BIOCHAR - PRODUCTION, DEVELOPMENT AND CHARACTERIZATION FOR ITS USE AS SOIL AMENDMENT

Former: PD Dr. Bruno Glaser, Soil Physics Section, University of Bayreuth, Universitaetsstr. 30, 95440 Bayreuth
Now: Prof. Dr. Bruno Glaser, Soil Biogeochemistry, Martin-Luther-University Halle-Wittenberg, von-Seckendorff-Platz 3, 06122 Halle

Summary
Pyrolysis generates char (Biochar), oil and gas products which can all be used as fuels. However, removal of crop residues for energy production can have deleterious effects on soil organic carbon (SOC) stocks and consequently on soil fertility. Pyrolysis of crop residues with Biochar-C returned to the soil may help maintain or increase stable SOC pools and improve soil fertility. Prof. Glaser did pioneering work identifying Biochar as a key factor for formation and sustainable fertility of Terra Preta (www.bayceer.uni-bayreuth.de/biochar). The Biorefining and Carbon Cycling Program at UGA is capable to produce Biochar from various feedstocks and under various production techniques (www.biorefinery.uga.edu). The proposed collaboration between the University of Bayreuth and the University of Georgia aims at optimizing material properties of Biochar. This increases the immediate benefits for agricultural use and thus reducing the conflicts between different land uses and establishes a significant carbon sink. In total, 66 biochars of different origin (feed stock and process) were investigated. From our results, we suggest the following biochar material properties thresholds: Molar O/C ratio < 0.6, molar H/C ratio < 0.4, Black Carbon content >15%, PAH content lower than national and / or international soil background values. Furthermore, a biochar special issue in Journal of Environmental Quality will be published in 2011.

1. Biochar material properties
In total, 66 biochar originating from different feedstock material and biochar production technologies were investigated. For more details, see Table 1. As proxied for biochar material properties we analysed elemental composition (C, H, N, O), functional groups (phenolic OH and carboxylic groups), polycyclic aromatic hydrocarbons (PAH) and specific surface area (BET method).

Table 1: Investigated biochar samples ordered according to feedstock and production process. Numbers are number of samples and temperature (℃).

Material \ Production process	Charcoal stack	HTC	Others	Pyreg	Rotary kiln	Wood gasifier	Total
Animal meal			1				1
Bamboo					10 / 350-550		10
Bark		1 / 200					1
Bark/needles				1 / 550			1
Coconut shells			2 / 350&650				2
Lop				1 / 550			1
Maize	1 / 350			1 / 550			2
Peanut shells			1 / 500				1
Rice hulls	1 / 350						1
Sewage sludge				1 / 550			1
Sugar beet		1 / 200					1
Sugar cane		19 / 200					19
Girasol			1 / 800				1
Walnut shells			1 / 800				1
Wheat				2 / 550			2
Wood	4 / 350		2 / n.d.		7 / 750	8 / 800	21
Total	6	21	8	6	17	8	66

While elemental composition can indicate the stability of biochar, functional groups are important for the nutrient holding capacity. The two-dimensional plot of the molar ratios of O/C vs. H/C is known as van Krevelen diagram (Fig. 1). From these data, a definition of biochar is suggested as H/C < 0.6 and O/C < 0.4 (Fig. 1). A proper definition of these thresholds is important as also natural organic compounds such as lignin exhibit relatively low H/C and O/C ratios (Fig. 1). From Fig. 1 it is obvious that PYREG and wood gasifier coals can be classified as biochars while coals from hydrothermal carbonization do not fullfil these requirements as they are located in the lignin and brown coal region (Fig. 1). Therefore, HTC material is not biochar.

These results are consistent with investigations on the stability of various biochars yielding mean residence times of pyrolysis chars of about 2,000 years (Kuzyakov et al., 2009) and decades for HTC material (Steinbeiss et al., 2009). Therefore, HTC material is not useful for long-term C sequestration, while pyrolysis coals (biochar) from PYREG and wood gasification are stable for millennia in soils.

