Theme 2. Soil, groundwater and sediment in the biobased, circular economy

ECOTOXICITY OF BIOCHARS FROM ORGANIC WASTES FOCUSING ON THEIR USE AS SOIL AMELIORANT

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Keywords: biochar, soil amendment, organic waste, ecotoxicity

Abstract

Biochars are produced from organic materials by pyrolysis and are used as soil amendment. According to the feedstock type and the conditions of pyrolysis the properties of the biochars can differ widely. If we apply biochars derived from organic waste materials as soil ameliorant it is important to assess the hazards and the risks of their application. In this study we assessed the physical, chemical, biological and ecotoxicological properties of thirteen biochars from two producers. Our aim was to assess their applicability as soil amendment prior to microcosm and field trials and to choose the best biochars able to improve the quality of degraded soils. The biochars were produced in a PYREG® type pyrolyzer at temperatures between 450 and 700 °C during 15-20 min residence time. The feedstock were grain husks, paper fibre sludge, digestate, wood screenings, miscanthus, vine, black cherry, natural biomass, straw, hazelnut shells, olive stones and meadow. Some biochars were post-treated with compost, organic liquid or stone powder. To assess the potential benefits and risks of their application to soil we measured their water holding capacity, pH, toxic metal content, microbial activity and toxicity to plants (*Sinapis alba* and *Triticum aestivum*) and animals (*Folsomia candida*). The biochars from mixed organic wastes with minerals and the biochar made from vine had elevated toxic metal content that indicates the potential risks of their application. The biochars from straw and natural biomass were toxic both to plants and animals. The grain husk biochars with fibre sludge, the black cherry biochar and the biochar from wood screenings seemed to be the most promising soil ameliorants as they ensured favourable conditions to plants, bacteria and soil living animals.

1. Introduction

Biochar is the product of thermal degradation of organic materials in the absence of air (pyrolysis), and is distinguished from charcoal by its use as a soil amendment (Lehmann and Joseph, 2009). Biochar has been described as a possible means to improve soil fertility as well as other ecosystem services and sequester carbon to mitigate climate change (Lehmann *et al.*, 2006; Sohi *et al.*, 2010).

The European Biochar Initiative (EBC, 2012) has recommended the biomass categories for production of biochar, including garden waste, agricultural and forestry waste, vegetable production waste, animal by-products, paper production waste etc. The feedstock affects several biochar properties with agronomic implications, including ash content (affects the soil mineral content), the H/C ratio (approximates aromaticity of the biochar and is an indication of its ability to be mineralized), pH (increases soil pH of acidic soils and affects mobility of ions in the soil), surface area (helps predict CEC and possible sorption of GHGs) and cation and anion exchange (may determine the potential for NH_4^+ and NO_3^- retention in N cycling) (Singh *et al.*, 2010; Liang *et al.*, 2006, Lehmann and Joseph, 2009, Krull *et al.*, 2009). The chemical characteristics of biochar produced from a feedstock depend considerably on pyrolysis conditions, especially temperature (Antal and Gronli, 2003). At low temperature, biochar chemical composition is closer to the original feedstock while high temperature biochar is closer to graphite (Masiello, 2004).

Benefits of biochar as a soil amendment may vary with its properties, time after its application, and in relation to soil texture and mineralogy. The observed effects on soil fertility have been explained mainly by a pH increase in acid soils (Van Zwieten *et al.*, 2010) or improved nutrient retention through cation adsorption (Liang *et al.*, 2006). However, biochar has also been shown to change soil biological community composition and abundance (Grossman *et al.*, 2010) having a variety of effects on the soil biota which may be associated with its impacts on C and N cycling. In spite of the positive effect that biochar may have on the soil, increasing attention is paid on biochar contamination with polycyclic aromatic hydrocarbons (PAHs) and trace metals (Freddo *et al.*, 2012), therefore posing a potential threat to the environment, a fact confirmed by ecotoxicity tests (Oleszczuk *et al.*, 2013).

This paper has the aim to assess the physical, chemical, biological and ecotoxicological properties of 13 biochars from two producers and to recommend the best fitting biochar for improvement of the quality of sandy soils.

2. Materials and methods

Thirteen biochars produced from various organic waste materials were investigated (see Table 1). The biochars originated from two biochar producers (marked with A and B) and were produced in a PYREG® type pyrolyzer. Type A biochars were produced at 450−500 °C pyrolyzis temperature with 20 minutes residence time and type B biochars were produced at 600−700 °C pyrolyzis temperature with 15 minutes residence time.

