



International Biochar Symposium: Biochar Contribution to Sustainable Agriculture



28th – 29th May 2015, Potsdam



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Heft 89

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Biochar – Contribution to Sustainable Agriculture

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Preface

For some years the application of biochar to agricultural fields has received increased attention by the scientific community as an innovative method to simultaneously sequester carbon in the soil, decrease greenhouse gas emissions from the soil and improve soil fertility. All over the world scientists have initiated research on the production of thermochemical conversion of biomass with different processes to biochars and hydrochars with the purpose of energetic use or application to agricultural soils to improve soil functions. Research on biochar was stimulated by different motivations with different foci around the world. In some Asian countries like China and Malaysia the ban of firing residual biomass in the field has induced the search for innovative concepts for their use. In other countries the mitigation of greenhouse gas emissions due to the carbon sequestration potential and the impact of biochar in soils on nitrous oxide and methane emissions has motivated research on the application of biochar in agriculture. Last not least biochar in the soil impacts agronomic relevant soil parameters and hence can contribute to more sustainable and resilient crop production.

This symposium focuses on research on the conversion of biomass to biochars and the effects of biochar applications on soil functions and the environment and its implications for sustainable agriculture. The Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB) works on the scientific analysis of different methods of carbonization of biomass material and its effects in agricultural systems since 2009 in various projects. The symposium aims to present results of the projects "Biochar in Agriculture – Perspectives for Germany and Malaysia", funded by the Leibniz Association and APECS (Anaerobic Pathways to Renewable Energies and Carbon Sinks), funded by the German Federal Ministry of Education and Research (BMBF) and discuss them with similar research approaches from all over the world. In total this issue contains 69 abstracts of research results from more than 20 countries from five continents.

We wish all participants an interesting and stimulating symposium.

Potsdam, May 2015

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Biochar effects on soil health and ecosystem sustainability

*J. Lehmann***11:30-12:00 Plenary Talk II (Hall 1)**

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Biochar in biorefinery systems - nutrient cycling and carbon sequestration

Mašek¹, O., Peters¹, C.

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Bio-refineries offer the prospect of reduced dependence on fossil fuel resources, not only for fuels, but also for chemicals and materials. A large body of research has been focused on development of methods for modifying plant structures, biomass pre-treatment, conversion and product separation, all with the aim to make an environmentally sustainable and economically viable bio-refinery concept a reality. This presentation will focus on a different aspect of the bio-refinery concept, that is no less important, and in fact can further and expand the concept. Biomass consists of four main constituents, cellulose, hemicellulose, lignin and minerals. The first two, and to some extent also lignin are the key targets for various conversion processes producing biofuels and chemicals. Minerals on the other hand are a by-product whose potential is yet to be realized. As biomass production requires minerals, such as N, P, K and others, the natural way to use this bio-refinery side-stream is as a fertilizer, and thus return it into the natural nutrient cycle. However, depending on the form in which the minerals are extracted during biomass pre-treatment and conversion, direct application to land may not be an option. Even if the minerals are in a form acceptable for land application, it may not be the most effective way, as nutrients supplied in this way are prone to leaching, and a different form of fertilizer, one with controlled release rate of nutrients would be desirable. Such product can be obtained by combining extracted minerals with another bio-refinery by-product, lignin, and subsequent thermal treatment of this blended material, either alone, or with biomass. This could be a particularly advantageous way of utilizing and adding value to low-quality lignins that are difficult to use for other high value applications. By adjusting the blend composition, i.e. fractions of minerals, lignin and biomass, and treatment parameters, such as densification and thermal treatment, it is possible to obtain fertiliser product with defined nutrient release characteristics (can be tuned to application) and desirable physical properties (for storage and handling). In addition, due to carbonization of the lignin (and biomass, if added), the resulting product could be viewed as biochar, and therefore offer carbon sequestration potential, in form of storage of solid stable carbon in soils. Besides bio-refineries utilizing terrestrial biomass, variations of this approach can be also used for residues from marine biomass bio-refineries. Marine biomass, due to its high mineral content offers especially high potential for nutrient recovery, particularly K and P, as demonstrated in recent research undertaken at the University of Edinburgh, results of which will also be presented as part of this presentation. Recovery and re-cycling of nutrients is an important aspect of bioenergy and bio-refinery applications, to achieve environmental sustainability, and biochar produced from or blended with bio-refinery co-products can be a viable solution.

Biochar as part of a farm-based biorefinery

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Biochar is more and more recognized as a multi-purpose multi-talent material that can gain economic value beyond carbon sequestration and soil amendment. One field of particular interest is the use of biochar and its by-product in a farm-based bio-refinery. Following the global strive to evolve from a fossil-fueled economy into a bio-economy, bio-refineries are expected to play a pivot role in the future of biomass use. They are expected to yield a broad range of products from construction materials to bulk chemicals and energies. They combine various technologies to reach a most efficient and, ideally, waste-free system. This work focused on i) the use of biochar from pyrolysis and HTC as bio-catalyst in anaerobic digestion (AD) for biogas production, on ii) AD of waste liquors from HTC (i.e. excess process water) and pyrolysis (i.e. bio-oil), and iii) formation of valuable chemicals during HTC. The results show that biochars can help to overcome process inhibition in AD, while vast parts of the waste liquors can be upgraded into biogas by simple AD technologies. Furthermore, biochars treated by AD were enriched with plant nutrients and HTC-derived chars showed less plant growth inhibition than fresh chars. With respect to HTC, extraction of high-valuable chemicals like 5-HMF from the process liquor could become a major source of income. Thus, it seems likely that biochar as both product and technology will play a major role in tomorrow's bio-refineries.

Biochar production in cookstoves as an opportunity for small-holder farming systems in Kenya

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2 ICRAF - World Agroforestry Centre

Biochar, or black carbon formed by heating biomass under oxygen-limited-conditions, can be used as a soil amendment to improve soil productivity and sequester carbon in the soil. However, for understanding the potential of biochar to contribute to reductions in greenhouse gas emissions, the alternative fate of biomass used for biochar production must be considered. Biochar-producing cook-stoves can have additional beneficial effects on greenhouse gas emission reductions and health by reducing fuel demand and reducing smoke. In a research project in Kenya, biochar production and use are investigated in small-holder farming systems. The effects of biochar on local soils are tested in pot and field trials. Moreover, the energy efficiency and GHG emission reduction potential from biochar producing cook-stoves are tested in participatory field trials. The cook-stove tests show significant reductions in fuel required to cook a standard meal, as well as reduced PM and CO emissions, in addition to well-functioning biochar production. In conclusion, biochar is seen as a very viable option in providing small-holder farmers with a win-win-win situation in their quest to improve soil productivity and crop yields, energy efficiency and health.

Investigation of phosphate and ammonium sorption capacities of treated and untreated biochars

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As the need for effective phosphate and ammonium recovery is important from environmental and socio-economic aspects, the objectives of this study were to investigate the phosphate and ammonium adsorption capacities of treated and untreated biochars derived from waste biomass feedstock and to evaluate the influence of physicochemical properties including elemental content, mineral content, CEC and surface functionality on nutrient sorption. Overall, this work was aimed at promoting a better understanding of the interaction of nutrients in low and high-temperature biochars produced from greenhouse waste and oak. Biochar post-treatment and biomass pre-treatments were done with acids, alkaline solutions and metal salts to investigate the effect of such treatments on phosphate and ammonium sorption. Phosphate and ammonium adsorption capacities were determined by adding 100mL of either phosphate or ammonium solutions to biochars and shaken at room temperature, after which 10mL aliquots of each sample were taken after 24 hours and filtered through 0.45µm syringe filters for Ion Chromatography analysis. The concentration of adsorbed ions were determined from the difference in initial and final phosphate and ammonium concentrations, taking into consideration biochar mass and volume of solution used. This procedure was repeated at varying phosphate and ammonium concentrations to determine the mechanism by which sorption occurred. Results showed that while untreated biochars adsorbed 0-4.4% and 9.4-11.5% phosphate and ammonium respectively, the treatment of oak and greenhouse waste improved phosphate adsorption from 3.6% to 70.3% in oak biochars, and from 2.1% to 66.4% in greenhouse waste biochars, which compare favourably with other adsorbents. However, ammonium adsorption in treated biochars improved only marginally. Based on findings from this study, it may be concluded that it is possible to enhance biochar phosphate adsorption capacities by the treatment of biochars or biochar precursors (raw feedstock). Findings also suggest that biochar mineral composition and surface functionality are key properties influencing biochar phosphate and ammonium adsorption capacity.

The Bespoke Biochar concept - elements of evidence

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Literature that documents effects of biochar on soil processes and plant growth is extensive, both under controlled conditions and in the field. Meta-analyses reflect the range in these effects as well as establishing their generalities. But there are few data points to capture the longevity of effects or dose–response relationships. The theoretical permutations of biochar types and soil types are almost infinite, are further extended when dose and frequency options are considered. Most studies deal with a small, manageable number of these possibilities, constrained further by availability of suitable biochar materials or other resource.

In the real world different constraints are imposed. Regulation, access to biomass and the availability of pyrolysis technology are key issues. Sometimes these constraints are absolute, but more often there is a large economic or social component: risk, wealth, work, time and so on. Decisions are at least based on an expectation or perception that benefits will considerably exceed the costs of implementation. Importantly the socio-economic context is also not static: climate change superimposed (in many countries) over urbanisation and industrialisation are relevant in determining which agricultural innovations can succeed.

The bespoke biochar concept recognised that the options that potentially work in a particular situation are fundamentally limited by the biophysical context – constraints to crop production being related to soil and climate interactions. But increasingly the socio-economic considerations have come to the fore. In many cases we needed to augment our basic understanding of biochar materials and relationships between their properties, function and manufacture. Rather we needed to propose modes that should be viable from a socio-economic perspective as well as sustainable in biophysical and environmental terms.

As part of a consortium project, UKBRC have tested the bespoke biochar concept in this wider context in Tamale, northern Ghana. The socio-economic constraints were established first, through survey by the Forestry Research Institute of Ghana with University of East Anglia, UK. The soil constraints were examined between Soil Research Institute of Ghana and UKBRC. A bespoke biochar option was judged to have a viable biophysical context in this case, leading to field tests aimed at alleviating key nutrient–pH constraints to crop growth. Availability of biomass for making suitable biochar and threshold crop response were defining criteria, the dose based on an assumed repeat frequency and sustainable rate of supply.

Tests at three farms in each of three villages found that our bespoke option generally achieved the required doubling of maize yield, when treated as an alternative to rec-

ommended management of crop nutrients using fertiliser. However, a reference biochar option performed equally well and, while we tested biochar as both an alternative and supplement to a fertiliser option we did not present a counterfactual. We did not fully consider the viability of locally designed manufacturing equipment, or extend the definition of bespoke biochar to composite products. These should be the logical extension to this initial test of purposeful selection recognising systems fit.

Interaction effects of biochar with nitrogen fertilizer applications to agricultural soils

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Biochar is known for its effects on agroecosystems, which may benefit farmers and the environment by increasing crop yields and mitigation global warming by sequestration of carbon in the soil and impacting soil microbial processes such that N₂O emissions from the soil are reduced.

However, the impacts of biochar applications to the soil are very complex and may also lead to undesired processes such as crop yield penalties and potentially adverse effects on the environment. This paper focuses on the interaction effects of nitrogen fertilizer and biochar applications. It analyzes the impact of biochar in interaction with nitrogen fertilizer on available nitrogen in the soil (N_{min}), N₂O emissions, response to soil biota and crop development. Further the question, to what extent biochar application may have an effect on optimal nitrogen fertilizer application is addressed based on crop response data from 2 years.

For this analysis data from a field experiment, located in Berge, Brandenburg, were used. The experiment was set up in September 2012 as a multifactorial experiment with different biochars (7.7 Mg biochar-C ha⁻¹). For this analysis we used data from the control and one biochar treatment with pyrolyzed wood, which was investigated in interaction with 4 different nitrogen fertilizer levels.

A combined analysis of yield response in 2012 and 2013 showed statistically significant effects of fertilizer application rates and statistically significant interaction effects of the factors biochar and nitrogen fertilizer application. The impact of biochar application on crop yields did not exceed 10 % of the crop yield for each level of fertilizer application. While at lower fertilizer rates biochar treatments had higher yields, this trend was reversed at higher fertilizer levels. Apparently the effects of biochar interact with nitrogen fertilizer supply.

