C. Generally, the higher the pyrolysis temperature the higher the DTG peak temperature and the residual mass.

Figure 1b shows the strongest characteristic absorbance at the time point of 29.8 min corresponding to DTG peak T_{max} = 325°C for P2, 29.7 min corresponding to DTG peak T_{max} = 324°C for P3, 29.6 min corresponding to DTG peak T_{max} = 323°C for P4, 66.0 min corresponding to DTG peak T_{max} = 688°C for P5, 64.6 min corresponding to DTG peak T_{max} = 674°C for P6, respectively. The changes in the absorbance of volatiles during pyrolysis in Figure 1b agree with the weight loss in the DTG curve shown in Figure 1a. The first stage of pyrolysis occurs below 150°C), and the weight loss is very minimal in TG. The characteristic bands of CO_2, H_2O, CH_4, and CO gradually appear and increase between 150°C and 400°C. Meanwhile, the organic species of furans, phenols, ketones, and aldehydes are generated. The strongest spectral intensity of the above components emerges after 30 min, which corresponds to the maximum weight loss rate in the DTG curve. The last stage of pyrolysis occurs > 400°C, and the absorbance gradually decreases. The releasing of gas products mainly focused at low temperatures (200-400°C).

Discussion

Thermal Analysis (TG/DTG) and IR Spectroscopy of PLBs

The major mass loss could be due to the hemicelluloses and proteins presents in the fibers, because the degradation of hemicelluloses, cellulose and lignin starts between 140 to 356 °C, 306 to 386 °C and 226 to 606 °C (Chaula et al., 2014). The overlapping of degradation of cellulose and lignin, the two major components present in the fiber found in the PL, has resulted in the additional mass loss in the wide range (Baniasadi et al., 2016), and it is the major decomposition step of PL (Basile et al., 2014; Heikkinen et al., 2004). Further, the mass loss beyond 650 °C was contributed by the degradation of $CaCO_3$ (Blamey et al., 2010). As reported by the (Giuntoli et al., 2009) calcium carbonate was used as a food additive in order to strengthen the chicken egg shells. Mimmo et al. (2014) suggested that biochars obtained at temperatures above 360℃ show broader thermal degradation reactions ending at 600°C due to a series of complex chain reactions characteristic of lignin and lignin-like structures as was confirmed by the O/C ratio around 0.7, which is characteristic of non-condensed aromatic structures (Hammes et al., 2006). Thermal analysis has confirmed that pyrolysis temperature affects the biochar structure influencing its recalcitrant characteristics (Mimmo et al., 2014).