To test the possible applicability of the biochars as soil amendment the following properties were measured: pH (Hungarian Standard 21470/2-81:1981), water holding capacity (Öhlinger, 1995), loss on ignition (ash content) (Sluiter *et al.*, 2008), toxic metal content (portable NITON XL3 Analyzer), aerobic heterotrophic colony forming units (Lorch *et al.,* 1995), common wheat (*Triticum aestivum*) and white mustard (*Sinapis alba*) root and shoot growth (Leitgib *et al.*, 2007), Collembola (*Folsomia candida*) mortality (Wiles *et al.*, 1998). Inhibition percentage to plant growth and Collembola mortality was calculated compared to sandy soil. Selected soil properties were also measured for biochars mixed into sandy soil (from Hungary) in 10 weight%.

To select the best biochar(s) for the improvement of sandy soils an evaluation system based on scores (from -5 as the least ideal to 5 as the most ideal) were created. The system took into consideration the ideal properties and effects of a soil amendment for acidic and sandy soil, eg. good water holding capacity, alkaline pH, low ash content, support for microbes, low toxic metal content and no toxic effect.

3. Results and discussion

The results for the thirteen biochars are summarized in Table 1 and 2. It is clear that the properties of biochars from different feedstock vary. However, nearly all of the biochars had alkaline pH and low ash content (high loss on ignition), except for the ones containing stone powder. Some contained high amount of toxic metals (eg. Zn and Cr) compared to the Hungarian Quality Criteria for soil. Most of the biochars have good water holding capacity as they are able to hold more than 100% water compared to their dry mass.

Table 1: Physical and chemical properties of the biochars

Name	Feedstock	WHC	pH	Ignition loss	Mo*	Zn	Cu	Cr
		%		%	mg/kg			
A1	grain husks and paper fibre sludge	169	8.8	60	8	34	15	<DL
A2	A1 post treated with stone powder and compost	105	6.8	32	2	33	<DL	<DL
A3	A1, digestate and different minerals like stone powders, P and Fe	116	8.3	37	14	775	123	59
A4	A3 post treated with organic liquid	114	8.0	40	12	863	133	24
B1	wood screenings	151	9.3	80	12	181	26	31
B2	miscanthus	268	9.2	88	15	29	14	<DL
B3	vine	179	9.8	84	13	316	114	59
B4	black cherry	169	8.5	95	14	46	16	<DL
B5	straw	312	10.0	82	14	274	23	33
B6	hazelnut shells	69	9.6	96	13	63	39	200
B7	meadow	197	9.0	93	22	82	43	154
B8	natural biomass	135	9.8	86	11	30	<DL	<DL
B9	spelts mixed with paper (2:1)	107	9.0	69	14	227	86	19

* The Hungarian Quality Criteria for soil based on KvVM-EüM-FVM Joint Decree No. 6/2009. are 7 mg/kg for Mo, 200 mg/kg for Zn, 75 mg/kg for Cu and Cr. DL: detection limit

The heterotrophic aerobic colony forming number of bacteria and fungi shows that biochars may have been colonized by microorganisms during storage in the open air (Table 2.). This indicates that biochars may ensure a habitat for a variety of microorganisms in soil. The toxicity tests show that most biochars represent a favourable environment for plants, however, five biochars have strongly inhibited (more than 80% inhibition) plant growth. The biochars have moderate effect on Collembolas: most of them caused 20–40% mortality.

Table 2: Aerobic colony forming units and ecotoxicity of the biochars

Name	Bacteria	Fungi	Mustard root	Mustard shoot	Wheat root	Wheat shoot	Collembola
	CFU/g soil		Inhibition %				
A1	1.4E+06	2.1E+04	-59	-21	12	-26	10
A2	4.9E+06	2.3E+05	-49	-19	22	46	0
A3	2.0E+07	1.4E+05	-128	9	31	21	25
A4	1.2E+07	1.7E+04	78	63	-10	47	30
B1	5.3E+05	5.2E+05	47	68	-1	-14	23
B2	2.1E+04	1.3E+03	100	100	15	64	40
B3	9.4E+03	2.8E+03	79	97	89	95	35
B4	4.9E+06	2.8E+03	-165	58	0	-17	18
B5	5.5E+03	8.2E+03	77	96	84	93	53
B6	2.1E+04	-	83	94	75	91	33
B7	6.2E+05	1.0E+03	-47	30	-203	28	38
B8	1.4E+06	2.0E+02	100	100	53	68	50
B9	3.2E+06	9.0E+05	-35	34	18	-22	68

-: not measured

To evaluate the possible toxic or beneficial effect of biochars when applied as soil ameliorants, biochars were mixed into sandy soil at 10 weight% (at 2−5 times higher biochar rate compared to usual application rate). The water holding capacity of the sandy soil increased 1.4−1.7 times in most cases (Table 3.). The same biochars showed toxic (from vine, straw and natural biomass) or stimulating (from grain husks and paper fibre sludge) effect to plants similarly to the tests without mixing them into soil. The results of the Collembola tests, however, are contradictory. It proves the importance of microcosm and field experiments before large scale applications.