Yield parameters, plant nutrient uptake and soil properties of rice cultivated on peaty soil amended with rice husk biochar

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Currently, rice husk biochar (RHB) is the only biochar available for commercialization in Malaysia, which is produced at rice mills as by-product from small scale producer. The application of this biochar as soil amendment is deemed feasible, logistically, for the improvement of rice production. A field trial was conducted to investigate the effects of RHB on rice cultivated in an area with peaty soil (pH 5.58, 172 g kg⁻¹ organic carbon and 6 g kg⁻¹ total nitrogen). The RHB (210 g kg⁻¹ C and pH of 8.46) was applied at the rates of 0, 5, 10, and 20 Mg ha⁻¹ and laid in randomized complete block design (RCBD) with four replications. RHB was applied one week before rice seeds (variety MR263) were sown through direct broadcasting. Harvesting was done at 112 days after sowing and plant sampling was carried out with 1 m² quadrants to determine rice yield components (grain yield, straw dry matter weight, number of tillers and panicles, panicle length, weight of 1000 filled grains, and percentage of filled grains). Total plant nutrient uptakes for nitrogen, calcium, magnesium, potassium, zinc, manganese, and copper were also determined. Soil samples were collected and analyzed for organic C, total N, available phosphorus, and pH. Results of the first crop cycle showed that peaty soil amended with RHB has the potential to improve rice crop production. The grain yield was positively correlated ($r^2 = 0.71$) with RHB application rates, with threshold level of 16 Mg ha⁻¹ RHB resulting in 7.63 Mg ha⁻¹ of grain yield. The grain yield was also positively correlated with panicle length ($r = 0.67$) and percentage of productive tiller ($r = 0.77$). Although, there was no significant effect on the straw dry matter weight and total number of panicle, but the percentage of productive tiller showed positive increment. Grain yield from the first cycle was positively correlated with the cumulative uptake of P ($r = 0.72$) by the rice plants. The RHB application significantly promoted an increment in percentage of productive tillers by 13% over the control treatment. A higher carbon content RHB, 437 g kg⁻¹ was applied in the second crop cycle. However, there was no significant positive response of RHB on grain yield, probably due to an uncommonly prolonged drought period. The application of RHB had no significant effects on the soil organic C, total N, available P, and pH for both crop cycles. Thus, the soil pH falls in the range of 5.4 to 5.8 after RHB application. Further study is needed to determine the long term effect of RHB soil amendment on rice cultivated on peaty soil.

Potential use of low-temperature gasification biochar as nutrient provider and soil improver – field evaluation

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Low-temperature gasification utilises biomass fuels with high ash content, such as straw, with high efficiency. The process can also destroy pathogens and unwanted organic substances in e.g. sewage sludge. This allows developing biochar as valuable soil amendments, also securing safe return of non-renewable resources such as phosphorus (P). The economic feasibility and sustainability of the technology is likewise improved. The objective of the present study was to test the amendment of soil with gasification biochar (GB) products in two experiments in farmer's fields, focusing on 1) soil fertility and carbon sequestration and 2) phosphorus fertilizer value.

On a temperate sandy loam soil (EXP1) macro-plots (12x100m) were established comparing straw incorporation or removal with straw GB application at rates of 0.5 – 10 tons ha. On a similar soil type, but depleted in P (11 mg P kg⁻¹ soil), standard plots (4x10 m) were established comparing two different superphosphate fertilizer levels with alternative P sources from straw GB, straw/sewage sludge GB and raw sewage sludge (EXP2). A number of classical agronomic soil and crop parameters were determined in both experiments.

Close dialogues with the individual farmer involved and other interested stakeholders in workshops were used to evaluate current findings and perspectives.

In EXP1, GB had a positive effect on chemical soil properties without any negative effects on soil biota and crop yields. The application of the highest GB dosage resulted in an increase of soil exchangeable potassium and soil pH. In EXP2, straw GB gave by tendency rise to higher yields compared to straw/sludge biochar at the lower P application rate, however, the overall spring barley yields were not significantly increased even after the addition of 60 kg superphosphate ha⁻¹, which might be attributed to a high P fixing capacity of the soil.

Judged by two years experimentation, straw GB as a fertilizer and a soil carbon sequestration agent was regarded as promising, showing the possibility to produce bioenergy from crop residues without negatively affecting soil quality. The relative costs and benefits for the farmers adopting such a new technology are still unclear though. Further research are also needed to verify specific nutrient plant availability in GB when substitut-

ing traditional mineral fertilizers. Several farmers raised concern about negative longer term consequences reducing microbial services when incorporating a rather inert material like GB instead of straw.

The use of agricultural residues and urban waste streams for bioenergy and subsequent return of residuals to agricultural soils is an important step towards closing nutrient cycles. Our results indicate that GB can be utilized as a renewable fertilizer and liming agent without any harmful effects on soil biota. However, more demand-driven involvement of farmers is required to bring the practical application of biochar into play.

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Trends in the local manufacture of biochar reactors – the Ghanaian experience

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The production of biochar has witnessed over the past years various variations in the design and construction of biochar reactors as well as the production and operation conditions with respect to the pyrolysis characteristics and the final temperature. Pyrolysis temperatures have an effect on biochar pH, CEC, OC content, O:C ratio, porosity and consequently on the microbial community.

Gaps in the scientific knowledge of biochar can be associated with the fact that the production protocols have not yet been standardized. The IBI Biochar standards do not prescribe production and handling parameters for biochar, but do include recommendation for safe production processes. It is the responsibility of the biochar manufacturer to produce biochar in a safe manner that complies with local and international regulatory requirements and treaties that govern thermal processes with respect to the production of volatile and particulate emissions and transport of goods. There is therefore the need to establish biochar production conditions that are consistent, reproducible and predictable such that comparative analysis can be made. The development of biochar reactors in Ghana have over the past years gone through various stages in the attempt to establish appropriate pyrolytic conditions for the reactors as well process control mechanisms for the fuel combustion necessary for the control of temperature. Various types of fuel for the combustion process have also been examined.

Comparison of the levels of polycyclic aromatic hydrocarbons in biochars and hydrochars

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To investigate the pollutants formed during the production of biochars and hydrochars derived from various waste biomass feedstocks, levels of polycyclic aromatic hydrocarbons were compared. Biochars and hydrochars produced from treated organic fractions of municipal solid waste, greenhouse and greenwaste at varying thermochemical conditions were compared with oak-derived biochars. Results showed Levels of PAH in the chars are comparable although the levels of extractable oxygenated hydrocarbons are higher in the hydrochars. These findings provide more insight into the levels of contaminants in biochars and hydrochars before they are used as soil amendments.

An African Biochar Consortium for capacity building on biochar production and use

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Pyrolysis technology and biochar have the potential to contribute to improved livelihoods for smallholder farmers in Africa, especially women, through increased soil fertility, farm productivity, energy efficiency, improved health and reduced drudgery. Biochar also has the potential to contribute to carbon sequestration and improve climate change adaptation options. However, it is a relatively young field of research with limited expertise. As biomass resources are limited, there are inevitable trade-offs between different uses of biomass for energy or as biochar applied to soil. Nevertheless, there are opportunities and niches for pyrolysis technology to enable win-win-solutions to improve livelihoods, natural resource management and climate change mitigation. A coordinated African Biochar Consortium can contribute to realizing the potential benefits and overcoming challenges of biochar development, production and use.

To this end, an expert network for biochar in Africa is being created, aiming to create a platform of biochar research for development (R4D) in Africa, to generate gender-responsive, evidence-based, accessible, and applicable knowledge that will equip farmers and practitioners with tools and technologies for pyrolysis and biochar production and use. The network will exchange experiences, coordinate research, facilitate participatory development and disseminate knowledge on biochar and pyrolysis technology.

The main hypothesis is that pyrolysis and biochar has the potential to provide solutions for waste management, sanitation, soil fertility, soil remediation, air pollution and energy supply in both rural and urban areas.

Biochar as an opportunity for improving agricultural productivity in small-holder farming systems in Kenya

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Biochar, or black carbon formed by heating biomass under oxygen-limited-conditions, can be used as a soil amendment to improve soil productivity and sequester carbon in the soil. However, for understanding the potential of biochar to contribute to reductions in greenhouse gas emissions, the alternative fate of biomass used for biochar production must be considered. Biochar-producing cook-stoves can have additional beneficial effects on greenhouse gas emission reductions and health by reducing fuel demand and reducing smoke. In a research project in Kenya, biochar production and use are investigated in small-holder farming systems in three locations. The effects of biochar on local soils are tested in pot and field trials. Experiments focus on combined effects of biochar, lime and mineral fertilizer. Different application rates of biochar produced from three feedstocks (coconut husk, maize and coffee husks) are compared in soils. Pot trials were performed growing maize during two consecutive seasons. Preliminary results from the pot trials show increased yields in treatments where biochar was applied, although the effect varied with soil type. In conclusion, biochar is seen as a very viable option in providing smallholder farmers with a win-win-win situation in their quest to improve soil and crop productivity, energy efficiency and health.

Feedstock and post-processing handling techniques of biochar influence on herbicide sorption characteristics.

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Maize (*Zea mays*), switchgrass (*Panicum virgatum*), and ponderosa pine (*Pinus ponderosa*) feedstock materials were processed under the same technique of a carbon optimized gasification process. The resulting biochars were allowed to air-cool, or were water-doused to minimize smoldering and fire hazards. The air-cooled materials were sieved to < 2mm or 2- to 4-mm sizes, whereas the water-doused biochars were used as a mixed size material. Studies examined sorption of atrazine or 2,4-D to two different soils (silty clay loam and loamy fine sand) mixed with 0, 1 or 10% addition of each biochar type using batch equilibrium techniques, as well as sorption to the biochar alone. The pH values in 0.01 M CaCl₂ of the maize and switchgrass biochars were above 9, whereas the pine biochar types were about 7.8. The addition of 1% biochar did not influence the pH of either soil type. The 10% addition did not change the pH of the silty clay loam soil but all biochar additions increased the pH of the loamy fine sand the native pH of 5.2 up to about 6 or greater, depending on biochar type and post-handling technique. Sorption of 2,4-D was about 20x greater than to soil alone when 1% maize or switchgrass biochar was added to either soil, whereas the pine biochar increased sorption by about 2x. Size and cooling had some influence but feedstock type had the greatest influence. The 10% biochar addition had 40x and 20x more 2,4-D sorption than the silty clay loam and loamy fine sand soils, respectively. Biochar sorbed atrazine from 10 to 200x more than soil alone. The 1% addition to soil increased sorption of the loamy fine sand, but did not influence atrazine sorption in silty clay loam soil. The 10% addition of biochar increased sorption of both herbicides with coefficients similar between soils and types.

Reduction of pollution of fresh groundwater irrigated areas using organo-mineral supplements

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It is known that coal and clay minerals have the ability to adsorb contaminants, and can serve as a barrier to biogeochemical aeration zone. Soil treated waste coal industry increases the absorption capacity of the soil and allows us to consider them as a shield against the ingress of environmental contaminants in groundwater.

The aim of our research was the creation of waste coal industry organo-mineral fertilizer. Its incorporation into the soil will form an artificial barrier to agricultural lands for the protection of groundwater. The technology of its receipt of the waste Angren brown cut was developed in 2006-2008 and received a patent of the Republic of Uzbekistan № IAP 03807 from 22.10.2008. The organo-mineral fertilizer consists of 42% coal dust, 33% clay and 25% fine sand. It contains 21% organic matter, 0.25% total nitrogen, 0.12% phosphorus, 0.3% potassium and movable $R_2O_5^-$ 16.9 mg / kg and K_2O 100 mg / kg. The composition of humic substances is presented in the following order: total humic acids - 5.7%, including 3.4% humic acid, fulvic acid 2.3%.

Laboratory studies were performed in order to reduce fertilizer residue inputs of fertilizers and pesticides in ground water from irrigated areas.

Experiments were carried out in a plastic column of 5.0 cm diameter and 100 cm length. Initially the pH and nitrogen content in the fertilizer as well as in the soil itself were measured. To this end a cotton swab was put on the bottom of each column. Then the fertilizer was poured into the first column and soil into the second. Distilled water was poured on top of both columns (to avoid the influence of nitrogen compounds contained in tap water). Each column fraction collected 10 filtrate volume of 50 ml, where pH (pH meter at) ion concentration of NO_3^- and NO_2^- (Griess reagent) and the concentration of NH_4 (Nessler's reagent) were quantified.

It can be seen that the fertilizer is acidic foods with a pH = 3.5. There are practically no nitrate and nitrite ions (NO_3^- and nitrite NO_2^-). The concentration of ammonium ions (NH_4^+) has decreased during filtration to 12.0 to 4.0 mg / l. The soil mainly contains small amounts of nitrate (10-42 mg / l) and nitrite ions (0,4-9,0 mg / l), ammonium ions is small (0.7-2.1 mg / l), the medium is slightly alkaline (pH = 8,10 ÷ 8,95).