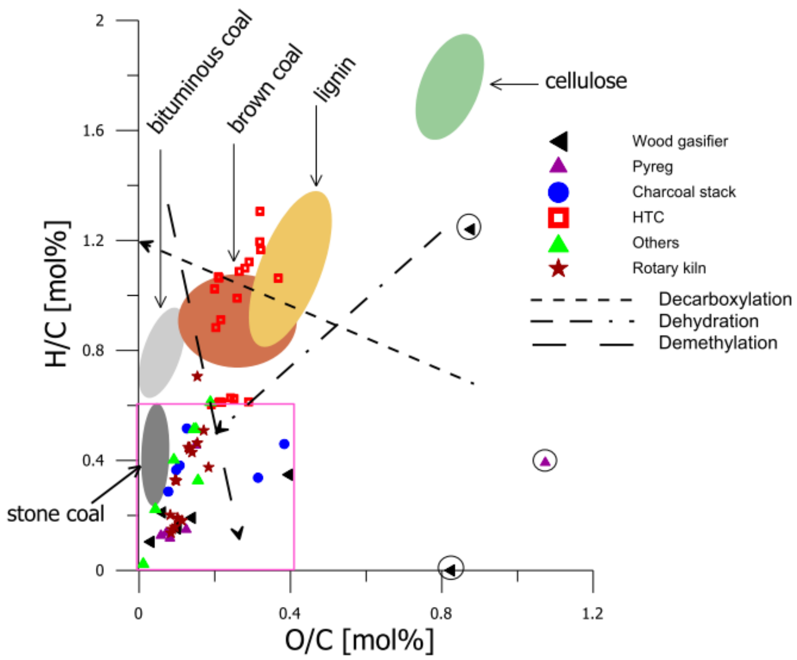

Figure 1: Van-Krevelen diagram of biochars from different feedstocks and production processes (for more details see Table 1) allowing a classification of the degree of condensation which is a measure for biochar stability. We propose the following thresholds for biochar: molar H/C ratio < 0.6 and molar O/C ratio < 0.4.

Another proxy for the differentiation between biochar and non-biochar material is the content of polyaromatic moieties (black carbon) using benzenepolycarboxylic acids (BPCA) as molecular markers (Glaser et al., 1998). As threshold for biochar we propose > 15% black carbon according to the BPCA method (Fig. 2).

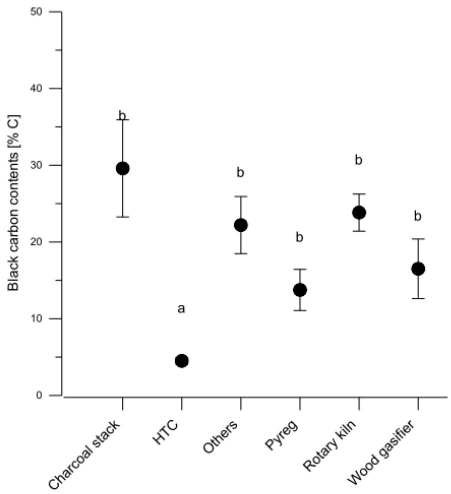

Figure 1: Black Carbon contents of biochars and HTC material presented in Table 1 (mean and standard error, $P < 0.05$, Tukey HSD test).

On the other hand, the specific surface area (BET method) did not allow a differentiation between different chars (Fig. 3). Therefore, no threshold could be determined for this parameter.

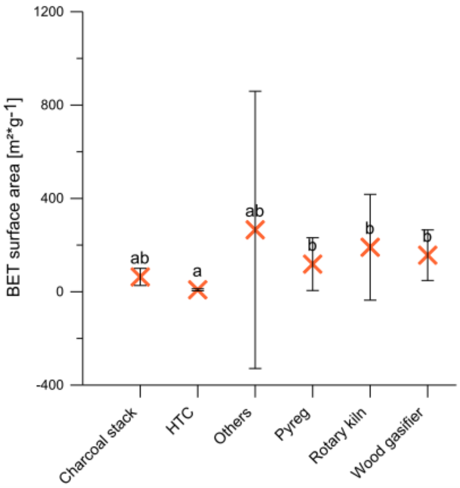

Figure 3: Specific surface area (BET method) of pyrolysis and HTC materials presented in Table 1 (mean and standard error, $P < 0.05$, Tukey HSD test).

A further criterion for the quality of biochar is the lack of contamination with both inorganic (e.g. heavy metals) and organic contaminants (e.g. polycyclic aromatic hydrocarbons (PAH), dioxins etc.). In this study, we could only evaluate polycyclic aromatic hydrocarbons (PAH, Fig. 4). Although chars from wood gasification are within the elemental composition and the black carbon thresholds, they exhibit extremely high PAH contents (Fig. 4). Therefore, they are not suited for soil amendment and thus, they cannot be classified as biochar. Surprisingly high PAH contents were also measured in the barbeque charcoals (Fig. 4) while all other investigated chars had low PAH contents (Fig. 4).

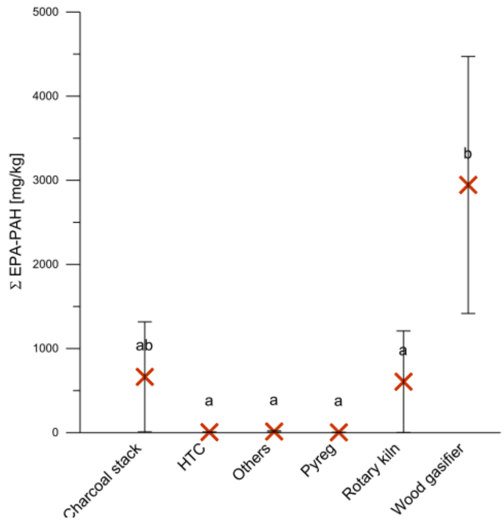

Figure 4: Sum of 16 EPA PAHs of different pyrolysis and HTC coals (mean and standard error, $P < 0.05$, Tukey HSD test).