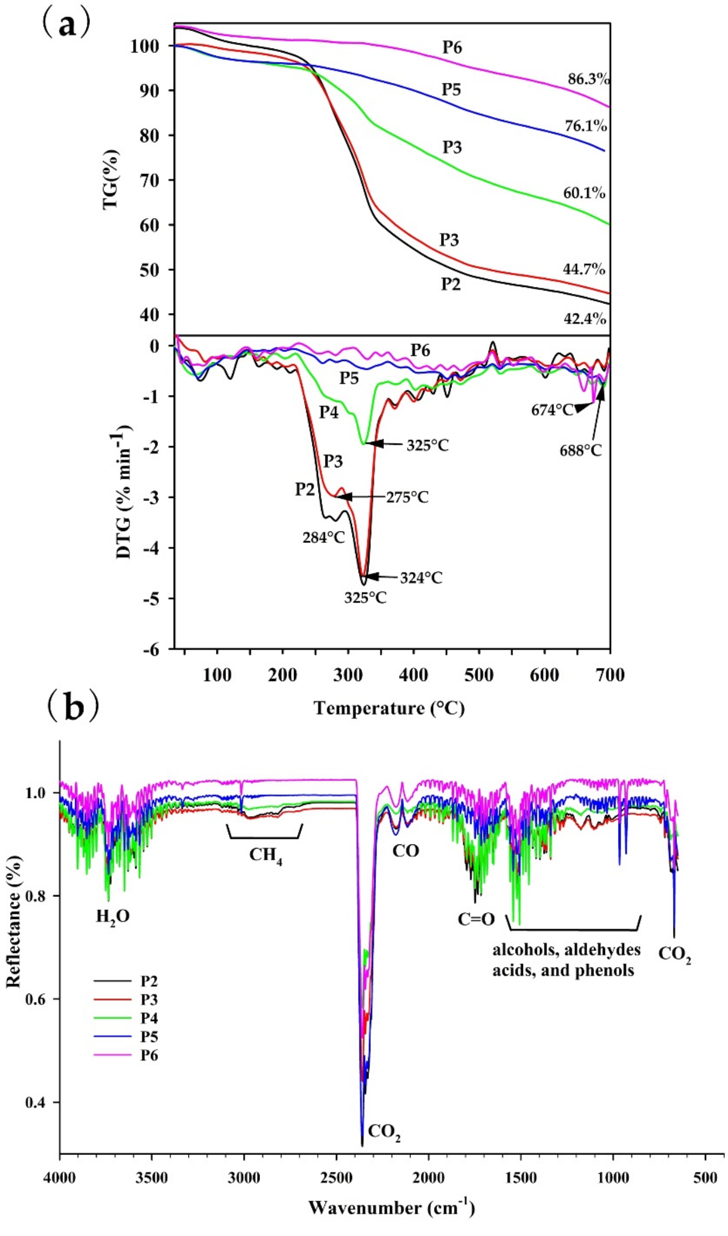

Figure S1. (a) Thermo gravimetric analysis of the five PLBs biochar produces from different temperature at constant heating rate (10°C min^{-1}) with N_2 gas at 20 mL min^{-1}. (b) IR spectrum for six PLBs corresponding to DTG peak (P2, T_{max} = 325°C; P3, T_{max} = 324°C; P4, T_{max} = 323°C; P5, T_{max} = 688°C; P6, T_{max} = 674°C) (P2, P3, P4, P5, P6 = poultry litter pyrolyzed at 200, 300, 400, 500, and 600 °C)

The specific wave numbers of the IR peak of the main gas species from biomass pyrolysis are listed as the following: CO_2: 2363 cm^{-1}, CO: 2167 cm^{-1}, CH_4: 3017 cm^{-1}, carbohydrate contained organic functional groups of C=O: 1730 cm^{-1}, carbohydrate contained organic functional groups C–O–C/C–C: 1167 cm^{-1} (Bassilakis et al., 2001; Yan et al., 2005; Yang et al., 2007). The bands between 4000 and 3400 cm^{-1} represent O-H bond stretching vibrations, related to H_2O, which came primarily from the evaporation and dehydration of the sample. The formation of CH_4, corresponding to the stretching vibration of C-H bonds at (3050–2650 cm^{-1}), can be caused by the cracking of the methoxyl (-O-CH_3), methyl (-CH_3), and methylene (-CH_2-) groups at < 500°C (Fu et al. 2011). The rupture of aromatic rings was observed at 500°C. The obvious characteristic absorbance at 2400–2240 cm^{-1} is representative of CO_2, which is mainly caused by the cracking and reforming of the functional groups of carboxyl (C=O) and carbonyl (C-O-C) (Fu et al., 2010). The characteristic band of CO (2230–2000 cm^{-1}) is very close to that of CO_2. The release of CO can be attributed to the breakage of ether bonds and C=O bonds; the secondary decomposition of the volatiles and char residues at >600°C can also form CO (Granada et al., 2012). The most obvious characteristic absorbance is C=O stretching absorbance (1880–1620 cm^{-1}), which indicates the presence of aldehydes, ketones, and organic acids (Gao et al., 2013). The bands at 1600–400 cm^{-1} are much complex, and identifying each component is difficult. Previous studies showed that these bands indicate the presence of some organics, including alcohols, aldehydes, acids, and phenols (Fasina and Littlefield, 2012; Fu et al., 2012; Granada et al., 2012).