Then the next series of experiments was started. Two columns were filled with the same soil to a height of 50 cm. In the first column 5 grams of fertilizer made from above 2 grams ammonium nitrate (NH_4NO_3) and another 2 cm of soil were added. The second column served as control. It made only 2 grams NH_4NO_3 and 2 cm of soil. Then, both top dolili column of 250 ml of distilled water and the fractions began collecting filtrates from the bottom volume of 50 ml. After selecting the next column top fraction was re-

filled with 250 mL of H₂O. Soil water passed through slowly, and the first portion of the filtrate was obtained the next day.

As seen therefrom, the filtrate from the column with ion NO₃⁻ fertilizer contains less than the control sample. Fertilizer especially in the initial phase of migration of nitrate ions essentially absorbs them, which positively affects the reduction of pollution of water infiltration. Changes in the concentrations of NO₂⁻ and NH₄⁺ were ambiguous and therefore not considered any further.

Findings:

1. Introduction of organo-mineral fertilizers increases the sorption properties of the soil, reduces the risk of groundwater contamination by residual amounts of mineral fertilizers.
2. Introduction of organo-mineral fertilizers contributes to humus, nitrogen, phosphorus and potassium in the soil, thereby creating a favorable power plant.

Effect of biochar amendment on dry season shallot yield in the Keta sand spit of Ghana

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The Keta sand spit is an important area for vegetable production because it overlies an easily accessible ground-water reservoir used for irrigation. However, in the dry season, yields of salt-sensitive vegetables such as shallots (*Allium cepa* L) are threatened by increased salinity of irrigation water. Biochar is emerging as a solution for reducing salinity stress in crops. A field experiment was conducted in the dry season (January – March) of 2015 in the Keta sand spit to determine the effect of biochar on shallot yield. Rice straw biochar at a rate of 0 and 3% was applied to soil at 20 cm depth. All treatments had 1.3kg/m³ of cow dung manure, nitrogen and potassium fertilizer at rates of 120 kg ha⁻¹ each. Preliminary results showed higher bulb yield, increased number of bulbs, and a larger proportion of small bulbs in the biochar amended plots compared to the control plots. In contrast, the control plants had a higher total fresh plant biomass (roots, bulbs and leaves). There was no significant difference between plants height and number of leaves between treatments. However plants from the control had higher dry matter content than plants in amended plots. Thus the increased in bulb yield is probably related to increased water holding content as a result of the biochar application.

The reduction of chromium phytotoxicity and phytoavailability to wheat (*Triticum aestivum* L.) using biochar and bacteria

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Chromium (Cr) is considered a serious environmental pollutant due to its wide industrial use. Toxicity of Cr to plants depends on its valence state. Cr(VI) is highly toxic and mobile whereas Cr(III) is less toxic. Cr accumulation in plants causes high toxicity in terms of alterations in the germination process, reduction in growth of roots, stems and leaves, which may affect total dry matter production and yield. Application of biochar and bacteria for remediation of chromium contaminated soils may provide a new solution to the problem. Biochar can potentially be used to reduce the bioavailability and leachability of chromium. Bacteria convert Cr(VI) to less toxic form Cr(III). We performed a pot experiment to investigate chromium (50 ppm) induced phytotoxicity in wheat (*Triticum aestivum* L.) and to reduce its phytoavailability by amending the contaminated soil with bacterial strains and biochar at 1% and 5%. For phytotoxicity test wheat plant was grown at different concentrations of chromium (10, 20, 30, 40 and 50 ppm). After 3 weeks subsequent reduction in root and shoot length, fresh and dry biomass, percentage germination, tolerance index, vigor stability index, total chlorophyll and protein was observed. Chromium uptake results showed 36% and 71% less chromium in roots and shoots of inoculated plants as compared to un-inoculated. Soil inoculated with consortia showed 3 folds less chromium uptake than inoculated with the individual strains. At 1% biochar significant reduction in chromium uptake; 60% in roots and 37.5% in shoots of *Triticum aestivum* L. was measured as compared to control. While increasing biochar concentration from 1 to 5% resulted in remarkable reduction in chromium uptake i.e. up to 66% and 89% in roots and shoots respectively. Findings of this study may help to reduce food chain availability of potentially toxic chromium by employing cost effective bioremediation amendments.

Immobilization and uptake reduction of heavy metals in mine soil using biochar

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The concentration of heavy metals in soil has been steadily increasing due to the increase of industrial activities and urbanization. One way to prevent the movement of metals in soils is the use of materials capable of retaining these elements. Thus, remediation strategies that provide in situ immobilisation of contaminants due to the addition of materials to the contaminated soils exhibit great potential. Among the adsorbents, biochar material, resulting from incomplete burning of biomass rich in carbon, can be a viable alternative to mitigate areas contaminated with heavy metals, due to its specific properties in surface retention, among others. Therefore, the aim of this study is to evaluate the application of biochar (BC) in contaminated soil with heavy metals and their effect on the growth of two plant species (jack bean and *Mucuna aterrima*).

In this experiment BC from sugar cane straw, produced at 700°C was applied to a mining soil contaminated with metals. The studied soil was collected in a former zinc mining area in Vazante, Minas Gerasis State, Brazil. The doses used were 1.5%; 3.0% and 5% (w/w) and jack bean and *Mucuna aterrima* plants used as tests. The soil solution from each pot was collected to evaluate the effects of BC in metal solubility, while the soil was analyzed by DTPA to evaluate the concentration of available metals.

The increase in BC doses caused significant decrease of Zn in the pore water sampled. Zn from soil solution cultivated with jack bean decreased from 84 to 48 $\mu\text{g L}^{-1}$, 104 to 51 $\mu\text{g L}^{-1}$ and from 61 to 40 $\mu\text{g L}^{-1}$, in the 1st, 2nd and 3rd collect, respectively. Biochar increased the concentration of macronutrients (P, K, Ca and Mg) and soil CEC. This release of nutrients is highly important in remediation of soil to supply nutrients, and therefore, to aid in the recovery of contaminated areas. The biochar amendment induced significant decrease in the availability of Cd, Pb and Zn from soil, with reductions of 33, 27 and 43%, respectively. Biochar application decreased the concentration of Pb and Zn in both root and shoots of jack bean and *Mucuna aterrima*. By reducing the availability of metals in the soil, the plant uptake also was diminished, and overall the heavy metal toxicity was lowered.

In conclusion, this study found that biochar produced from sugar cane straw reduce the availability of heavy metals to plants and suggest that biochar application may have potential for remediation of soil contaminated by heavy metals from mining area.

Effect of biochar on soil temperature and rice yield in cold waterlogged paddy in southern china

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A field experiment was conducted to investigate the effect of exogenous organic matters - bamboo biochar (BB), rice straw biochar (RB) and rice straw (RS) on soil temperature and crop yield in a cold waterlogged paddy in Zhejiang province, southern China. BB and RB were derived from pyrolysis of bamboo chips and rice straw at 600°C, respectively. The amounts of BB, RB and RS added to the soil were based on the C contents at 4.5 t C ha⁻¹. A blank treatment was set as control (CK). Each treatment had 3 repeats with randomized block design. A probe-type data collector was used for recording the soil temperature at depth of 5, 10 and 20 cm at daily 8:00, 14:00 and 22:00 from 1st July to 31st Oct, 2012. Rice grain yield were measured after harvest.

Results showed that BB and RS significantly decreased soil average temperature of all depths during July and August compared to CK and RB. BB remained the decreasing impact on October, while the effect of RS turned to be opposite on September. Comparing with CK, RB showed no significant effects during July and August, but it reduced soil average temperature from September to October. From another aspect, BB, RB and RS all elevated soil temperature at 8:00 (RS>BB>RB>CK), but decreased soil temperature at 14:00 (CK>RB>BB>RS), and the order was RS>BB≥RB≥CK at 22:00. In terms of soil layer, temperature was reduced by BB at all depths, and by RB mainly at 5 and 10 cm. RS showed significantly decreasing impact on soil temperature at 5 cm, while increasing impact at 20 cm, and no impacts at 10 cm. In more detail, compared to CK, soil temperature was reduced to a maximum extent by 7.72°C, 7.32°C and 11.25°C by BB, RB and RS at depth of 5 cm at 14:00 on July 20, respectively. While BB, RB and RS raised soil temperature to a maximum extent by 5.00°C (5 cm, 14:00, July 14), 9.47°C (10 cm, 14:00, July 20) and 3.71°C (5 cm, 8:00, Oct 19), respectively.

In brief, all these three kinds of exogenous organic matters kept soil temperatures from too high or too low in the cold waterlogged paddy. Moreover, RB significantly increased soil available phosphorus and potassium by 16.5% and 22.3%, respectively, and promoted the assimilation of potassium by 12.0% in rice straw. RB had the most remarkable effect on rice yield improvement. This could be attributed to the more nutrition uptake of crop driven intensively by RB even though the impacts on the soil temperature were not positive enough.

Effects of different biochars and digestate on N₂O fluxes under field conditions

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Field studies that have investigated the effects of char materials on the emission of nitrous oxide (N₂O) are still scarce. Therefore, we conducted a field trial with bio- and hydrochars and measured N₂O emissions for one whole year. It was hypothesised that the incorporation of chars reduces the emissions of N₂O. In particular, upon adding the hydrochars, labile C also entered the soils and therefore it was expected that denitrification would increase. This would result in a larger abundance of nosZ genes, which are functional marker genes of denitrification. Chars were produced by pyrolysis and hydrothermal carbonisation (HTC) using either maize silage or wood residues as feedstock. In addition, after production chars were post-treated with digestate in order to accelerate the aging process of the chars and to eliminate undesirable substances. Chars were applied to the soil and raised the C content by about 40%. Emissions of N₂O were measured weekly and soil samples for inorganic nitrogen (N) and soil water-content were taken once a month. Additionally, the abundance of nosZ genes was determined in October 2012 and in June 2013. To ascertain the influence of several factors on the emissions of N₂O, a mixed linear model was applied. The treatment with pure digestate emitted the most N₂O compared to the control and char treatments. However, this was significant only in one case. There were no great differences between the char treatments due to high spatial variability and gene abundance of nosZ did not differ between treatments. The results of the model showed that environmental parameters like precipitation and inorganic N played a greater role than the type of char. Overall, emissions of N₂O were relatively low. This was attributed to the heterogenic distribution of the chars and the sandy soils that did not favour the production of N₂O. To conclude, the emissions of N₂O were mainly influenced by temperature and precipitation and to a minor extent by the type of char and post-treatment.

Green use of black gasification biochar: microbial community diversity and function in a Danish sandy loam soil amended with gasification straw biochar – a farmer's field study

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The limited amount of biomass and waste materials available for energy production require efficient conversion technologies. Recently, low-temperature gasification technology has attracted attention as a highly efficient way to process biomass for different purposes and at small or medium scale. In combination with reusing the by-product (biochar) as a fertilizer it is true sustainable technology suitable for a commercial market. Biochar is known to enhance soil fertility and carbon sequestration, but little is known about its impact on soil microbial communities and their role in ecosystem services. Furthermore, the quality of the biochars strongly depends on the original feedstock and the technology process. The objective of the present study was to give insights on the response of soil microbial community composition and function to two different doses of straw gasification biochar (SGB) versus traditional straw field application in a Danish agricultural field. The outcome of this study would contribute to the overall evaluation of SGB amendment as a sustainable agricultural practice for the future.

This study compared the effects of two amendment levels (1.4 and 6 t ha⁻¹) of wheat SGB with the traditional straw application in a Danish farmer's field. Wheat SGB was produced by low temperature gasification (Pyrooneer[®], 750°C) and applied twice in two succeeding growing seasons (2013/2014). The energy conversion process provided SGB with a high content of plant-available nutrients and recalcitrant carbon, and with a low content of PAHs and heavy metals.

Soil samples were collected three months after the last SGB amendment and analysed for pH, total organic matter, exo-enzymatic activity, catabolic community profile (MicroResp), soil toxicity test (BioTox[™]), microbial biomass (ATP) and genetic diversity of bacterial community (16S sequencing).

Compared to fresh straw, SGB amendments had no significant effect on total soil organic matter, microbial biomass content and did not generate a response in the toxicity test. In contrast, SGB induced variation in some of the specific enzymatic activities (reduction in cellulase and increase in oxidase activity) and an increased soil pH, although the catabolic potential and the genetic diversity of the soil bacterial community were unaffected.

