Italian Journal of Agronomy
A Journal of Agroecosystem Management
Official Journal of the Italian Society for Agronomy

Appendix

Crop response to soils amended with biochar: expected benefits and unintended risks

Raghunath Subedi, Chiara Bertora, Laura Zavattaro, Carlo Grignani

Italian Journal of Agronomy 2017; [Ahead-of-Print]: 794_Appendix
doi: 10.4081/ija.2017.794

Appendix Table 1. Physico-chemical properties of selected BCs as influenced by feedstock type and pyrolysis temperature (PT).

Reference	Feedstock	PT	C	N	C/N	S	P	K	Ca	Mg	VM	Ash	pH	CEC	SA
		°C	%	%	−	%	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}	%	%	−	cmol kg^{-1}	g m^{-2}
Subedi *et al*., 2016	Poultry litter	400	52.1	5.85	9.0	0.79	12.2	38.8	28.3	17.3	44.9	25.3	9.5	30.2	5.4
Subedi *et al*., 2016	Poultry litter	600	52.8	4	13.0	0.8	15.4	58.8	35.9	24	24.7	35.4	10.4	27.5	6.3
Subedi *et al*., 2016	Swine manure	400	54.9	2.23	24.6	0.24	9.7	16.2	20.3	15.7	29.9	27.5	10	52.5	5.8
Subedi *et al*., 2016	Swine manure	600	57.9	1.79	32.4	0.39	15.5	35.3	28.9	21.3	17.8	34.5	10.4	18.6	10.6
Ameloot *et al*., 2013a, 2016	Swine manure digestate	350	51.3	1.77	29.0	na	1.58	2.296	2.76	0.79	47.5	2.48	7.99	na	1.32
Ameloot *et al*., 2013a, 2016	Swine manure digestate	700	55.5	1.97	28.2	na	2.42	2.81	4.11	1.16	14.2	2.75	9.09	na	9.02
Cantrell *et al*., 2012	Dairy manure	350	55.8	2.6	21.46	0.11	10	14.3	26.7	12.2	53.5	24.2	9.2	na	1.64
Cantrell *et al*., 2012	Dairy manure	700	56.7	1.51	37.55	0.15	16.9	23.1	44.8	20.6	27.7	39.5	9.9	na	186.5
Cantrell *et al*., 2012	Poultry litter	350	51.1	4.45	11.48	0.61	20.8	48.5	26.6	9.46	42.3	37.7	8.7	na	3.93
Cantrell *et al*., 2012	Poultry litter	700	45.9	2.07	22.17	0.63	31.2	74	40.2	14.5	18.3	46.2	10.3	na	50.9
Cantrell *et al*., 2012	Swine solids	350	51.5	3.54	14.55	0.8	38.9	17.8	39.1	24.4	49.8	32.5	8.4	na	0.92
Cantrell *et al*., 2012	Swine solids	700	44.1	2.61	16.90	0.85	59	25.7	61.5	36.9	13.4	52.9	9.5	na	4.11
Cantrell *et al*., 2012	Turkey litter	350	49.3	4.07	12.11	0.55	26.2	40.1	40.4	8.5	42.1	34.8	8	na	2.6
Cantrell *et al*., 2012	Turkey litter	700	44.8	1.94	23.09	0.41	36.6	55.9	56.1	12.4	20.8	49.9	9.9	na	66.7
Mukome *et al*., 2013	Turkey litter	700−800	15.6	0.78	20.0	1.072	66.1	70.5	na	na	na	64	10.9	24.4	21.8
Singh *et al*., 2010	Paper sludge	550	31.6	0.21	150.48	1.59	0.378	0.52	179	2.83	20.9	47.5	9.22	212.1	na
Bachmann *et al*., 2016	Paper sludge +wheat husks	500	51.1	1.39	36.76	0.116	6.054	10.016	62.2	3.324	na	34.7	9.3	na	97.8
Bachmann *et al*., 2016	Sewage sludge	600	18.5	2.13	8.69	0.691	60.531	4.096	33.2	8.877	na	72.4	7.09	na	56.5
Mukome *et al*., 2013	Softwood +algal digestate	600−700	58.1	0.41	141.7	0.0685	0.8	1.9	na	na	na	6.4	6.8	67	2
Ameloot *et al*., 2015	Pine	400	74.4	0.25	297.6	0.00	0.029	na	na	na	30.2	1.05	na	na	0.22
Ameloot *et al*., 2015	Pine	500	81.7	0.22	371.4	0.01	0.036	na	na	na	19.1	1.11	na	na	22.7
Lagharai *et al*., 2015	Pine sawdust	400	51.7	0.86	60.1	na	17.8	78.1	270.4	na	29.2	3.2	4.2	21.5	6.2
Usman *et al*., 2016	Conocarpus	400	76.2	0.42	181.4	na	1.083	9.61	na	na	na	na	9.85	na	109.8
Singh *et al*., 2010	Eucalyptus wood	400	69.7	2.6	26.81	0.028	0.127	1.43	11.2	0.67	27.09	3.21	6.93	39.1	na