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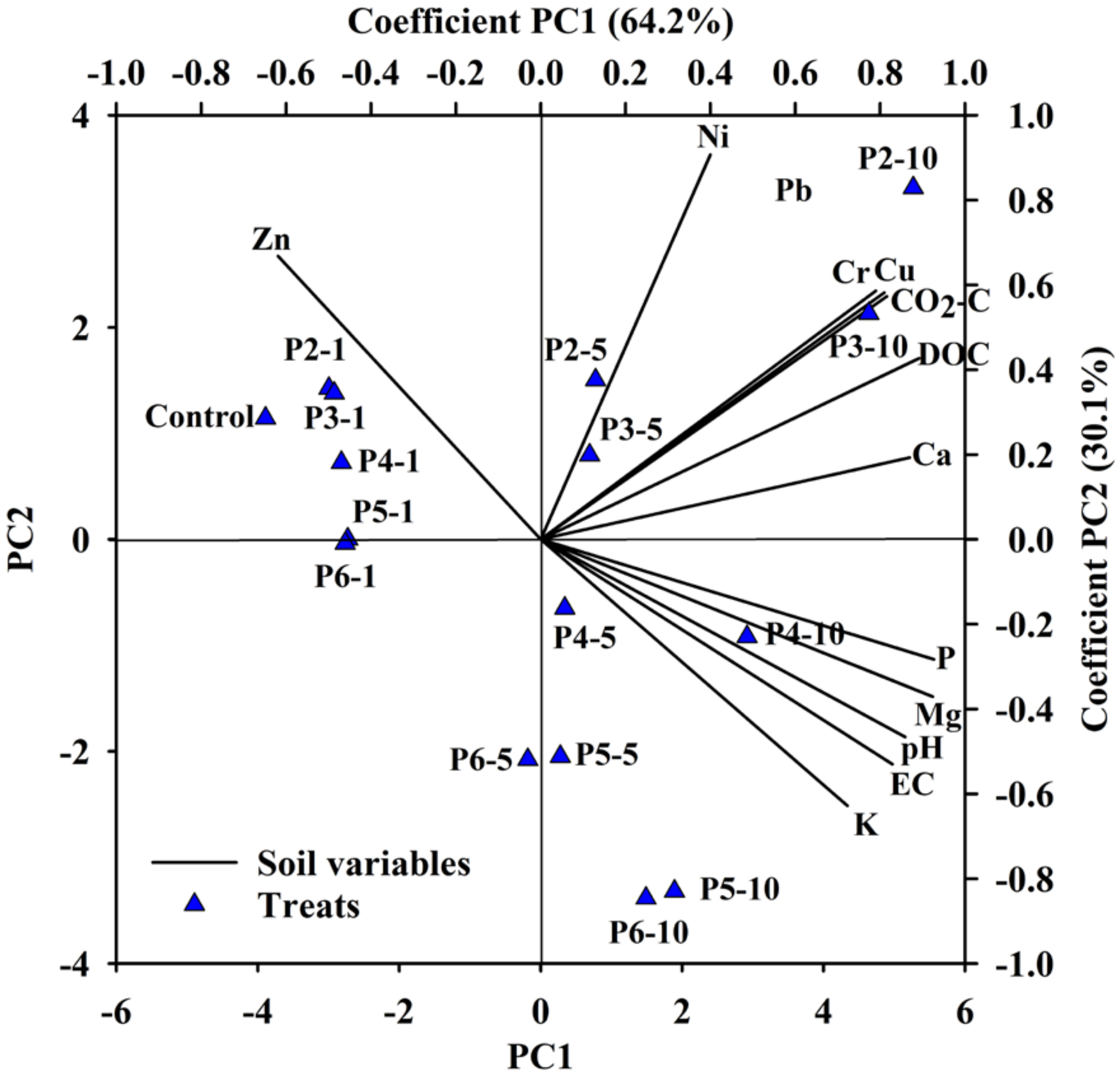

Figure S2. Principal component analysis, based on soil chemical characteristics and cumulative CO_2-C after 56-d incubation period, in soil treated with 0% (control), 5.0% (-5), and 10% (-10) PLB (P2, P3, P4, P5, P6 = poultry litter pyrolyzed at 200, 300, 400, 500, and 600 °C).

Table S1. Characteristics of the five studied biochars.