Our results showed that the soil microbial community responded to SGB amendment with modified enzyme activities, leading to significant changes in functional diversity without disturbing the basic bacterial community composition.

Our results suggest that SGB is a microbiologically benign amendment in soil with carbon sequestration potential. The presented energy by-product can be considered as a sustainable management of organic residues with no foreseen short time impacts on soil microbial communities and soil functions. Hence, SGB represents a novel synergy between bioenergy production and soil productivity focusing on a closed loop principle matching biomass exports from the field with strategies securing return of important nutrients and soil structuring elements like recalcitrant carbon.

Comparison of biochar effect on chemical and microbiological factors in a pot experiment on lettuce and tomato

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The beneficial effects of biochar, obtained from the carbonization of orchard pruning residues were analyzed on lettuce (*Lactuca sativa* L.) and tomato (*Solanum lycopersicum* Mil.) in a pot experiment with four substrates. Lettuce plants were grown in poor soil (PS), poor soil plus biochar (PSB), poor soil plus compost (PSC) and poor soil ((in term of carbon content and nitrogen content) plus compost and biochar (PSCB). Tomato plants were grown in poor soil (PS), poor soil plus biochar (PSB), rich soil (in term of carbon content and nitrogen content) (RS) and rich soil plus biochar (RSB). The effects of different substrates were assessed by chemical, physical and microbiological analysis of soil. Additionally, a first screening was done on the potential toxicity of biochar on plant seeds, using *Lepidium sativum* as model species, and earthworm (*Lombricus terrestris*) as bioindicator of the soil quality (Standard methods: ISO 17512-1:2008). To accomplish this aim, the main chemical parameters of the substrates were analyzed: moisture, pH, electrical conductivity (EC), ash, organic matter (OM), cation exchange capacity (CEC), total nitrogen (N), total and available phosphorus (P) and organic carbon (C_{org}). The main nutritional traits (free sugar, phenols, protein content, etc) were determined in plants. The amounts of toxic elements were assessed in plants and substrates. In detail, sixteen polycyclic aromatic hydrocarbons and main polychlorinated biphenyls were analyzed after automated Soxhlet extraction using 1:1 (v/v) acetone/hexane (EPA methods 3541) and quantified by GC-MS. The heavy metal concentrations were analyzed by using atomic absorption spectrophotometer (ISO 11466). For microbiological analysis, the activity of 19 hydrolytic enzymes was assessed by API-ZYM system together with the analysis of total aerobic viable, cellulolytic and spore-forming bacteria.

Experimental results showed that biochar was not toxic to biotic soil communities (seeds and earthworms). The chemical analysis of PS lettuce plants indicated that biochar increased EC, OM, total N, C_{org}, total and available P in PSB and PSCB. However, the highest increments were obtained in PSCB. The chemical analysis of soil growing tomato plants demonstrated that the biochar addition increased EC, OM, C_{org}, total N and moisture in PSB and RSB; whereas total and available P increased in PSB and RSB, respectively. Again, the highest increments were obtained in RSB. No variations were recorded in Cd, Cr, Co and Pb content between the different treatments.

Microbiological analysis confirmed that biochar increased the microbe biomass and the enzymatic activities.

Analyses of substrate-microbe-plant system provide an experimental framework that help defining the benefit and toxicity of biochar addition on physical and chemical properties of PS and RS, as well as the interactions with microbial communities.

Biochar improves plant yields: results of pot experiments on lettuce and tomato

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Biochar soil amendment is globally recognized as a strategy to improve soil fertility and to mitigate climate change. However, recently published researches, highlighted as the biochar effects on crops are more dependent by the site characteristics (climate, soil and other environmental parameters), than the intrinsic biochar characteristics, chemical and physical. In this view, the soil fertility could constrain the expected beneficial biochar effects. In our research, we have applied different levels of soil fertility to assess the effects of the biochar amendment on lettuce (*Lactuca sativa* L.) and tomato (*Solanum lycopersicum* L.).

The experiment was done on pot in a greenhouse during summer 2014. Lettuce plants were grown on poor soil (in term of carbon content and nitrogen content) (PS), poor soil plus biochar (PSB), poor soil plus compost (PSC) and poor soil plus compost and biochar (PSCB). Tomato plants were grown on poor soil (PS), poor soil plus biochar (PSB), rich soil (in term of carbon content and nitrogen content) (RS) and rich soil plus biochar (RSB). Each treatment was replicated 10 times. The biochar was obtained from the carbonization of orchard pruning residues and it was applied at rate of 65 g kg⁻¹ dry weight of soil. The compost used was a commercial product (composted olive mill wastes) and it was applied at rate of 50 g kg⁻¹ dry weight of soil. The lettuce and tomato plants were fully irrigated through the experimentation until harvest, after 9 weeks. Morphological traits of six plants for each treatment were weekly recorded and analyzed by Image J software. In detail, for lettuce the following leaves parameters were taken: number, area, length, width and perimeter; for tomato the measurements were taken on number of leaflets and compound leaves, stem height and branching. At harvest, the following tomato fruits parameters were measured: number, length and diameter. At the end of experiment, stem and root biomass allocation (fresh and dry weights) of lettuce and tomato plants were determined. Leaf water potential, gas exchange and chlorophyll content were measured during the experimentation on five randomly selected plants for each treatment.

The lettuce experiment demonstrated that the morphological plant traits, both above and below ground, increased in plants grown in PSB, PSC and PSCB, compared to PS. Ecophysiological traits indicated that the transpiration rate, stomatal conductance, leaf assimilation rate potential and water leaf potential were significantly higher in PSB respect to PS, while no significant differences were found between PSC and PSCB.

The tomato experiment demonstrated a not so evident biochar effects on morphological and ecophysiological plant traits among substrate treatments.

Our results indicated that biochar added to non-fertile soil increase yield of lettuce, thus, biochar could effectively be used to implement low-input cropping systems. On the other hand, biochar shows neutral/negative effects on tomato yield, without adding benefits to high-inputs crops as recently observed in field experiment.

Effects of biochar application and soil temperature on aggregate dynamics, C fractions and basal respiration of a loess soil

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A potential climate change-related rise in soil temperature might lead to an intensified decomposition of soil organic matter (SOM) and enhanced emission of CO₂. In contrast, biochar applications to arable soils are considered as a management option to increase and stabilize the SOM content and to store CO₂. The SOM can experimentally be subdivided into fractions differing in their importance for the long-term CO₂ storage because of different mean residence times. For example, aggregate-size fractions are characterized by longer residence times of the associated SOM with decreasing aggregate size. To date, the effect of biochar applications on such SOM fractions in dependence of soil temperature is largely unknown. The objective of this study was to clarify the influence of biochar and soil temperature on the amount and composition of experimentally separated SOM fractions and basal respiration rates.

For this, four replicates were taken from four different treatments of the Hohenheim Climate Change experiment (loess soil, cultivated with rapeseed) in 0-5 and 5-15 cm soil depth: ambient and elevated (+2.5°C, for five years before sampling) soil temperature, each with or without application of biochar (30 t ha⁻¹, one year before sampling) derived from *Miscanthus* (700°C). Bulk soil samples were physically, chemically, and biologically characterized and SOM fractions were separated by wet-sieving. The resulting data for each soil depth were analyzed with a two-way analysis of variance.

The results so far show that the application of biochar, independent of the soil temperature and depth, led to a significant ($p < 0.05$) increase in basal respiration. No effects were found on the dry yields of the aggregate fractions separated by wet-sieving. We expect to detect more distinct differences between SOM fractions regarding composition and turnover by further spectrometric, spectroscopic, and isotopic analyses.

Is biochar a “competitor” for NH₄ availability in N fertilized systems?

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Biochar is known to improve nutrient balance in soil-plant system through peculiar effects on the macro-nutrients cycles, in particular nitrogen (N). Despite the important implications in terms of reduction of fertilizers use, biochar interactions with mineral fertilization remains unclear.

We studied the biochar impact on NH₄ absorption efficiency of processing tomato in an outdoor pot experiment, using two different soils and hypothesizing that high nutrient inputs could limit the expected biochar benefits. By applying a ¹⁵N labeled fertilizer, we investigated the mechanisms involved in biochar and plant nitrogen uptake. The experiment was done during Summer 2014, at the experimental area of the National Research Council of Florence, using processing tomato, cultivar Pietrarossa. A randomized pot experiment was set to compare biochar effects on two different soils. Soil(1) was a silt clay textured with alkaline pH (7.5), 0.17% nitrogen content (N), 2.20% organic carbon (C). Soil(2) was a sandy soil textured with sub-acid pH (5.8), 0.23% N and 1.99% C contents. Biochar was obtained by fast pyrolysis at 1200°C using wheat bran pellet as feedstock and was manually applied in each plot at 0.15 m depth, in proportion of 14 t ha⁻¹. For each soil, five replications were applied to the following treatments: C (soil without plant and biochar); CB (soil + biochar without plant); P (soil + plant without biochar); PB (soil + biochar + plant). Nitrogen fate in the soil-plant system was investigated by means of ¹⁵N labeled solution (NH₄Cl), applied weekly for a N total of 45.28 gr/pot. Analyses of ¹⁵N abundances in soil, leaves, stem and roots enabled to derive a complete N partitioning. Soil and plant samples were analyzed through IRMS. N partitioning was then calculated using the following mass balance formula: NI (%) = 100(δN-δNc)/(δNI-δNc), where: NI is ¹⁵N % content in soil or plant; δNc is the isotopic composition (δ¹⁵N) of control soil or plant; δN is the δ¹⁵N in soil or plant samples, δNI is the δ¹⁵N of the labelled solution.

Different soils respond differently to biochar amendment. The higher ¹⁵N contents were found in Soil(1) at 0.0-0.20 m depth with more than 20% of ¹⁵N available in biochar plot. In Soil(1) the biochar improved the plant height (+23%) and plant biomass (+ 8%). The plant nitrogen absorption efficiency increased during the first month, disappearing at the end of the experiment. In Soil(2) biochar did not show any effect on plant height and aboveground biomass but an increase of root biomass (13%). Total fruit production in-

creased in biochar plots with a major increase in Soil(2), the percentage of non-marketable fruits being reduced. Our results demonstrate that biochar affects plant N uptake of processing tomato in relation to application depth. The beneficial effects of the biochar are dependent on physical and chemical soil characteristics. Overall, the biochar amendment positively affects the marketable production.

Influence of EPS on aggregate stability – an enzymatic method for biofilm detachment in sandy soils

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The stability of soil aggregates against shear and compressive forces as well as water caused lability is an integral marker of soil quality. High stability results in less soil compactability, a dynamic water transport, retention and aeration regime, increased rooting depth and protection of soil organic carbon (SOC) against microbial degradation. For decades the importance of biofilm extracellular polymeric substance (EPS) on aggregate stability is canonical because of its distribution and geometric structure among primary particles. However, not much is known about the contribution of EPS in relation to other aggregate stabilizing factors, which is mainly due to methodological reasons. Thus, in this work we modified an enzymatic method for biofilm detachment and adopted the method to be used for studying the effects of EPS on soil aggregate stability. The method includes an enzymatic pre-treatment of soil samples with different concentrations of α -glucosidase, β -galactosidase, DNase and lipase followed by a sequential ultrasonic treatment for disaggregation and density-fractioning of SOC. Also the bacterial DNA ratio of sessile and suspended cells after enzymatic treatment was measured by quantitative real-time PCR to ascertain EPS as an enzyme target. Whereas the release of occluded light-fraction SOC increased after enzyme exposure at 50 J/ml, differences at higher energy levels were insignificant. By contrast, the release of the free light fraction decreased with enzyme treatment. Bacterial cell release only showed an increase at highest enzyme concentrations. These results confirm a considerable influence of biofilms on aggregate stability, although the enzyme treatment seems not to be sufficient for total biofilm removal.

Effect of biochar and fertilizer application to different soil types on maize growth

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Recent studies have demonstrated that the application of biochar as a soil amendment has the potential to improve plant growth and consequently increase crop yields in addition to contributing towards long-term carbon (C) storage in soils. This is important especially in the highly weathered soils of the tropics with low soil organic matter and available nutrients.

The objective was to determine the effects of biochar and fertilizer application to different soil types on maize growth and nutrient uptake.