With a principal component analysis, it is also possible to differentiate between different production processes of biochars (Fig. 5). Therefore, statistical analysis of PAH contents and PAH pattern allows a process allocation of biochars with unclear origin (Fig. 5). High PAH contents are found in wood gasifier and barbeque charcoals which are mostly caused by high naphthalene and high phenanthrene contents (Fig. 5). HTC material is characterized by low PAH contents dominated by phenanthrene (Fig. 5).

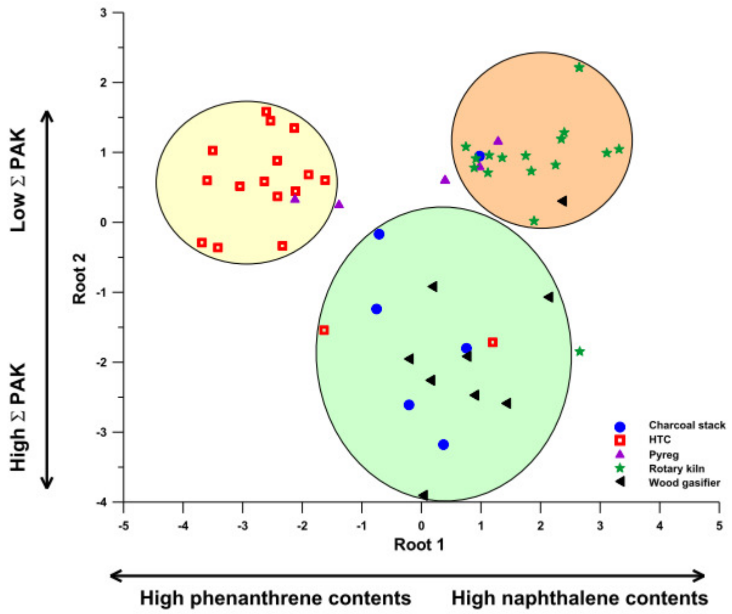

Figure 5: Scatter plot of canonical scores of principal component analysis of individual PAH contents. Each data point represents individual biochar samples.

Summarizing, we suggest the following parameters and thresholds for the identification of bichars: Molar O/C ratio < 0.6, molar H/C ratio < 0.4, black carbon content > 15%, PAH content smaller then local background values.

2. Biochar composts

The objective of a greenhouse experiment was to find the optimal biochar compost mixture and amount for soil fertility and thus, for plant growth. The investigated biochar-composts had increasing biochar amounts ranging from 0 – 500 kg biochar per ton of compost (Table 2). With these mixtures, a pot experiment was conducted with two different soils (sandy and loamy) and oats (*Avena sativa*) were planted and grown for 4 months. Results of this experiment are shown in Fig. 6. On both soils, higher plant growth was observed with increasing amounts of biochar-compost. Interestingly, at the same biochar-compost amendment level, plant growth was higher, the higher the amount of biochar (Fig. 6). This effect was more pronounced on the sandy soil compared to the loamy soil.

Table 2: Applied amounts of compost and biochar (as biochar-compost with increasing amounts of biochar) for the pot experiment with oats (*Avena sativa*) during 4 months growth. Numbers represent the corresponding amounts of compost and biochar (tons per hectare) for individual treatments.

	Compost Mg ha^{-1}			**Biochar Mg ha^{-1}**		
Treatment	**50**	**100**	**200**	**50**	**100**	**200**
B0	**50.00**	**100.00**	**200.00**	**0.00**	**0.00**	**0.00**
B25	**48.28**	**96.56**	**193.12**	**1.72**	**3.44**	**6.88**
B50	**46.78**	**93.56**	**187.12**	**3.22**	**6.44**	**12.88**
B100	**44.09**	**88.18**	**176.35**	**5.91**	**11.82**	**23.65**
B250	**36.95**	**73.91**	**147.82**	**13.05**	**26.09**	**52.18**
B500	**26.96**	**53.91**	**107.83**	**23.04**	**46.09**	**92.17**