Characteristics [1]	Raw	P2 [2]	P3	P4	P5	P6
pH [3]	8.10	6.94	6.83	7.12	9.66	9.81
EC (dS m^{-1})	8.96[3]/10.1[4]	9.18[3]/9.23[4]	9.33[3]/9.52[4]	8.50[3]/10.5[4]	8.69[3]/12.4[4]	8.71[3]/12.5[4]
Available N (g kg^{-1})	--[5]	11.4	10.6	5.65	0.94	0.39
CEC (cmol(+) kg^{-1})	30.0	37.5	33.2	21.9	31.5	29.3
M3-P (g kg^{-1})	6.43	7.95	6.32	6.46	8.86	6.38
M3-K (g kg^{-1})	20.4	27.9	24.3	25.4	42.9	35.1
M3-Ca (g kg^{-1})	8.01	8.40	6.96	7.48	10.1	8.29
M3-Mg (g kg^{-1})	4.58	5.45	4.52	4.42	5.76	4.19
Total P (g kg^{-1})	--[5]	9.28	11.6	13.4	20.9	19.8
Total K (g kg^{-1})	--[5]	24.0	28.8	33.4	49.4	47.9
Total Ca (g kg^{-1})	--[5]	17.8	22.8	26.2	40.3	38.3
Total Mg (g kg^{-1})	--[5]	6.14	7.45	8.73	13.8	13.0
C%	33.7	36.4	39.1	41.0	46.4	46.3
N%	2.4	3.17	3.19	3.53	3.55	3.39
H%	5.48	5.42	5.11	4.89	2.74	2.65
O%	42.0	41.5	39.1	34.6	17.4	17.1
S%	1.08	1.10	1.08	1.18	1.84	1.82
(O+N)/C atomic ratio	1.01	0.93	0.82	0.71	0.35	0.34
O/C atomic ratio	0.83	0.76	0.67	0.56	0.25	0.25
H/C atomic ratio	1.95	1.79	1.57	1.43	0.71	0.69

C Type (%) Distribution of C Chemical Shift (ppm) (Integrated Results of Solid-State ^{13}C NMR Spectra)	Raw	P2	P4	P6
Paraffinic C (0–50 ppm)	12	14	20	25
Substituted aliphatic C including alcohol, amines, carbohydrates, ethers, and methyl and acetal C (50–109 ppm)	76	71	57	17
Aromatic C (109–145 ppm)	4.4	5.7	11	35
Phenolic C (145–163 ppm)	3.7	4.3	5.7	10
Carboxyl C (163–190 ppm)	3.5	5.1	4.8	4.9
Carbonyl C (190–220 ppm)	0.2	0.3	1.4	7.8
Aliphatic C [6]	88	85	77	42
Polar C [6]	84	80	69	40
Aliphatic polar C [6]	76	71	57	17

[1] P2, P3, P4, P5, P6 = poultry litter pyrolyzed at 200, 300, 400, 500, and 600 °C; [2] EC = electrical conductivity; CEC = cation exchange capacity; M3 = Mehlich–3 extractable; [3] The pH and EC of the biochar were measured using 1:5 solid; the solution ratio after shaking for 30 min in deionized water was calculated; [4] Biochar EC was measured after shaking the biochar–water mixtures (1:5 solid: solution ratio) for 24 h; [5] -- = No data; [6]Aliphatic C: total aliphatic C region (0–109 ppm); polar C: total polar carbon region (50–109 ppm and 145–220 ppm); aliphatic polar C: polar carbon in the aliphatic region (50–109 ppm). [Abstracted from Tsai and Chang [42]]

Table S2. The results of basic statistical description of soil parameters.

Variable: Cumulative CO_2-C (mg kg^{-1})				
Moments				
N	48	Sum weights	48	
Mean	4491	Sum Observations	215546	
Standard deviation	4415	Variance	19493709	
Skewness	1.409	Kurtosis	0.815	
Uncorrected SS	1884122622	Corrected SS	916204328	
Coefficient Variation	98.3	Std Error Mean	637	
Basic Statical Measures				
Location		Variability		
Mean	4491	Std Deviation	4415	
Median	2248	Variance	19493709	
Mode	1801	Range	14402	
		Interquartile Range	5580	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.7465	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.2967	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.8465	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	4.8138	Pr > A-Sq	<0.0050

Variable: pH				
Moments				
N	48	Sum weights	48	
Mean	5.83	Sum Observations	280	
Standard deviation	0.90	Variance	0.80	
Skewness	-0.31	Kurtosis	-1.66	
Uncorrected SS	1669	Corrected SS	37.7	
Coefficient Variation	15.37	Std Error Mean	0.13	
Basic Statical Measures				
Location		Variability		
Mean	5.83	Std Deviation	0.90	
Median	6.28	Variance	0.80	
Mode	4.90	Range	2.55	
		Interquartile Range	1.68	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.8410	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.2393	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.5768	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	3.2557	Pr > A-Sq	<0.0050

Variable: Electrical conductivity (dS m^{-1})				
Moments				
N	48	Sum weights	48	
Mean	2.63	Sum Observations	126	