Five soil samples, varying in texture (clay, silt loam, sandy loam, clay loam and loam) and chemical properties were collected from the top 20 cm of soil. The samples were homogeneously mixed, air-dried and passed through a 2-mm sieve. The biochar used in the study was generated by pyrolysis of pine wood feedstock. The treatments consisted of (i) control, (ii) fertilizer ($100 \text{ kg N ha}^{-1} + 70 \text{ kg P ha}^{-1}$) and (iii) fertilizer ($100 \text{ kg N ha}^{-1} + 70 \text{ kg P ha}^{-1}$) + Biochar at 20 g kg^{-1}). The biochar and fertilizer were mixed thoroughly with 5 kg of soil in plastic pots measuring 25 cm in height and 25 cm in diameter. The treatments were laid out in a completely randomized design and replicated three times. The pots were wetted to field capacity and thereafter three maize seeds were planted per pot to a depth of approximately 0.5 cm and thinned to one (1) plant per pot after germination. The pots were watered regularly as necessary. The plants were harvested 45 days after planting (DAP) and the following parameters were determined: dry matter yield (DM), root biomass, P and N concentration and P and N uptake.

The effect of soil type on dry matter accumulation was significant ($P < 0.01$). The sandy loam soil produced significantly higher DM (15.7 g/pot) than all the other soil types. Treatments affected ($P < 0.05$) DM accumulation with fertilizer + biochar treatment producing significantly higher DM yield (10.2 g/pot) than fertilizer alone (9.4 g/pot) and control (7.0 g/pot). The interaction between soil type and treatments did not affect DM accumulation. The effect of soil type on root biomass was significant ($P < 0.01$). The sandy loam soil produced significantly higher root biomass (8.8 g/pot) than all the other soil types. Treatments affected ($P < 0.05$) N concentration with fertilizer treatment producing higher plant N concentration than the control and the fertilizer + biochar treatments. The effect of soil type on N uptake was significant ($P < 0.01$). The N uptake of plants in the sandy loam soil (367.3 mg/g) was higher than in all the other soils. Treatments affected ($P < 0.05$) N uptake with the fertilizer and fertilizer + biochar treatments having significantly higher N uptake than the control treatment. In summary, the application of biochar and fertilizer led to higher DM accumulation in the sandy loam soil. Although the N

uptake was higher in the sandy loam soil, no difference was observed between the fertilizer and fertilizer + biochar treatments.

How soil amendment with biochar affects the productivity of a millet over millet field experiment at ISRA - CNRA research centre of Bambey in Senegal

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So far in Senegal, charred biomass (biochar) was mostly known for green charcoal to prevent the degradation of natural resources. Based on the biochar benefits revealed in the literature, we decided performing experiments to assess the effects of biochar treatments on improving sandy soil properties and crop yield increases of millet over millet field one the main Senegalese agricultural system.

In 2011, experiments were carried out in a millet field located at ISRA – CNRA research Centre of Bambey in Senegal in a randomized complete bloc design to test the 10 following treatments: Control; Recommended NPK millet dose rate; 5 t/ha rice husk biochar; 10 t/ha rice husk biochar; 5 t/ha *Typha australis* biochar + 5 t/ha cow manure; 10 t/ha *Typha australis* biochar + 5 t/ha cow manure; ½ NPK dose rate + 5 t/ha de rice husk biochar; ⅓ NPK dose rate + 5 t/ha de rice husk biochar+ 5 t/ha cow manure; ⅓ NPK millet dose rate + 5 t/ha de rice husk biochar and ⅓ NPK millet dose rate + 5 ha *Typha australis* biochar + 5 t/ha cow manure. 2011 crop yield were recorded and soil collected before the 2012 cropping season and characterized

Significant improvement on soil pH ($6.65 \leq \text{pH} \leq 7.05$ against 5.5 before application) was obtained. Total Carbon (1.90 – 3.40% against 1.84% before application) and available phosphorus (35.61 – 65.16 ppm against 33.32 ppm before application) were also significantly enhanced. Compared to the control, biochar combination with ½ dose rate of organic manure (cow dung) or mineral fertilizers (NPK) significantly increased grain yield and equaled the full cow manure or NPK millet dose rate application. However the application of biochar alone decrease millet yield.

Our results indicate that judicious soil amendment with biochar could be a sustainable way of improving sandy soil proprieties and consequently crop yield increase but, assessing the long terms effects is needed.

The effect of sewage sledge and their biochar as mulch and top-soil incorporated on some soil attributes, plant growth in a loss soil with high specific surface area in a temperate climate

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Biochar (BC) application as a soil amendment has aroused much interest and was found to considerably improve soil nutrient status and crop yields on poor soils. However, information on the effect of BC on temperate soils is still insufficient. The primary objective in this study was to investigate the effect of pyrolysis temperature on the structure (e.g., surface functional groups and surface areas) of biochar and to assess the influence of biochar on the soil quality and plant production. The result may also provide a reference for the use of biochars as a solution in agricultural waste management and as a soil amendment to reduce the environmental risk of agrochemicals.

We investigated the effects of BC on soil nutrient, crop yield, and quality in a greenhouse pot experiment. We compared BCs of two different temperature (400°C and 650°C). The BCs were applied at two rates (1% and 3%, which would correspond to 30 and 90 t ha⁻¹ in the field). Soybean was grown successively within one year. The investigated soil properties included pH, electrical conductivity (EC), cation-exchange capacity (CEC), calcium- acetate-lactate (CAL)-extractable P (PCAL) and K (KCAL), C, N, and nitrogen-supplying potential (NSP).

The results show pH and CEC increase in all soils. The C:N ratio increased at 3% application rate. Improving the soil nutrient status partly, yield of the crop was significantly increased through BC application (by up to 68% in 400°C). Despite improving the soil nutrient status partly, yields of the crop was not affected (in 650°C). Only the BC (in 400°C) in the range of the control and even increased soybean yield by 6%. The initial yield reduction was accompanied by notable decreases (Cu, Fe, Mn, Zn) and increases (Mo) in micronutrient concentrations of plant tissues while nitrogen concentrations were hardly affected.

The results of the pot experiment show that despite additional mineral fertilization, short-term growth inhibition may occur when applying BC without further treatment to temperate soils.

Effects of biochars, digestate and mineral N fertilizer on soil C and N and crop yields on a sandy soil

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This paper presents the outline of a three factorial field experiment and first results regarding the effects of biochar in interaction with post-treatment (digestate incorporation/fermentation) and mineral nitrogen (N) fertilizer application. We investigated (I) the impact of biochars originated from wood or maize silage, carbonized by pyrolysis or HTC and treated with or without digestate, (II) the interaction of biochar from pyrolyzed wood and mineral N-fertilization and (III) the interaction of biochar from pyrolyzed wood, mineral N-fertilization and digestate incorporation on soil total C (Ct) and N (Nt) and crop yields.

In September 2012 we set up a three factorial field experiment with five different biochars (pyrolyzed wood – W(py), pyrolyzed maize silage – M(py), fermented pyrolyzed maize silage – M(py)+D, hydrothermal carbonized maize silage – M(htc) and fermented hydrothermal carbonized maize silage – M(htc)+D) and W(py) applied to a sandy soil at a rate of 7.7 Mg biochar-C ha⁻¹. In the first year winter wheat (*Triticum aestivum* L.) was cultivated, followed by rye (*Secale cereale* L.) and the catch crop fodder radish (*Raphanus sativus* L. var. *oleiformis* Pers.). Before biochar application and after each harvest Ct and Nt in the upper 20 cm of the soil was determined as well as the crop yields and the yield structure, development and quality of wheat.

After harvest of the first crop (winter wheat), carbon content in the upper 20 cm of soil was found to be significantly positive affected by W(py). Crop yields of winter wheat and rye were not affected by any biochar with or without digestate incorporation/fermentation, respectively, whereas oil radish showed significant interaction effects of biochar x mineral N fertilizer. Wheat grain contained highest amount of phosphorous, potassium and magnesium in M(py) treatments. Yield quality parameters like falling number and sedimentation value were significantly increased by biochar application (W(py)). Sedimentation value showed a significant interaction effect of biochar x digestate x fertilizer N rates in that statistically significant lowest values were detected in treatments without biochar, digestate or mineral N fertilization addition compared to all other treatments.

In spite of various chemical properties of biochars originated from different substrates and carbonization methods, merely limited effects on crop growth, development, yield, yield structure and quality were detected in the first year. Yet, it has to be mentioned that the biochar application rates in this study were comparatively low. However, a significant increase in Ct concentration in the upper 20 cm of the soil could be shown.

Root growth and yield of spring wheat influenced by different biochars

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Over the last few years the use of biochar in agriculture has been investigated for its potential benefits regarding water holding capacity of the soil, nutrient retention, and crop yield. However, it is currently unclear how different types of biochars will influence these parameters under varied growing conditions.

To quantify the influence of different biochars and the addition of digestate/fermentation of biochars and/or nitrogen fertilizer on the yield of spring wheat we conducted a 3-factorial pot experiment. The factor biochar was included with four levels (without, Pyro, HTC, Pyreg) and the two factors digestate and nitrogen fertilizer were included with two levels (with, without) and 4 replications. While significant differences between the treatments were observed, treatments with only biochar showed no significant straw or grain yield increase. The grain number per ear was lower in the treatments without nitrogen.

To investigate the effects of different types of biochar on root growth of spring wheat rhizoboxes with the four treatments “without biochar”, “Pyreg”, “Pyro” and “HTC” were set up using 3 replicates per treatment and two plants per rhizobox. Significant differences between the treatments were observed in plant and root dry matter. The results suggest that Pyro-char had positive effects on the root and shoot growth.

Our results showed that biochars can have positive effects on crop performance when applied in combination with nitrogen or nitrogen and digestate. In addition, different types of biochars affected root growth differently.

Optimization of production conditions of hydrochars from sewage sludge for germination and growth of *Lolium perenne*

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Nowadays, EU countries produce more than 10 million tonnes of dried sewage sludge (SS) per year (Laturnus et al., 2007). This residue is rich in N, P and other micronutrients, which may turn it into a useful fertilizer, if subsequent pollution with heavy metals and pathogens can be avoided. Pyrolysis of this material prior to its land application can help to eliminate such pathogens and may have an additional benefit to increase the carbon sequestration in soils after its application.

The main goal of this study was to determine the conditions for the hydrothermal carbonization of sewage sludge which are the most beneficial for the plant growth on a typical soil of the Mediterranean area.

The hydrochars derived from sewage sludge collected from the Experimental Wastewater Treatment plant CENTA (<http://www.centa.es/>), located near Seville, Southern Spain. Hydrothermal carbonization was carried out at 200°C and 260°C with residence times of 30 min and 1h. They were used as soil amendment in a greenhouse incubation study which was carried out for 80 days using a Calcic Cambisol (IUSS Working Group WRB, 2007) and an amount of hydrochar equivalent to 5 and 25 t ha⁻¹ (n = 4). Control pots, without hydrochar addition, were also settled (n = 4). In each pot, 25 seeds of *Lolium perenne* were planted and their germination, the survival rate and biomass production of the plants per pot were measured periodically. In addition, a characterization of the hydrochars was carried out to determine their main chemical and physical properties as well as the presence of heavy metals and organic pollutants.

Although hydrochar amended pots exhibited lower germination rates than the unamended pots, the total biomass production per pot raised significantly for all tested hydrochars. The first may be due to the presence of and PAHs in the hydrochars. Whereas hydrochars produced at 260°C resulted in a significantly higher amount of harvested plant biomass than those heated at 200°C, the residence time of the hydrochars in the reactor had no impact on plant growth. The higher nitrogen amount of the hydrochars produced at 200°C compared to those produced at 260° may explain the better effect on plant growth of the former compare to the latter.

Hydrothermal carbonization of sewage sludge at 200°C, regardless the residence time, seems to be the most suitable production conditions for *Lolium perenne* growth. In addi-

tion, a washing with water and acetone of the hydrochar before its use may be appropriated to avoid the decrease in the germination rate observed.

Laternus F, von Arnold K, Grøn C (2007). Organic Contaminants from Sewage Sludge Applied to Agricultural Soils. *Env Sci Pollut Res* 14, Special Issue 1, 53–60

Exploring the agronomic and physiological benefits of biochar pyrolysed at different temperature and compost for improved agricultural productivity

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The production and use of biochar presents many opportunities for soil augmentation and carbon sequestration. Biochar and compost have the potential to improve crop quality and serve as sources of nutrients for degraded soil. However, the variable application rates, uncertain feedstock effects and unspecified pyrolysis temperature present different challenges for biochar production and utilization. These studies were conducted to investigate the effect of compost and biochar produced from different feed stocks under different temperatures on the growth, yield, nutrient uptake and chlorophyll content of two maize varieties..