Table 3: WHC and toxicity of biochars mixed into sandy soil in 10%

Name	WHC*	Mustard root	Mustard shoot	Wheat root	Wheat shoot	Collembola
	%	Inhibition %				
A1	50	-15	-15	12	-26	35
A2	39	28	57	22	46	60
A3	41	15	65	31	21	20
A4	40	33	77	-10	47	5
B1	45	15	29	-1	-14	10
B2	-	-23	-36	15	64	5
B3	-	69	66	89	95	0
B4	48	-13	11	0	-17	10
B5	-	64	55	84	93	13
B6	-	-18	21	75	91	13
B7	47	7	41	-203	28	70
B8	46	69	60	53	68	15
B9	42	15	34	18	-22	15

*WHC for sandy soil was 27%. -: not measured

A scoring system was created to evaluate the applicability of biochars as soil amendment. The results are shown in Figure 1. Larger total score indicates better performance. From the point of view of further application for the treatment of sandy soils the best biochars were: A1 from grain husks and paper fibre sludge, B1 from wood screenings and B4 from black cherry. However, the treated or post-treated biochars (A2, A3 and A4) seem to be less effective for soil improvement compared to the untreated biochar (A1) based on the selected properties. Vine and straw biochars did not perform well according to this evaluation.

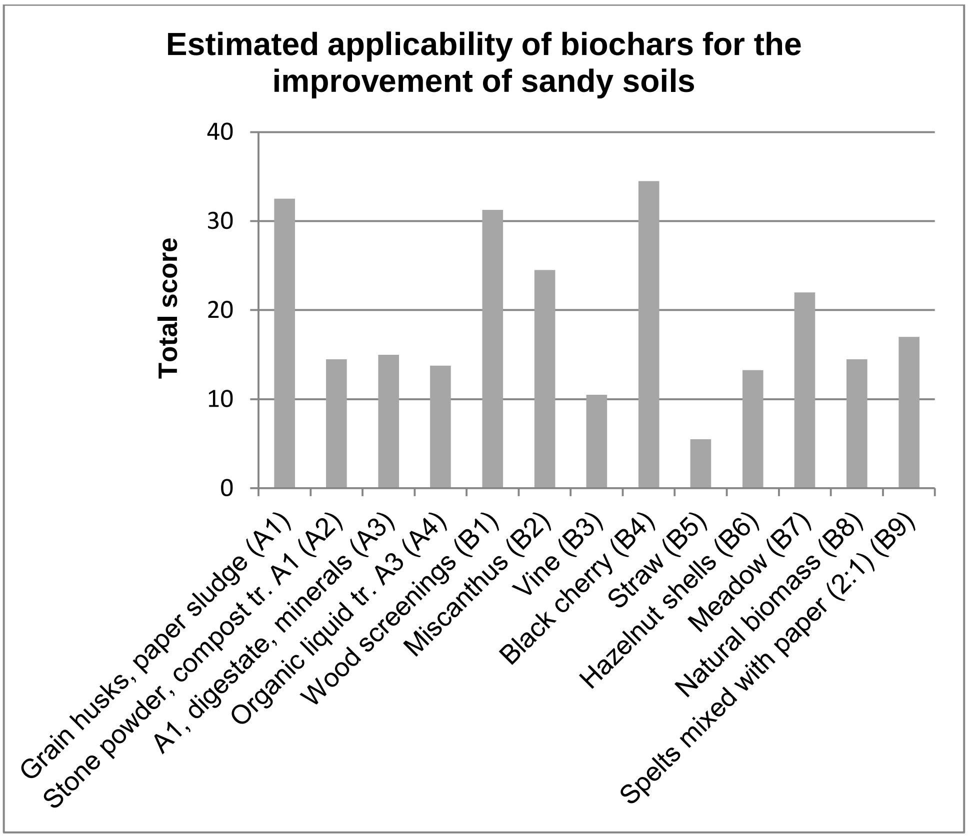

Figure 1: Total score for the tested biochars according to feedstock type

4. Conclusions

In this study selected properties of 13 biochars were tested to assess their future applicability as soil ameliorant. It can be concluded that physical, chemical, biological and ecotoxicological properties of the assessed biochars depend greatly on the pyrolyzed feedstock type. However, the effect of pyrolyzis temperature, residence time, age, storage etc. could also change the biochars' properties and could be further evaluated. We concluded that biochars from grain husk and paper fibre sludge, wood screenings and black cherry had the most favourable properties regarding their application as soil ameliorant in sandy soils. Therefore as the next step of our experiments we will apply these biochars in soil microcosms and field plots for the improvement of sandy soils (see Molnár *et al.*, 2015).

5. Acknowledgement

The work was carried out in the frame of the „Terra Preta" project, registration number HU09-0029-A1-2013 supported by the EEA Grants and the Norway Grants within the „Green Industry Innovation Program" of the Norwegian Financial Mechanism 2009−2014.

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