Standard deviation	1.30	Variance	1.70	
Skewness	0.27	Kurtosis	-1.09	
Uncorrected SS	411	Corrected SS	79.8	
Coefficient Variation	49.6	Std Error Mean	0.19	
Basic Statical Measures				
Location		Variability		
Mean	2.63	Std Deviation	1.30	
Median	2.61	Variance	1.70	
Mode	1.33	Range	4.11	
		Interquartile Range	2.25	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.9064	Pr < W	0.001
Kolmogorov-Smirnov	D	0.2134	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.2057	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	1.5134	Pr > A-Sq	<0.0050

Variable: Dissolved organic carbon (mg kg^{-1})				
Moments				
N	48	Sum weights	48	
Mean	285	Sum Observations	13661	
Standard deviation	261	Variance	68145	
Skewness	1.50	Kurtosis	1.15	
Uncorrected SS	7090803	Corrected SS	3202825	
Coefficient Variation	92	Std Error Mean	38	
Basic Statical Measures				
Location		Variability		
Mean	285	Std Deviation	261	
Median	181	Variance	68145	
Mode	101	Range	892	
		Interquartile Range	240	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.7609	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.2025	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.7262	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	4.2772	Pr > A-Sq	<0.0050

Variable: P (mg kg^{-1})				
Moments				
N	48	Sum weights	48	
Mean	17.8	Sum Observations	856	
Standard deviation	14.8	Variance	220	
Skewness	0.35	Kurtosis	-1.45	
Uncorrected SS	25597	Corrected SS	10317	
Coefficient Variation	83.0	Std Error Mean	2.14	
Basic Statical Measures				

Location		Variability		
Mean	17.8	Std Deviation	14.8	
Median	15.5	Variance	220	
Mode	2.50	Range	38.8	
		Interquartile Range	31.0	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.8425	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.2184	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.3637	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	2.6209	Pr > A-Sq	<0.0050

Variable: K (mg kg^{-1})				
Moments				
N	48	Sum weights	48	
Mean	793	Sum Observations	38065	
Standard deviation	709	Variance	502683	
Skewness	0.81	Kurtosis	-0.34	
Uncorrected SS	53811634	Corrected SS	23626089	
Coefficient Variation	89.4	Std Error Mean	102	
Basic Statical Measures				
Location		Variability		
Mean	793	Std Deviation	709	
Median	616	Variance	502683	
Mode	174	Range	2223	
		Interquartile Range	995	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.8650	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.1817	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.2724	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	2.0333	Pr > A-Sq	<0.0050

Variable: Ca (mg kg^{-1})				
Moments				
N	48	Sum weights	48	
Mean	477	Sum Observations	22907	
Standard deviation	112	Variance	12443	
Skewness	0.02	Kurtosis	-0.87	
Uncorrected SS	11516723	Corrected SS	584834	
Coefficient Variation	23.4	Std Error Mean	16.1	
Basic Statical Measures				
Location		Variability		
Mean	477	Std Deviation	112	
Median	459	Variance	12443	
Mode	267	Range	421	
		Interquartile Range	183	

Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.9541	Pr < W	0.0586
Kolmogorov-Smirnov	D	0.1291	Pr > D	0.0443
Cramer-von Mises	W-Sq	0.1398	Pr > W-Sq	0.0326
Anderson-Darling	A-Sq	0.8209	Pr > A-Sq	0.0329

Variable: Mg (mg kg^{-1})				
Moments				
N	48	Sum weights	48	
Mean	215	Sum Observations	10301	
Standard deviation	97.6	Variance	9531	
Skewness	-0.13	Kurtosis	-1.57	
Uncorrected SS	2658611	Corrected SS	447973	
Coefficient Variation	45.5	Std Error Mean	14.1	
Basic Statical Measures				
Location		Variability		
Mean	215	Std Deviation	97.6	
Median	227	Variance	9531	
Mode	105	Range	283	
		Interquartile Range	209	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.8654	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.2284	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.3722	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	2.5017	Pr > A-Sq	<0.0050

Variable: Cr (mg kg^{-1})				
Moments				
N	48	Sum weights	48	
Mean	0.206	Sum Observations	9.89	
Standard deviation	0.275	Variance	0.076	
Skewness	2.01	Kurtosis	2.94	
Uncorrected SS	5.60	Corrected SS	3.56	
Coefficient Variation	134	Std Error Mean	0.040	
Basic Statical Measures				
Location		Variability		
Mean	0.206	Std Deviation	0.275	
Median	0.070	Variance	0.076	
Mode	0.060	Range	1.01	
		Interquartile Range	0.215	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.6385	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.3015	Pr > D	<0.0100
Cramer-von Mises	W-Sq	1.3027	Pr > W-Sq	<0.0050