Biochars were produced from two types of feedstocks (Rice husk and dried Mexican sunflower) under different temperatures (300, 350 and 400°C) using biochar reactor. Compost was made from Mexican sunflower (*Tithonia diversifolia*) and poultry manure using Partially Aerated Composting Technique (PACT-2). These were then characterized and applied at three levels (5, 10 and 15ton/ha). The experiment was laid out in a Completely Randomized Design (CRD) with four replicates. Data were collected on vegetative and yield parameters of maize, nutrient uptake as well as chlorophyll contents.

The results showed that rice husk pyrolyzed at relatively high temperature (400°C) and Mexican sunflower pyrolysed at 300°C increased the biochar yield and efficiency. However, low temperature (300-350°C) and application rate at 15t/ha increased the growth and yield parameters of maize with rice husk biochar performing better than sunflower. Compost applied at higher rates of 10 and 15ton/ha also performed better than lower rate. The chlorophyll pigment formation was enhanced in maize treated with higher rate of biochar. Different pyrolysing temperatures and feedstocks influenced the nutrient compositions of biochar. Variations were observed in the carbon contents and concentrations of primary nutrients which are essential for soil fertility improvement. The carbon content of Rice husk biochar was the highest (53 g/kg) under the pyrolysing temperature of 350°C followed by that of 400°C and the lowest was at 300°C. Similarly, Fe and Mn were more in Rice husk under this temperature than other materials. The carbon content, potassium, calcium iron and manganese concentrations of Sunflower biochar however increased with increasing temperature and the highest concentrations were found at 400°C.

The result of this study showed clearly the potential of compost and biochar amendments under different conditions for improving maize yield. Biochar yield decreases with increase in pyrolysis temperature while larger proportion of the feedstock was conserved at low temperature.

PAHs in biochar - influence of pyrolysis unit, pyrolysis conditions, feedstock and pre-/post treatment

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Biochar can contain contaminants originating from the feedstock used and/or contaminants introduced during the production process. Polycyclic aromatic hydrocarbons (PAHs) fall into the latter category and reported concentrations in biochar vary greatly. So far it is unclear how biochar will be categorized and under which regulations biochar will be treated (fertilizer/soil amendment, by-product, waste material). Nevertheless, threshold values for PAHs will have to be met for biochar to be applied on soils. Guideline values have been proposed already such as in the European Biochar Certificate (EBC) or in the International Biochar Initiative (IBI) guidelines. Since biochar sorbs PAHs strongly, a much harsher PAH extraction than for soil is necessary; in this study, as in the EBC recommended, a 36 h soxhlet extraction using toluene was applied for determination of 16 US EPA PAHs. So far systematic studies of the influence of specific pyrolysis conditions and feedstock characteristics on PAH concentrations in biochar are lacking. Understanding of this relationship is necessary for designing and operation of biochar generation systems to produce biochar with low PAH content, as even relatively small changes can result in large differences.

In this study the influence of various pyrolysis parameters on the PAH concentrations in biochar were investigated e.g., carrier gas flow rate, peak temperature, and residence time at peak temperature. Around 90 different biochars were systematically produced in a continuous slow pyrolysis unit (UKBRC) and analysed for 16 US EPA PAHs. Besides pyrolysis parameters, effects of feedstock alteration and pre-treatment were examined. The objectives of this study were to investigate which factors in the production of biochar have the biggest influence on PAH concentration and based on the results, to give recommendations on conditions for production of low-PAH biochar.

The result is a unique set of data which shows, for example, that PAH concentrations in biochar are highly influenced by carrier gas flow rate. The residence time and temperature were revealed to have little effect, except for the highest pyrolysis temperature investigated (750°C), resulting in the highest PAHs concentrations. PAH guideline values (IBI) were exceeded by a large proportion of the biochars, however, in most of the cases the exceedance was due to the presence of high concentrations of naphthalene which made up to 100% of the detectable PAH concentrations. Thus, as it is known that naphthalene toxicity is very low, using the recommended threshold values for 16 US EPA PAHs doesn't appear to be appropriate. The results of this work present an important step towards setting up recommendations for production of clean (low-PAH) biochar.

Anaerobic treatment of HTC waste water at different temperatures

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Hydrothermal carbonization (HTC) is an artificial coalification process producing a solid phase that is discussed in a variety of applications. Besides the solid phase, HTC also produces a liquid phase. This process liquor contains high amounts of dissolved organic compounds and requires further treatment. However, aerobic treatment technologies are associated with a relatively high energy demand. The aim of this experimental study was to investigate the feasibility of using HTC waste water for anaerobic digestion. The experimental focus was placed on process performance and influence of potential inhibitors contained in HTC liquor. Anaerobic digestion yields methane that can replace at least part of fossil fuel maintaining the HTC process itself.

The HTC liquor used in this study was obtained from an HTC demonstration plant located at Leonberg, Germany processing municipal sewage sludge. Citric acid was used as a potential catalyst for HTC reaction. The process liquor had a starting COD of approximately 31 g L^{-1} with a pH-value of 5. The experimental set-up consisted of two 26 L anaerobic filters filled with biofilm carriers. Both reactors were operated continuously for 20 weeks. The set-up was used to investigate different temperature levels – $37 \text{ }^{\circ}\text{C}$ (mesophilic) and $55 \text{ }^{\circ}\text{C}$ (thermophilic). Both reactors were fed with an increasing organic loading rate (OLR) reaching $5 \text{ g}_{\text{COD}} \text{ L}^{-1} \text{ d}^{-1}$.

After start-up, both reactor systems proved to be very stable throughout the experiment. The OLR increases and resulting hydraulic retention time decreases from over 30 days in the beginning down to 5 days at the highest load were anticipated after only a few days. The overall methane rates of both reactor systems showed values of up to $0.18 \text{ L g}_{\text{COD}}^{-1}$ and were not influenced by the increasing OLR. Volumetric methane fractions of the produced biogas stabilized at around 70% and were only slightly lower in the thermophilic system. Other trace gases could only be found in minimal concentrations of less than 100 ppm. Approximately 50% of the added COD were converted to methane. The overall COD degradation rates stabilized at around 75%.

It can be concluded that HTC liquor is a suitable material for anaerobic digestion allowing a waste treatment and integrated methane production leading to better efficiency and economics of an industrial-scale HTC plant. Especially in the context of modern waste water treatment plants, HTC technology offers an upgrading possibility. The process liquor as a by-product can be easily recycled. Further studies are required to reveal specific nutrient requirements of HTC liquor digestion and to cover a broad range of different HTC process liquors.

Biochar colonization by anaerobic microorganisms

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Terra preta do Indio is a typical horticultural anthrosol in the Amazonas region derived from long-term human landscape cultivation. This distinct type of soil is characterized by high storage capacity of plant nutrients as well as a high content of carbon enabling agriculture even on soils with low humus and/or nutrient content. Due to certain similarities in consistence and composition, biochar is recently discussed as a valuable artificial soil amendment to obtain similar positive effects on soil fertility like terra preta. In addition to the structural and compositional analysis of biochars, the interaction of the chars with living microorganisms is studied to explain the effect of biochar enriched soils from a microbiological point of view. Due to the closed biogas reactor system the study of biochar colonization with microorganisms by minimizing the confounding factors is more easier compared with soil trials.

In this study the microbial interaction caused by colonization, biofilm formation, and degradation with two types of char (hydrochar and pyrolyzed char) is examined using a mesophilic gas lift biogas reactor.

In samples taken from mesophilic and thermophilic biogas systems at various time points the bacteria-to-archaea ratio was determined by DNA-based quantitative PCR. In addition, the treated chars were investigated with respect to their surface properties by gas adsorption method (BET). In addition, chemical analyzes were performed to determine the content of dry matter, organic dry matter, elemental composition (C, H, N, S) and the content of trace elements over time.

Caused by feedstock and process conditions during carbonization the pyrochar shows higher stability while fermentation. Due to the colonization of the char this leads to a measurable reduction of pore surfaces in the pyrochars. In contrast to this the instability of the hydrochar lead to an increase of the specific surface area compared with the unfermented sample. Most interesting is the dynamic population of the microbial community over time under anaerobic conditions.

Characterization of organic compounds in mixed feedstock biochar generated from waste materials

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Biochar application to the soil has been considered as an effective strategy for improving soil functions. Since biochar particles interact with soil compounds, it is essential to develop a biochar with specific characteristics relevant to selective soil in order to meet the soil constraints and plant requirements. Therefore, the objective of the present work was to study the physiochemical properties of organic compounds in mixed feedstock biochar produced from two Australian agricultural residues, wheat straw and chicken litter (WsCl) at three temperatures (450°C, 550°C and 650°C). Proximate and ultimate analyses of both raw feedstock and produced biochars were determined and mass loss was monitored. The biochar samples were characterized using scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), Fourier transform infrared (FTIR) spectroscopy, Raman spectroscopy and Liquid Chromatography – Organic Carbon Detection (LC-OCD) to identify the effects of pyrolysis conditions on organic compounds and their interactions with mineral phases. The WsCl biochar obtained at 650°C had relatively higher pH, fixed carbon and ash content with lower volatile matter than the raw biomass. The results also suggested complex reactions between organic and mineral phases at higher processing temperatures which subsequently resulted in mineral attachment arose from chicken litter particles inside the pores and on the surface of wheat straw particles. Moreover, the absorption peaks associated with aliphatic carbon structures decreased and transformed into aromatic carbon structures as confirmed by FTIR results. In addition, a significant change occurred in dissolved organic carbon (DOC) during the heat treatment process which resulted in a much lower DOC in the high temperature WsCl biochars, where low molecular fractions were dominant.

Characterization of biochar for agricultural use in north of Iran

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Black carbon may significantly affect nutrient retention and play a key role in a wide range of biogeochemical processes in soils, especially for nutrient cycling. Black carbon is the main component of biochar. In this study evaluated characterization of three kinds of biochars which made by stove research, under condition of slow pyrolysis at 500°C. Also effects of this biochars on some chemical characteristics of clay soil in north of Iran measured. Therefore, after making biochars of wood, rice straw and papermill waste biomass, exchangeable Ca, Mg, Na and K, available Fe, total P and total C of biochars were measured. Analyses of biochars sample have revealed high levels of essential elements. Also, in order to evaluated the effect of these three different types of biochars on clay soil, biochars and soil passes through a 2-mm sieve and applied three different levels of biochars at a rate of 10, 20 and 30 g kg⁻¹ soil. After 1 and 3 months the elements were measured. Results show that after one and three months addition of biochars to soil, exchangeable Ca, Mg, K and total C significantly increased almost in all treatments. Available Fe significantly decreased and exchangeable Na and total P showed varied results.

Soil pore structure characteristics after two years biochar application: A case study in a sandy loam field

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Soil pore structure comprises the size and shape of soil pores, and has a major impact on water retention and gas movement. The porous nature of biochar suggests that its application to soil can potentially alter soil pore structure characteristics, and the purpose of this study was to evaluate the effects of birch wood biochar (20, 40, and 100 Mg ha⁻¹) applied to a sandy loam on soil total porosity and pore structure indices. Bulk and intact soil samples were collected for physicochemical analyses and water retention and gas diffusivity measurements between pF 1.0 and pF 3.0. Biochar application reduced bulk density and increased total porosity especially for soil with 100 Mg ha⁻¹ biochar (16% and 14% reduction in bulk density and total porosity, respectively). Biochar application above 20 Mg ha⁻¹ enhanced water retention and the trend increased with increasing biochar application rate, where the maximum increment was 12% at 100 Mg ha⁻¹ biochar treatment. A pore size distribution index, *B*, derived from water retention, indicated a wider soil pore size distribution in biochar-amended soil than in the reference soil, especially for the 100 Mg ha⁻¹ application. At given matric potentials, biochar increased soil air-filled porosity by up to 25%. However, there was no difference in gas diffusivities between biochar-amended soil and the reference soil. At pF 3.0, the soil pore system became more tortuous after biochar application with a trend that pore tortuosity increased with increasing biochar rate. Overall, addition of a wood-based biochar to a sandy loam soil resulted in a soil structure with broader pore size distribution and higher tortuosity of the inter-aggregate pore network. Similar studies with other types of biochars and soils are recommended towards better understanding of biochar effects on soil functions and services.