Singh *et al.*, 2010	Eucalyptus wood	550	83.6	2.1	39.81	0.049	0.217	2.36	21.3	1.08	11.98	4.42	8.82	34.8	na
Ameloot *et al.*, 2013a, 2016	Willow wood	350	60.6	0.89	68.1	na	0.17	0.332	1.36	0.0805	35.1	0.23	6.26	na	0.68
Ameloot *et al.*, 2013a, 2016	Willow wood	700	74.8	1.34	55.8	na	0.26	0.825	9.56	0.455	22.8	1.28	8.77	na	2.17
Mukome *et al.*, 2013	Hardwood (mixed)	370−520	53.3	1.96	27.2	0.592	4.7	12	na	na	na	15.5	6.8	44.5	95.9
Mukome *et al.*, 2013	Softwood (mixed)	600−700	68.2	0.51	133.7	0.037	1.3	2.6	na	na	na	2.4	7.5	26.2	25.2
Beesley *et al.*, 2013, Fellet *et al.*, 2011	Orchard pruning	500	23.1	0.29	79.66	0.0874	3.69	18.5		9.78	na	na	10	na	141
Genesio *et al.*, 2015; Rombolà *et al.*, 2015	Orchard pruning	500	77.8	0.91	85.49	0.048	23.3	13.9	24.9	28.7	na	19.9	9.8	101	410
Mukome *et al.*, 2013	Softwood (fir)	410	65.7	0.21	312.9	0.005	0.2	1.2	na	na	na	2.6	7.1	10	2.8
Mukome *et al.*, 2013	Softwood (fir)	510	83.9	0.36	233.1	0.011	0.2	1.3	na	na	na	3	7.3	12	165.8
Mukome *et al.*, 2013	hardwood (mixed)	370−520	87.3	0.59	148.0	0.014	0.7	8.5	na	na	na	5	9.2	9.1	164.1
Mukome *et al.*, 2013	Softwood (pine)	500−650	71.2	0.91	78.2	0.048	0.8	7.2	na	na	na	17	7.9	3.2	4.9
Van Zwieten *et al.*, 2010	Green waste	600	78	0.14	557.1	0.0036	0.1	0.55	1.4	0.4	na	na	7.5	3.2	na
Bachmann *et al.*, 2016	Wood shavings	620	81.9	0.35	234.00	0.042	0.765	6.763	21.7	1.724	na	11.3	9.91	na	316.1
Subedi *et al.*, 2016	Wood chip	1000	89.3	0.27	335.4	0	0.73	2.6	13.6	3.2	15.3	7.8	11	14.8	178.3
Puga *et al.*, 2015	Sugarcane straw	700	68.8	0.9	76.4	0.19	0.9	11	7.7	2	na	13.4	10.2	14.3	5
Mukome *et al.*, 2013	walnut shell	900	55.3	0.47	117.7	0.094	6.4	93.2	na	na	na	40.4	9.7	33.4	227.1
Subedi *et al.*, 2015	Miscanthus	250 (HTC)	51.6	0.23	224.3	0	0.455	1.30	4.83	6.63	75.8	6.24	5.61	1.3	5.9
Subedi *et al.*, 2015	Miscanthus	600	73.6	0.26	283.1	0	1.34	7.87	18.37	8.20	14.1	20.83	10.1	22.3	249.9

PT, pyrolysis temperature; VM, volatile matter; CEC, cation exchange capacity; SA, surface area; HTC, hydrothermal carbonisation; na, not available/not analysed.