Anderson-Darling	A-Sq	7.1188	Pr > A-Sq	<0.0050

Variable: Cu (mg kg^{-1})				
Moments				
N	48	Sum weights	48	
Mean	2.25	Sum Observations	108	
Standard deviation	2.59	Variance	6.73	
Skewness	1.62	Kurtosis	1.50	
Uncorrected SS	559	Corrected SS	316	
Coefficient Variation	115	Std Error Mean	0.37	
Basic Statical Measures				
Location		Variability		
Mean	2.25	Std Deviation	2.59	
Median	0.86	Variance	6.73	
Mode	0.39	Range	9.03	
		Interquartile Range	2.84	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.7120	Pr < W	<0.0001
Kolmogorov-Smirnov	D	0.3003	Pr > D	<0.0100
Cramer-von Mises	W-Sq	0.9809	Pr > W-Sq	<0.0050
Anderson-Darling	A-Sq	5.5404	Pr > A-Sq	<0.0050

Variable: Ni (mg kg^{-1})				
Moments				
N	48	Sum weights	48	
Mean	2.09	Sum Observations	100	
Standard deviation	1.42	Variance	2.01	
Skewness	0.81	Kurtosis	0.16	
Uncorrected SS	304	Corrected SS	94.4	
Coefficient Variation	67.8	Std Error Mean	0.20	
Basic Statical Measures				
Location		Variability		
Mean	2.09	Std Deviation	1.42	
Median	2.00	Variance	2.01	
Mode	0.49	Range	5.31	
		Interquartile Range	1.96	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.9125	Pr < W	0.0016
Kolmogorov-Smirnov	D	0.1117	Pr > D	0.1372
Cramer-von Mises	W-Sq	0.1365	Pr > W-Sq	0.0365
Anderson-Darling	A-Sq	1.1276	Pr > A-Sq	0.0055

Variable: Zn (mg kg^{-1})				
Moments				
N	48	Sum weights	48	

Mean	2.09	Sum Observations	100	
Standard deviation	1.42	Variance	2.01	
Skewness	0.81	Kurtosis	0.16	
Uncorrected SS	304	Corrected SS	94.4	
Coefficient Variation	67.8	Std Error Mean	0.20	
Basic Statical Measures				
Location		Variability		
Mean	2.09	Std Deviation	1.42	
Median	2.00	Variance	2.01	
Mode	0.49	Range	5.31	
		Interquartile Range	1.96	
Teats for Normality				
Test	—Statistics—		—*p* Value—	
Shapiro-Wilk	W	0.9125	Pr < W	0.0016
Kolmogorov-Smirnov	D	0.1117	Pr > D	0.1372
Cramer-von Mises	W-Sq	0.1365	Pr > W-Sq	0.0365
Anderson-Darling	A-Sq	1.1276	Pr > A-Sq	0.0055

Table S3. Standardized canonical coefficients (SCC) and correlation coefficients (*r*) between the first two canonical discriminant functions (Can) and variables.

Variables	Can1 (82.5%)		Can2 (11.4%)	
	SCC	***r***	**SCC**	***r***
pH	4.856	0.880***	12.60	0.412*
Dissolve organic carbon	-10.00	0.315	12.85	0.865***
P	-1.499	0.856***	6.083	0.451*
K	65.44	0.996***	-25.48	0.052
Ca	-1.660	0.377*	7.810	0.866***
Cr	1.656	0.145	0.454	0.866***
Cu	3.632	0.150	-0.177	0.898***
Zn	-3.396	-0.800***	-2.570	-0.202

[1] * $p < 0.01$; ** $p < 0.001$; *** $p < 0.0001$.

Table S4. Significant test of water extraction solution pH, electrical conductivity, and dissolve organic carbon after 56 days incubation.