The response of root associated microbial activity to biochar amendment

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The application of biochar to soil is considered to mitigate climate change by increasing carbon storage in soils but also to improve fertility of degraded soils, improve plant growth, increase fertilizer efficiency, and suppresses soil pathogens. However, biochar applications can cause substantial changes in the microbial activities in the rhizosphere soil. These effects are dependent on the type of biochar and biochar concentration. The aim of this work was to investigate the response of root associated beneficial microbes to biochar amendments and to determine how biochar affects microbial interactions with plants. The experiment was conducted in pot experiments using loamy sandy soil taken from ZALF Experimental Field Station, Müncheberg, Germany. Hydrothermal carbonization char (HTC) and Pyro-char from maize silage was used as a soil amendment at concentrations of 1, 2 and 3%. The leguminous plants, soybean and chickpea were grown under climate-regulated growth chambers for two months. Plant growth parameters such as root and shoot length, dry biomass, nodulation, and some physiological properties were measured. The microbial diversity and plant beneficial traits such as production of phytohormones, cell wall degrading enzymes, antagonistic activity against plant pathogenic fungi, ACC deaminase activity, and phosphate solubilizing abilities of bacterial strains were determined. The results showed that the effect of biochar on root associated beneficial bacteria varied with the type of biochar, and concentrations. The population density of root associated bacteria (CFU) was significantly ($P < 0.05$) higher for the HTC char than the Pyro-char amended soil. In comparison to control soil, the rhizosphere soil amended with biochar contains significantly higher amounts of microorganisms with plant growth promoting properties and antagonistic activity against plant pathogenic fungi. Furthermore, the bacterial diversity of the rhizosphere of soybean grown in HTC char amended soil was more diverse compared to soil without biochar, including species such as *Pseudomonas*, *Bacillus*, *Stenotrophomonas*, *Pantoea*, *Achromobacter*, *Artrobacter*, *Rhizobium*, *Enterobacter*, and *Serratia*. We concluded that HTC char enhanced positive interactions between plant and root associated bacteria in loamy sandy soil more than Pyro-char, and improved plant growth is an indirect rather than a direct effect depending on plant associated bacterial activity.

Evaluation of pinewood biochar and olive mill effluent combinations effects on wheat, green beans, and Bambara groundnuts growth using sand and Oxisol pot trials

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Olive mill effluent disposal poses problems for producers and raises environmental concern. On-land disposal of untreated olive mill effluents is known to negatively affect plant growth. Phenolic content of the effluent affects seed germination depending on concentrations. We suggest biochar as a natural sorbent to counteract the negative effects of the effluent-related soil pollution. We explored the sorption capacity of the pinewood biochar for the removal of total phenol from the olive mill effluent. Further, we determined the effectiveness of soil priming with biochar to neutralize the effects of simulated effluent on-land disposal in pot trials on the growth of wheat and green beans in sand and bambara groundnuts in loamy B horizon of an Oxisol.

The pinewood biochar was prepared using slow pyrolysis at 450°C. A suspension of different doses of biochar 0, 0.5, 1, 2, 5, 7.5 and 10g and effluent of 50% dilution was used to determine the percent removal of phenol from the effluent using Folin reagent. A 4x4 factorial pot experiment in complete randomized design (CRD) was conducted in the greenhouse with alkaline sand medium on green beans and wheat. The effluent was applied at the rates equivalent to 0, 50, 100, and 200m³/ha while the biochar rates were 0%, 0.5%, 2.5%, and 5%. Another 2 x 6 factorial pot experiment in CRD was done also in the greenhouse with Oxisol medium on bambara groundnut. The effluent rates were 0, 50, 100, 200, 400, 800m³/ha with biochar rates of 0 and 2%. Plant Height (PH), above, below ground, total biomass, plant chlorophyll content, Number of Leaves (NL) and Spikes (NS), were monitored through plant growth stages and yield at harvest.

The results showed that 100% of total phenol removal may be achieved with pine wood biochar in a sorption experiment. The wheat pot trial showed that increased biochar rates significantly decreased biomass while increased effluent rates significantly decreased both PH (14-11cm), NL and total biomass within the first 3 weeks of growth. The effluent and biochar combinations had no significant effect on PH and NL but significantly decreased biomass. Beans pot trial showed increased biochar rates significantly increased PH (15-17cm), NL (8-10) and decreased the chlorophyll. Increasing effluent rates had no significant effect on all studied plant parameters but the effluent and biochar combinations only significantly improved PH after 3 weeks of growth. The Bambara groundnuts showed that increased effluent rates delayed germination but significantly affected yield while biochar and effluent rate combinations significantly improved the yield especially at effluent rate of 200m³ with biochar 2%. Other growth parameters like

plant height and number of spikes showed no significant difference between the treatments.

Overall, the results showed that biochar is a good sorbent for organic pollutants present in olive mill effluents. Application of biochar to soil intended for on-land disposal of the effluent may be recommended. The recommended rates and its effectiveness will depend on the volumes of on-land effluent disposal.

Effect of pyrochar and hydrochar amendments on sorption and mineralization of the herbicide isoproturon in an agricultural soil

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Carbon (C)-rich, solid products from pyrolysis (pyrochars) and hydrothermal carbonization (hydrochars) amendments to soil are thought to improve soil fertility and allow C sequestration. Due to a high surface area and a considerable amount of functional groups, we hypothesized that application of pyrochar or hydrochar to an agricultural soil will lead to a reduction in bioavailability of pesticides, thereby reducing the risk of groundwater contamination. To compare effects of feedstock and production conditions, chars from different feedstock materials (digestate, Miscanthus, woodchips) and production processes (pyrolysis at 750°C, hydrothermal carbonization at 200°C and 250°C) were applied to a loamy sand at two different amounts (0.5% and 5% dry weight) and sorption and incubation experiments with ¹⁴C-labeled isoproturon (IPU, 0.75 kg ha⁻¹) were carried out. The capacity of agricultural soils to adsorb organic contaminants could be enhanced by amendment of both, pyrochars and hydrochars. Amendment with pyrochar reduced the amount of in situ available IPU in the soil by a factor of up to 2283 while hydrochar application led to a reduction by a factor of 3–13. Sorption of IPU could be best predicted by the surface area of the charred material. Due to the great importance of surface area as a driving factor for the sorption capacity, the influence of feedstock material was of less importance compared to the production conditions. The bioavailability of IPU was related to the degradability of the added chars. Mineralization of IPU after 50 days of incubation in pure soil amounted 8.1% of the applied IPU. In pyrochar-treated soil, IPU mineralization was reduced by 81% (±6%) and in hydrochar-treated soil, the reduction amounted 56% (±25%). Compared to pyrochars, hydrochars contain higher amounts of water extractable C and oxygen containing functional groups, to which the pesticide may bind reversibly. This allows for controlled pesticide mineralization while reducing the risk of leaching and pesticide accumulation in hydrochar amended soil.

Biochar actions in the environment

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Meanwhile, biochar has reached human and animal nutrition. Increasing contradictory scientific results urgently request a more detailed investigation of mechanisms of how biochar interacts with the environment. I will summarize current state of the art of theoretical and observed biochar mechanisms under different ecological aspects.

Expected effects due to physico-chemical structure of biochar:

The chemical structure of fresh biochar is characterized by a high proportion of condensed aromatic moieties and low proportions of functional groups, biologically degradable organic carbon, and ash. From a physical point of view, biochar is a porous media. The big surface area is dominated by pores in the nm range, while the plant-available water-holding capacity is dominated by pores bigger than 20 μm . Ash components can serve as mineral fertilizer for plants and microorganisms. Labile (not aromatic) organic carbon can be assimilated by soil microorganisms, probably explaining the rapid initial microbial activity and respiration (CO_2 emission) after biochar addition to soil. Condensed aromatic moieties of biochar are much more stable than natural organic matter and can act as long-term C sink in soil due to its intrinsic chemical recalcitrance. Interaction of biochar with soil minerals will occur only after partial oxidation and formation of functional groups such as phenolic or carboxylic groups. Enhanced biological activity especially during composting will facilitate and promote such reactions.

Physical biochar interactions, especially with water:

Biochar influences many physical soil properties such as primary and secondary structure, porosity, permeability and density. The chemical structure of biochar is dominated by hydrophobic poly-condensed aromatic moieties repelling water, while the physical structure of biochar is dominated by macro and micro pores attracting water. If water is in contact with biochar, it is attracted by hydrophilic functional groups (phenolic, carboxylic) and by capillary forces of pores. New scientific evidence provided interactions of water with graphene sheets of biochar despite their hydrophobic chemical character.

Chemical biochar interactions – stability versus reactivity:

The stability of biochar was controversially discussed in scientific literature. Potential explanations for this discrepancy are methodological aspects as well as the variable proportion of stable poly-condensed aromatic carbon of biochar. A quantification of this poly-condensed aromatic C is crucial with respect to the C sequestration potential of biochar. On the other hand, reactivity of biochar is crucial for other positive ecosystem functions such as nutrient holding capacity and formation of stable organo-mineral complexes and / or soil aggregation.

Biotic biochar interactions with plants and microorganisms:

Soil microbial diversity is a function of soil (especially pH) and site properties (temperature and precipitation). As biochar can influence those properties, it has also indirect effects on soil microbial diversity. Therefore, for a proper investigation of direct biochar effects on soil microbial diversity, these factors need to be kept constant, which is most often not the case. Nevertheless, direct biochar effects on soil microorganisms has been reported, which can be explained by the high surface area and the occurrence of easily degradable organic carbon attached to this surface.

Toxicological aspects of biochar in the environment:

Thermochemical conversion of organic matter involves production of low molecular weight condensed aromatic moieties also known as polycyclic aromatic hydrocarbons and dioxins. Hydrothermal carbonization does not produce such compounds due to the relatively low temperature. On the other hand, hydrothermal carbonization produces a variety of low molecular organic compounds potentially toxic for plants. Contents of polycyclic aromatic hydrocarbons and dioxins can be kept low by technical parameters (temperature, separation of biochar and condensates). Phytotoxic low molecular weight organic compounds of hydrochars can be eliminated by biological post-production processes such as aerobic composting. Little scientific literature exists about the biological actions of biochar in men and animals. However, biochar should act similar to activated charcoal. The only constraint is particle size, which should be higher than 10 μm to avoid accumulation in lung tissue.

Summary and conclusions:

From the physico-chemical structure of biochars, a number of biochar reaction mechanism in the environment can be deduced, especially with respect to stability and physical and chemical reactivity. More difficult and thus, less certain are biotic interactions with microorganisms, plant, animal, and men.

An economic assessment of soil carbon sequestration with biochar in Germany

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Due to its high carbon stability, the soil incorporation of biochar is increasingly discussed as a promising means to remove carbon dioxide from the atmosphere and, thus, to help mitigate climate change. Against Germany's targets for the reduction of its annual greenhouse-gas (GHG) emissions – a 55% cut below the 1990 level by 2030 and a 80-95% cut by 2050 –, this paper analyzes whether the deployment of slow-pyrolysis biochar in agricultural soils in Germany – combined with the use of the pyrolysis by-products as renewable sources of energy – could be a viable mitigation strategy.

Focusing on carbon dioxide, methane and nitrous oxide, the economic assessment of biochar in Germany is based on the technical GHG mitigation potential of biochar and its associated costs for the years 2015, 2030 and 2050. The analysis is performed for a wide range of feedstocks (such as cereal straw, forestry residues, certain types of wood and green waste, short-rotation coppice, solid manure) and against the baseline scenario of conventional feedstock management, including decomposition on site, biomass combustion, composting and manure management. Moreover, it covers a variety of biomass-availability scenarios, pyrolysis-technology scales and future price developments for fossil fuels and GHG emission certificates. Throughout, the study accounts for feedstock-specific biochar yields, carbon contents and other biochar properties from an extensive literature survey.

Overall, biochar allows for an annual technical GHG mitigation potential in Germany in the range of 2.8-10.2 million tonnes of carbon-dioxide equivalents (Mt CO₂e) by 2030 and of 2.9-10.6 Mt CO₂e by 2050 if any cost considerations are neglected. This corresponds to approximately 0.4-1.5% and 0.3-1.1% of the respective 2030 and 2050 GHG reduction targets. However, the mitigation potential is drastically reduced if costs are taken into account. In 2050, for example, only about a third of the 10.6 Mt CO₂e can be mitigated at costs below 75 €/t CO₂e – the then assumed maximum price for GHG emission certificates.

Biochar soil amendment – an efficient strategy for climate change mitigation?

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Biochar has been proposed as a new key instrument at the nexus of biomass carbon flows including value added potential pertaining to climate protection, soil amelioration, agriculture, energy supply, and waste management. The comprehensive assessment of a biochar strategy to mitigate climate change, i.e., through capitalizing on the additional carbon sequestration by dry or wet torrefied biomass, requires analyses of many individual factors influencing the overall sustainability of biochar use. Important factors involve the resource competition in biomass feedstock, the “cradle to grave” carbon footprint of industrial biochar, the stability of biochar in soils, the yield effects in crops, and not at last the profitability of biochar applications for crop production. While the two latter issues seem the least related to mitigating climate change, they are key factors to get biochar stored in soils worldwide. Based on a literature review, the study provides a snapshot of the carbon sequestration, the effect of biochar application on agricultural crop yield and the present economic benefit to farmers. A simple calculation for the example of Germany revealed that the relative contribution of agricultural biochar use will be small compared to the total anthropogenic CO₂ emission. The majority of recent studies showed that positive effects on crop yield are not unchallenged but effects often remain small and insignificant at best.