Appendix Table 2. Trace elements (heavy metals) composition of selected BCs as affected by feedstock type and pyrolysis temperature (PT).

Reference	Feedstock	PT	As	Cd	Cr	Cu[c]	Pb	Mn	Mo	Ni	Zn	PAH
		°C	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Subedi *et al*., 2016	Poultry litter	400	na	bdl	na	349	12.9	1099	na	52	1164	na
Subedi *et al*., 2016	Poultry litter	600	na	bdl	na	366	13.1	1437	na	52	1633	na
Subedi *et al*., 2016	Swine manure	400	na	bdl	na	156	bdl	455	na	26	585	na
Subedi *et al*., 2016	Swine manure	600	na	bdl	na	180	12.8	513	na	26	770	na
Cantrell *et al*., 2012	Dairy manure	350	0.78	0.18	6.58	99	0.89	525	7.83	16.1	361	na
Cantrell *et al*., 2012	Dairy manure	700	1.05	bdl	10.1	163	0.46	867	10	25.3	423	na
Cantrell *et al*., 2012	Poultry litter	350	25.1	0.25	5	213	1.03	640	11	7.79	712	na
Cantrell *et al*., 2012	Poultry litter	700	29.5	0.11	6.86	310	1.09	948	13	11.4	1010	na
Cantrell *et al*., 2012	Swine solid	350	0.91	0.57	24.8	*1538*	2.6	1453	18.3	16.2	3181	na
Cantrell *et al*., 2012	Swine solid	700	1.64	0.23	36.5	*2446*	bdl	2240	27.4	25.6	4981	na
Cantrell *et al*., 2012	Turkey litter	350	138	0.72	8.31	535	2.01	710	7.16	28.6	690	na
Cantrell *et al*., 2012	Turkey litter	700	166	0.73	10.4	726	bdl	986	10.1	39.6	909	na
Domene *et al*., 2015	Bull manure	350	na	0.08	2.1	35.6	3.54	na	na	2.36	132.9	na
Domene *et al*., 2015	Bull manure	550	na	0.42	18.6	44.2	2.47	na	na	14.01	319.5	na
Domene *et al*., 2015	Digested dairy manure	300	na	bdl	2.3	47.5	24.27	na	na	5.75	129.2	0.0003
Domene *et al*., 2015	Digested dairy manure	600	na	bdl	3.1	58.3	bdl	na	na	3.86	200.1	0.0002
Domene *et al*., 2015	Food waste	300	na	bdl	6.3	41.9	41.15	na	na	6.4	49.4	0.0004
Domene *et al*., 2015	Food waste	600	na	bdl	8.7	10.9	bdl	na	na	9.82	64.1	0.0001
Bachmann *et al*., 2016	Paper sludge +wheat husk	500	na	0.17	8.8	28.7	17.4	127	na	7.4	57.4	0.0023
Bachmann *et al*., 2016	Sewage sludge	600	na	3.42	64.2	475	135.7	514	na	60.1	2047.8	0.0008
Hossain *et al*., 2015	Waste water sludge	550	8.8	4.7	230	*2100*	160	na	na	740	740	na
Domene *et al*., 2015	Paper mill waste	300	na	bdl	8.2	17.8	1.62	na	na	7.09	25.71	0.0002
Domene *et al*., 2015	Paper mill waste	600	na	0.002	11	21.2	13.92	na	na	11.27	50.5	0.0003
Domene *et al*., 2015	Oak	350	na	0.55	14.5	120.1	20.66	na	na	9.1	109.1	na
Domene *et al*., 2015	Oak	550	na	0.11	0.9	25.1	5.47	na	na	1.23	15.1	na
Domene *et al*., 2015	Pine wood	350	na	1.4	0.6	13.5	8.5	na	na	1.25	20.9	na