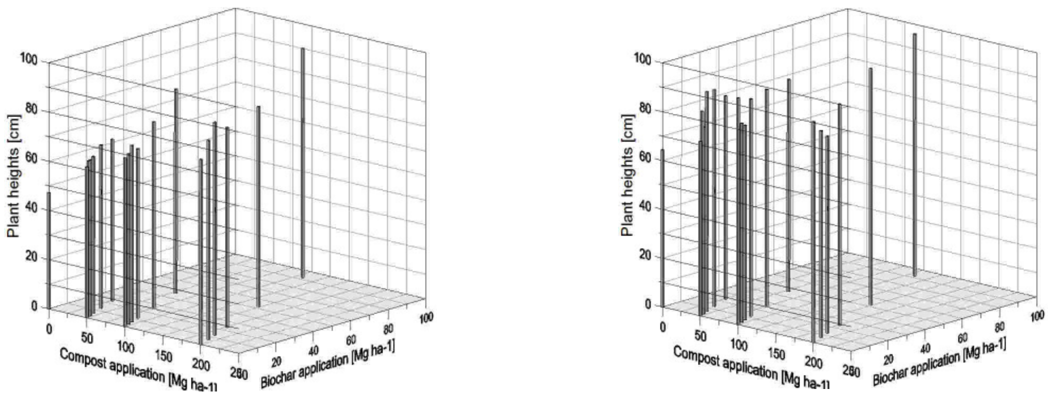

Figure 6: Height of oats (*Avena sativa*) after 4 months growth period in the greenhouse on a sandy soil (left) and a loamy soil (right) as function of different biochar-composts representing a variety of biochar (0 – 50%) and compost amount (0 – 200 Mg ha^{-1}).

3. US Biochar Conference and further action

We participated at the US Biochar Conference (June 27 – 30) in Ames (Iowa). At this conference, further biochar collaboration was discussed. It is planned to collaborate in international Biochar initiatives such as EU calls etc. Furthermore, a joint Special Issue on Biochar will be edited for the Journal of Environmental Quality. A preliminary compilation of proposed Biochar papers is given in Table 3.

Table 3: Planned Biochar manuscripts for publication in the Biochar Special Issue of "Journal of Environmental Quality" (Editors: Glaser Bruno and Jim Ippolito).

Author	Title	Affiliation	MS	Contact
Prost K,Borchard N, Siemens J, Kautz T, Möller A. Amelung W	Changing Properties of biochar from gasification and slow pyrolysis while composting	Soil Science, Bonn, Germany		
Julia Krümmelbein, Nils Dietrich und Thomas Raab	Effects of Biochar/Charcoal on soil structure development as influenced by wetting and drying	Soil Protection, BTU Cottbus, Germany		kruemmel@tu-cottbus.de
Inge Bargmann und Martin Kücke	Effect of soil application of hydrothermal carbonization chars on growth and nutrient uptake of barley and phaceolus beans and nutrient contents in the soil	JKI Braunschweig		martin.kuecke@jki.bund.de
B. Weber[1], E. A. Stadlbauer[1], S. Stengl[1], Ch. Koch[1], K. Albert[2], M. P. Bayer[2], D. Steffens[3]	Production of carbon materials from biomass by hydrothermal carbonization and low temperature conversion: A comparison of techniques	Dept. Of Natural Sciences, University of Applied Sciences Giessen	x	ernst.a.stadlbauer@mni.fh-giessen.de
Jan Mumme, Mamadou Diakité, Jürgen Kern, Fabian Rupp, Lion Eckervogt, Judith Pielert	Hydrothermal carbonization of digestate and cellulose – a comparative analysis	ATB Potsdam		jmumme@atb-potsdam.de
Kloß, Gerzabek et al.	Physical, chemical and ecotoxicological characteristics of slow pyrolysis biochars from different feedstocks	Soil Science, Vienna, Austria		stefanie.kloss@boku.ac.at
Reents H J, Kohls K, Erez B	The effect of Biochar in combinations with organic fertilizer on soil properties and plants in a pot experiment	Ecological Farming Freising		reents@wzw.tum.de
D. Busch, C. Kammann, L. Grünhage, C. Müller	Simple biotoxicity tests for risk evaluation of carbonaceous soil additives: I. Establishment and reproducibility of four test procedures	Plant Ecology, Uni Giessen		
D. Busch, C. Kammann, A. Wagner, S. Schimmelpfennig, B. Glaser?, M. Kaupenjohann, L. Grünhage, Zubin Xie, C. Müller	Simple biotoxicity tests for risk evaluation of carbonaceous soil additives: II. Comparison of different biochars, hydrochars and other soil C additives	Plant Ecology, Uni Giessen		
C. Kammann, S. Hepp, C. Augustenborg, C. Eckhard, L. Grünhage, C. Müller	Effects of different biochars and hydrochars added to soils on CO2, N2O and CH4 fluxes from vegetated and non-vegetated soils	Plant Ecology, Uni Giessen		
Kern, Jürgen	Long-term GHG fluxes on sandy soil amended with different types of biochar	ATB Potsdam		jkern@atb-potsdam.de
S. Schimmelpfennig, B. Glaser	Thresholds for biochar material properties	Soil Biogeochemistry, MLU Halle		bruno.glaser@landw.uni-halle.de