Treats[1]	pH		Electrical conductivity		Dissolve organic carbon	
	Mean±SD	Change (%)[2]	Mean±SD (dS m^{-1})	Change (%)[2]	Mean±SD (mg kg^{-1})	Change (%)[2]
Control	4.4±0.07 k		0.8±0.02 l		68.3±2.3 j	
P2-1	4.6±0.07 j	3	1.2±0.01 k	54	105±1.9 i	54
P2-5	5.5±0.06 g	24	2.5±0.03 h	211	360±17 d	427
P2-10	6.5±0.02 d	47	3.5±0.01 d	328	932±28 a	1264
P3-1	4.9±0.02 hi	10	1.2±0.02 k	54	101 ±0.2 i	48
P3-5	6.3±0.01 f	41	2.5±0.03 h	211	324±15 e	375
P3-10	6.6±0.03 c	49	3.7±0.03 c	354	826±17 b	1109
P4-1	4.8±0.01 i	9	1.3±0.02 jk	58	99.3±1.6 i	45
P4-5	6.3±0.03 f	41	2.7±0.08 g	240	272±2.9 f	299
P4-10	6.7±0.03 b	51	4.0±0.03 b	393	554±41 c	710
P5-1	4.9±0.02 hi	10	1.3±0.00 i	65	87.0±1.0 ij	27
P5-5	6.5±0.04 e	45	3.2±0.05 e	291	168±4.1 g	146
P5-10	6.9±0.04 a	54	4.9±0.00 a	507	250±7.5 f	266
P6-1	4.9±0.02 h	11	1.3±0.01 ij	64	82.3±1.0 ij	20
P6-5	6.5±0.01 d	47	3.0±0.03 f	276	134 ±0.9 h	97
P6-10	6.9±0.02 a	55	4.9±0.00 a	502	190 ±1.4g	178

[1]: P2, P3, P4, P5, P6 = poultry litter pyrolyzed at 200, 300, 400, 500, and 600°C; -1 = 1% biochar addition; -5 = 5% biochar addition; -10 = 10% biochar addition; [2]: Percentage expressed as the difference of value between biochar amended treatments and un-amended control treatment; 0% indicates as No change in amount of those properties due to biochar addition; [3]: Means (n =3) compared within a column followed by a different lowercase letter are significantly different at $p < 0.05$ using a one-way ANOVA.

Table S5. Significant test of water extractable P, K, Ca, and Mg after 56 days incubation.

Treats[1]	P		K		Ca		Mg	
	Mean±SD ($mg\ kg^{-1}$)	Change (%)[2]	Mean±SD ($mg\ kg^{-1}$)	Change (%)[2]	Mean±SD ($mg\ kg^{-1}$)	Change (%)[2]	Mean±SD ($mg\ kg^{-1}$)	Change (%)[2]
Control	1.80 ±0.20 h[3]		19.1 ±2.00 l		264 ±4.54 j		66.3 ±1.80 i	
P2-1	2.28 ±0.19 h	27	93.5 ±0.07 k	388	387 ±5.63 gh	46	104 ±1.83 h	57
P2-5	12.7 ±0.64 g	608	498 ±16.1 h	2502	625 ±10.4 b	136	222 ±3.03 g	235
P2-10	35.7 ±0.30 b	1883	1055 ±14.7 d	5410	674 ±5.70 a	155	318 ±1.15 c	381
P3-1	2.30 ±0.20 h	30	100 ±3.26 k	424	384 ±6.88 ghi	45	104 ±2.05 h	57
P3-5	14.5 ±0.24 f	706	555 ±12.2 g	2798	569 ±6.82 d	115	218 ±3.81 g	229
P3-10	39.8 ±0.26 a	2107	1224 ±7.71 c	6297	604 ±5.42 c	128	318 ±1.08 c	379
P4-1	2.36 ±0.14 h	31	122 ±2.82 j	537	389 ±13.0 g	47	107 ±2.60 h	61
P4-5	17.0 ±0.90 e	843	689 ±21.1 f	3499	561 ±21.5 d	112	237 ±8.74 f	258
P4-10	39.6 ±1.18 a	2098	1500 ±18.1 b	7739	556 ±5.11 d	110	335 ±9.54 a	406
P5-1	2.80 ±0.19 h	56	175 ±3.73 i	815	371 ±2.60 hi	40	111 ±0.99 h	67
P5-5	24.1 ±1.35 d	1236	1018 ±8.20 e	5218	511 ±16.4 e	93	267 ±7.00 d	303
P5-10	39.5 ±0.76 a	2092	2231 ±8.56 a	11556	455 ±11.1 f	72	342 ±4.23 a	416
P6-1	2.54 ±0.23 h	41	175 ±3.23 i	814	368 ±4.49 i	39	109 ±0.93 h	65
P6-5	17.4 ±0.65 e	865	1023 ±13.9 e	5242	462 ±5.89 f	75	247 ±2.53 e	273
P6-10	31.1 ±0.56 c	1627	2211 ±20.7 a	11453	456 ±2.88 f	73	326 ±2.57 b	392