Domene *et al*., 2015	Pine wood	550	na	0.17	4.3	65.3	36.48	na	na	0.84	37.5	na
Fellet *et al*., 2014	Fir tree pellet	350–400	bdl	bdl	bdl	bdl	bdl	358	bdl	bdl	36	na
Fellet *et al*., 2014	Fir+manure pellet	350–400	na	1.35	49.2	296	0.547	524	na	116	350	na
Singh *et al*., 2010	Eucalyptus wood	400	na	na	na	21	na	na	na	4	1312	na
Singh *et al*., 2010	Eucalyptus wood	550	na	na	na	16	na	na	na	23	1599	na
Genesio *et al*., 2015, Rombolà *et al*., 2015	Orchard pruning	500	na	na	na	97	na	84	na	na	104	1.1038
Beesley *et al*., 2013, Fellet *et al*., 2011	Orchard pruning	500	na	0.03	24	17.1	23.3	444	na	16.6	513	na
Kloss *et al*., 2014	Mixed woodchip	525	1.5	0.04	na	17.6	6	168.2	1.1	na	na	na
Bachmann *et al*., 2016	Wood shaving	620	na	0.06	16.3	12	2	301	na	9.4	42.8	0.0029
Subedi *et al*., 2016	Wood chip	1000	na	bdl	na	53	13.2	397	na	40	79	na
Domene *et al*., 2015	Maize stalk	350	na	bdl	2.2	21.5	1.71	na	na	0.98	66.1	0.0016
Domene *et al*., 2015	Maize stalk	550	na	0.16	2.5	30.5	4.31	na	na	2.18	87.8	0.0018
Subedi *et al*., 2015	Miscanthus	600	na	bdl	na	52.5	13.1	656.1	na	52.5	131.2	na
Subedi *et al*., 2015	Miscanthus	250 (HTC)	na	bdl	na	bdl	13.1	91.2	na	0.001	130	na
IBI, 2014	Threshhold limit[a]		12–100	1.4–39	64–1200	63–1500	70–500	na	5–20	47–600	200–7000	6–20
EBC, 2012	Threshhold limit[b]		na	1–1.5	80–90	100	120–150	na	na	30–50	400	4–12

PT, pyrolysis temperature, PAH, polycyclic aromatic hydrocarbon, HTC, hydrothermal carbonisation, na, not available/not analysed, bdl, below detection limit. [a]Values set by International Biochar Initiative; [b]values set by the European Biochar Certificate; [a,b]the lower and upper threshold limits for each element per standard represent the premium and basic quality grade BCs respectively; [c]values for Cu, in italics, exceeding the threshold limit set by both certificate standards.

References

Ameloot N, De Neve S, Jegajeevagan K, Yildiz G, Buchan D, Funkuin YN, Prins W, Bouckaert L, Sleutel S, 2013a. Short-term CO_2 and N_2O emissions and microbial properties of biochar amended sandy loam soils. Soil Biol. Biochem. 57:401-10.

Ameloot N, Graber ER, Verheijen FGA, De Neve S, 2013b. Interactions between biochar stability and organisms: review and research needs. Eur. J. Soil Sci. 64:379-90.

Ameloot N, Sleutel S, Das KC, Kanagaratnam J, De Neve S, 2015. Biochar amendment to soils with contrasting organic matter level: effects on N mineralization and biological soil properties. Glob. Chang. Biol. Bioenergy 7:135-44.

Ameloot N, Maenhout P, De Neve S, Sleutel S, 2016. Biochar-induced N_2O emission reductions after field incorporation in a loam soil. Geoderma 267:10-6.

Bachmann HJ, Bucheli TD, Dieguez-Alonso A, Fabbri D, Knicker H, Schmidt HP, Ulbricht A, Becker R, Buscaroli A, Buerge D, Cross A, Dickinson D, Enders A, Esteves VI, Evangelou MW, Fellet G, Friedrich K, Gasco GG, Glaser B, Hanke UM, Hanley K, Hilber I, Kalderis D, Leifeld J, Masek O, Mumme J, Carmona MP, Calvelo Pereira R, Rees F, Rombolà AG, de la Rosa JM, Sakrabani R, Sohi S, Soja G, Valagussa M, Verheijen F, Zehetner F, 2016. Toward the standardization of biochar analysis: the COST action TD1107 interlaboratory comparison. J. Agric. Food Chem. 64:513-27.

Beesley L, Marmiroli M, Pagano L, Pigoni V, Fellet G, Fresno T, Vamerali T, Bandiera M, Marmiroli N, 2013. Biochar addition to an arsenic contaminated soil increases arsenic concentrations in the pore water but reduces uptake to tomato plants (Solanum lycopersicum L.). Sci. Total Environ. 454-455:598-603.

Cantrell KB, Hunt PG, Uchimiya M, Novak JM, Ro KS, 2012. Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar. Bioresour. Techol. 107:419-28.

Domene X, Enders A, Hanley K, Lehmann J, 2015. Ecotoxicological characterization of biochars: role of feedstock and pyrolysis temperature. Sci. Total Environ. 512-513:552-61.

EBC, 2012. European biochar certificate. Guidelines for a sustainable production of biochar European Biochar Foundation, Arbaz, Switzerland. Version 6.1 of 19th June 2015. Available from: http://www.european-biochar.org/biochar/media/doc/1364855734492.pdf

Fellet G, Marchiol L, Delle Vedove G, Peressotti A, 2011. Application of biochar on mine tailings: Effects and perspectives for land reclamation. Chemosphere 83:1262-7.

Genesio L, Miglietta F, Baronti S, Vaccari FP, 2015. Biochar increases vineyard productivity without affecting grape quality: Results from a four years field experiment in Tuscany. Agric. Ecosyst. Environ. 201:20-5.

Hossain MK, Strezov V, Nelson PF, 2015. Comparative assessment of the effect of wastewater sludge biochar on growth, yield and metal bioaccumulation of cherry tomato. Pedosphere 25:680-5.

IBI, 2014. International biochar initiative. Standardized product definition and product testing guidelines for biochar that is used in soil (version 2.0 of 27 Oct. 2014). Available from: http://www.biochar-international.org/characterizationstandard

Kloss S, Zehetner F, Oburger E, Buecker J, Kitzler B, Wenzel WW, Wimmer B, Soja G, 2014. Trace element concentrations in leachates and mustard plant tissue (Sinapis alba L.) after biochar application to temperate soils. Sci. Total Environ. 481:498-508.

Laghari M, Mirjat MS, Hu Z, Fazal S, Xiao B, Hu M, Chen Z, Guo D, 2015. Effects of biochar application rate on sandy desert soil properties and sorghum growth. Catena 135:313-20.

Mukome FND, Zhang X, Silva LCR, Six J, Parikh SJ, 2013. Use of chemical and physical characteristics to investigate trends in biochar feedstocks. J. Agric. Food Chem. 61:2196-204.

Rombolà AG, Meredith W, Snape CE, Baronti S, Genesio L, Vaccari FP, Miglietta F, Fabbri D, 2015. Fate of soil organic carbon and polycyclic aromatic hydrocarbons in a vineyard soil treated with biochar. Environ. Sci. Technol. 49:11037-44.

Singh B, Singh BP, Cowie A, 2010. Characterization and evaluation of biochars for their application as a soil amendment. Aust. J. Soil Res. 48:516-25.

Subedi R, Taupe N, Ikoyi I, Bertora C, Zavattaro L, Schmalenberger A, Leahy JJ, Grignani C, 2016a. Chemically and biologically-mediated fertilizing value of manure-derived biochar. Sci. Total Environ. 550:924-33.

Subedi R, Taupe N, Pelissetti S, Petruzzelli L, Bertora C, Leahy JJ, Grignani C, 2016b. Greenhouse gas emissions and soil properties following amendment with manure-derived biochars: influence of pyrolysis temperature and feedstock type. J. Environ. Manag. 166:73-83.

Usman ARA, Al-Wabel MI, Ok YS, Al-Harbi A, Wahb-Allah M, El-Naggar AH, Ahmad M, Al-Faraj A, Al-Omran A, 2016. Conocarpus biochar induces changes in soil nutrient availability and tomato growth under saline irrigation. Pedosphere 26:27-38.

Van Zwieten L, Kimber S, Downie A, Morris S, Petty S, Rust J, Chan KY, 2010. A glasshouse study on the interaction of low mineral ash biochar with nitrogen in a sandy soil. Aust. J. Soil Res. 48:569-76.