[1]: P2, P3, P4, P5, P6 = poultry litter pyrolyzed at 200, 300, 400, 500, and 600°C; -1 = 1% biochar addition; -5 = 5% biochar addition; -10 = 10% biochar addition; [2]: Percentage expressed as the difference of value between biochar amended treatments and un-amended control treatment; 0% indicates as No change in amount of those properties due to biochar addition; [3]: Means (n =3) compared within a column followed by a different lowercase letter are significantly different at $p < 0.05$ using a one-way ANOVA.

Table S6. Significant test of water extractable Cr, Cu, Ni, and Zn after 56 days incubation.

	Cr		Cu		Ni		Zn	
Treats[1]	**Mean±SD (μg kg^{-1})**	**Change (%)**[2]	**Mean±SD (mg kg^{-1})**	**Change (%)**[2]	**Mean±SD (mg kg^{-1})**	**Change (%)**[2]	**Mean±SD (mg kg^{-1})**	**Change (%)**[2]
Control	34.7 ±0.30 h		0.37 ±0.02 i		2.19 ±0.07 f		3.01 ±0.13 b	
P2-1	67.7 ±1.16 fg	95	0.88 ±0.02 fg	139	2.64 ±0.11 e	21	3.14 ±0.15 ab	4
P2-5	310 ±21.0 c	795	4.02 ±0.23 c	993	3.23 ±0.03 c	48	1.52 ±0.16 d	-50
P2-10	986 ±46.3 a	2745	8.90 ±0.42 a	2316	5.41 ±0.24 a	147	1.11 ±0.05 fg	-63
P3-1	65.7 ±1.49 fg	89	0.84 ±0.02 fgh	127	2.69 ±0.11 e	23	3.24 ±0.15 a	8
P3-5	247 ±14.1 d	613	3.40 ±0.19 d	822	2.86 ±0.01 d	31	1.35 ±0.04 e	-55
P3-10	774 ±12.2 b	2132	7.67 ±0.13 b	1983	4.48 ±0.09 b	105	1.00 ±0.06 g	-67
P4-1	53.0 ±2.81 fgh	53	0.64 ±0.04 ghi	73	2.02 ±0.07 g	-8	2.20 ±0.08 c	-27
P4-5	132 ±2.98 e	281	1.85 ±0.05 e	402	1.47 ±0.07 h	-33	0.61 ±0.10 h	-80
P4-10	291 ±31.3 c	739	3.47 ±0.24 d	842	1.99 ±0.14 g	-9	0.37 ±0.02 i	-88
P5-1	45.3 ±2.62 gh	31	0.45 ±0.01 i	23	1.32 ±0.05 i	-40	1.18 ±0.07 f	-61
P5-5	60.7 ±1.72 fgh	75	0.76 ±0.02 gh	105	0.53 ±0.02 j	-76	0.12 ±0.00 j	-96
P5-10	80.0 ±4.30 f	131	1.04 ±0.04 f	183	0.50 ±0.01 j	-77	0.08 ±0.03 j	-97
P6-1	41.0 ±1.32 gh	18	0.39 ±0.01 i	6	1.28 ±0.07 i	-42	1.18 ±0.13 f	-61
P6-5	54.7 ±0.90 fgh	58	0.58 ±0.00 hi	57	0.48 ±0.01 j	-78	0.14 ±0.01 j	-95
P6-10	62.0 ±1.09 fgh	79	0.73 ±0.02 gh	99	0.39 ±0.04 j	-82	0.06 ±0.02 j	-98

[1]: P2, P3, P4, P5, P6 = poultry litter pyrolyzed at 200, 300, 400, 500, and 600°C; -1 = 1% biochar addition; -5 = 5% biochar addition; -10 = 10% biochar addition; [2]: Percentage expressed as the difference of value between biochar amended treatments and un-amended control treatment; 0% indicates as No change in amount of those properties due to biochar addition; [3]: Means (n =3) compared within a column followed by a different lowercase letter are significantly different at $p < 0.05$ using a one-way ANOVA.