The average annual added value in crop yield calculated from a review of 160 field experiment results was only 1,10 EUR per 1 Mg biochar applied to soil. Finally, considering the current average costs of biochar, the economic viability of biochar cannot recommend its general use in agricultural crop production.

Effects of biochar-compost on plant growth, biomass and crop yield in pot and field trials of selected plants from different climate zones

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The application of biochar-compost (BCC) had been proposed as an effective and sustainable soil amendment to increase crop yields and plant growth. We studied those effects in 2-years pot trials at the Botanic Garden Berlin-Dahlem (BG) and in a 3-years field trial in Ghana.

In the northern region of Ghana, farmers face the problem of nutrient-poor soils with low soil fertility and low soil organic matter content. This study is to address the potential of using BCC as an organic matter- and nutrient-rich material to improve soil fertility and to increase crop yield and therefore improving food security.

The pot trials focused on quality aspects of BCC, produced at the BG in comparison to the previously used purchased compost. Furthermore the aspects of peat substitution and reduction of fertilizer were considered.

In Ghana a decentralized composting site was established to produce a nutrient-rich BCC of organic waste from households, food markets and sheabutter production and charcoal from the traditional charcoal production. The impact of BCC on crop yield and plant growth was studied in a 3-years field experiment on farms around Tamale and Walewale area. A quantity of at each 12.5 Mg ha⁻¹ BCC was applied to five fields of 4000 m². Guinea corn, maize and groundnut were used as trial crops.

At the BG the effects of BCC on plant growth were studied in pot trials with eleven different plant species of three different climate zones (tropical, subtropical and temperate) in greenhouses. The BCC contained 20 Vol% of biochar. The pot trials were set up with two substrate treatments (BCC and pure compost) and a control. All substrates were each mixed with different additives as required for the plants. Plant substrates with BCC and pure compost had 12 Vol% less of peat than the control.

The field trial in Ghana was carried out on a loamy sandy soil and a sandy loam. The soil had a pH (0.01 M CaCl₂) of between 4.5 to 7.0 and a mean organic matter content of between 0.7 to 2.1%. The application of BCC resulted in an increase of soil pH of between 0.27 to 0.54 pH units. The study revealed significant effects of BCC on plant growth and crop yield when compared with the control. Yield increases of a factor of between 1.3 and 1.7 could be obtained. A yield increase of 10.4% was observed on a BCC fertilized field compared with a NPK fertilized field.

The BCC produced at the BG fulfilled the quality requirements of the German Compost Quality Assurance Organization. The pot trials provided different results in plant growth regarding the plant species. Significant differences in plant height and biomass were found for *Carica papaya* and *Geranium maderense* ($p < 0.05$). No differences in plant growth were found for *Nerium oleander* and *Coffea arabica*.

Concerning a sustainable agriculture in Ghana the use of BCC helps to increase crop yield and improves soil quality. The use of BCC at the BG enables to reduce the use of peat and fertilizer.

The use of biochar substrates for soil reclamation - results of experiments in Northeastern Germany

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After the model of the very fertile "Terra preta do Indio" in Amazonia, the joint project "LaTerra" takes up a new technology for the production of organic substrates using biochar as admixture to the composting and fermentation of biomass to test its application for soil improvement, reclamation and remediation purposes. Processing organic materials or residues and the creation of high quality organic soil improving materials will close material cycles and contribute to the value added on a regional scale. This should be an essential part of a sustainable material flow management.

The paper presentation will focus on the application of biochar substrates for the reclamation of sandy soils in Northeastern Germany. Lignite mining activities leave raw soils without humus on dumps and tips. The rapid formation and maintenance of a balanced humus and nutrient budget is of great importance. Field, lysimeter and pot experiments are part of the research program in order to find out the impact of biochar substrate application on soil functions and plant growth and to derive quality criteria and recommendations for practice.

The results of the experiments show that application of biochar substrates (BCS) improved soil properties like nutrient supply, organic carbon content, water storage and cation exchange capacity. However, crop yields did not increase in the year of application on the test sites or even decreased on the dumped soil with rising amounts of BCS. This is a consequence of nitrogen immobilization and sorption in the soils treated with BCS. Therefore, BCS applications should be combined with mineral fertilization of nitrogen and BCS production should be modified aiming to improve contents and release of plant available nitrogen.

In the third year after BCS-application variants treated with 60 t ha^{-1} BCS 15 showed highest yields, exceeding the variants with mineral fertilization by trend. Long-term experiments are necessary to clear the sustainability and economic feasibility of biochar substrates use in reclamation and agriculture.

Characterization of biochar from tender coconut husk and its impact on soil properties in ferralitic soils

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Tender coconut husk is a major biowaste which accumulates on the road sides and it is a rich source of nutrients. The best way to utilize it for crop production without environmental pollution is by converting it to biochar. Biochar was produced from tender coconut husk using biochar kiln and it was characterized for various physical and chemical characteristics. To investigate the efficacy of biochar (BC) from tender coconut husk for enhanced crop production, a field experiment was conducted at College of Agriculture, Vellayani of Kerala Agricultural University, India.

The treatments were

1. Package of Practices Recommendation (POP),
2. BC @ 10 t ha⁻¹ + NPK,
3. BC @ 20 t ha⁻¹ + NPK,
4. BC @ 30 t ha⁻¹ + NPK as per OP,
5. BC @ 20 t ha⁻¹ + 75% NPK,
6. BC @ 10 t ha⁻¹ + FYM @ 10 t ha⁻¹ + 75% NPK,
7. BC @ 10 t ha⁻¹ + vermicompost @ 5 t ha⁻¹ + 75% NPK as per POP,
8. BC @ 20 t ha⁻¹ + 2 % PGPR + NPK,
9. BC @ 20 t ha⁻¹ + AMF @ 200 g m⁻² + NPK.

It was an RBD with 9 treatments and 3 replications. The tender coconut husk biochar produced was having an alkaline pH (9.13) with CEC of 15.26 cmol kg⁻¹, Water Holding Capacity (WHC) of 226.00 per cent, bulk density of 0.14 Mg m⁻³ and BET surface area of 157.93 m² g⁻¹. Application of tender coconut husk BC @ 30 t ha⁻¹ along with NPK had significant influence on soil pH, CEC, water holding capacity, porosity, bulk density and per cent water stable aggregates. Soil pH and CEC were found to be significantly increased from 4.93 to 6.57 units and 3.14 to 5.43 cmol kg⁻¹ respectively when BC was applied. WHC of the soil increased from 30.89 (POP) to 48.78% whereas per cent water stable aggregates elevated from 56.78 to 80.26%. Soil bulk density was found to be reduced from 1.32 to 1.20 Mg m⁻³.

Business models for a sustainable land use by means of biochar substrates – a technical and economical modelled view

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This paper analyses selected possible uses of biochar and biochar substrates from an economic point of view: agricultural use for improving the fertility of soils; cleaning up of areas contaminated by petroleum derived hydrocarbons; direct sale to consumers e.g. for private gardening purposes. The analysis is based on a model which delineates the main technical and economical characteristics of the production process of biochar substrates. It is used to simulate the effect of variations of the most important drivers on profitability.

It is shown, that the production of biochar is the most expensive part of the production of biochar substrates. Especially modern methods of pyrolysis and fixed bed combustion are relatively expensive. If biochar is only a by-product of energy generation by using organic material, the production costs might be reduced, particularly when such energy generation is subsidized. Due to the high investment costs the degree of utilization of the technical equipment is important.

Under normal circumstances agricultural usage of biochar does not cover the expenses of production and distribution in comparison to conventional fertilizers. However, a few constraints have to be made. The proceeds calculated are of crops grown on low-yield soil, e.g. rape. Different results may be attained if high revenue crops such as potatoes are planted. Furthermore the positive external effects of biochar substrates not internalized in the market price of land or crops, that could justify governmental subsidies, are not calculated in the model.

Cleaning up contaminated areas by using biochar is economically feasible as well as the niche market of the distribution of biochar substrates on the internet and via building supplies stores. Probably such niche markets and further governmental subsidies are necessary to enable further technical development of production technologies and reducing production costs of biochar.

Calculating the time-dependent climate impact from a biochar–bioenergy system.

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Decentralized heat generation can be an attractive option in short rotation coppice willow bioenergy systems since it reduces the need for transports of wet and bulky biomass. Pyrolysis can be used to generate heat for local needs as well as biochar for soil application. An important property of the biochar is its potential as a carbon sequestration agent.

The objective of this study was to quantify the contribution to the global mean surface temperature change over time from different system components of a carbon sequestering biochar-bioenergy system generating heat for local use.

A bioenergy system was modeled, where biochar was produced at the farm using slow pyrolysis. A 20 hectare short rotation coppice willow plantation was established on fallow land to provide feedstock for the pyrolysis plant. The biochar was assumed to be returned to the field while the pyrolysis gases were used to run the pyrolysis process and supply heat in the vicinity of the pyrolysis plant. Literature data was used to calculate the emissions of the three most important greenhouse gases (carbon dioxide, methane and nitrous oxide) for all processes in the system.

Time-dependent life cycle assessment methodology was used to assess the climate impact of the bioenergy-biochar system. No difference was made between biogenic or fossil carbon. The climate impact of carbon stock changes were assessed by modelling annual net emissions and uptake of all sources and sinks of carbon within the system. The climate impact of the system was characterized using the global mean surface temperature change (ΔT_s) as a function of time. All system components were also characterized using GWP₁₀₀. Emissions taking place during the first 50 years from the establishment of the willow were calculated. The effects of these emissions on ΔT_s were evaluated for another 50 years, making the total length of the evaluation period 100 years.

The product distribution from the pyrolysis process was 28% biochar, 18% non condensable gases and 62% condensable gases (44% water content, including feedstock moisture). Of the chemical energy in the feedstock (LHV) 25% was converted into heat in a gas boiler. The total GWP₁₀₀ of the cultivation system was 44 g CO₂-eq/MJ heat. Using fuel oil to generate an equivalent amount of heat would have generated 90 g CO₂-eq/MJ heat. When taking the SOC stock changes and biochar sequestration into account the total GWP₁₀₀ decreased to -269 g CO₂-eq/MJ heat. The biochar effect on

ΔT s was more than 6 times greater and of opposite sign to the NO_2 and fossil CO_2 emissions combined.

In conclusion, biochar can have a large impact on the climate impact of a biochar-bioenergy system. The low energy conversion efficiency makes comparisons with other systems difficult without taking indirect effects into account. Time-dependent life cycle methodology can aid in understanding the temporal effects of a bioenergy system on the climate.

Biochar in Malaysia, Indonesia, Zambia and Nepal: soil dynamics, technology, life-cycle assessment and implementation

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A suite of multidimensional biochar projects in tropical countries will be presented, with a special emphasis on Malaysia. In that country, an upscale Belonio gasifier was constructed to make rice husk biochar. The agronomic performance of this biochar was compared to that of burned rice husk, a rest product from the rice milling industry, in pot trials and field trials in sand soil and in acid sulphate soil. Biochar proved to be effective in both soils, and the controlled Belonio biochar was better than the burnt rice husk. Experiments on soil dynamics showed that it is several factors that contribute to agronomic effects of biochar: water retention in Zambia and sandy Malaysian soil, pH effects on Sumatra and acid sulphate soil in Malaysia, and water drainage effects on West-Timor. Biochar on Sumatra was shown to strongly decrease N₂O emissions, and a pH increase was probably part of the reason.

Technology: improper technology will result in emissions of CO, CH₄ and smoke. Gas emission data have been obtained for several type of retort and traditional technologies in all four countries, and show that retort technology is about a factor of four cleaner than traditional technology.

A life-cycle analysis for the Zambian situation showed that biochar implementation is optimal when done with proper technology, but that non-improved technology still is favorable in a life-cycle perspective if crop yield responses are big enough. A life-cycle and cost-benefit analysis for Indonesia showed that soil amendment is better than biochar briquetting, mainly because of carbon sequestration effects and the high labor required to make briquettes.

Analysis of volatile and semi-volatile components in hydrochar: prospects and challenges

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The integrated assessment of hydrochars meant for environmental applications such as soil amendment or in waste water treatment certainly requires knowledge on nature and amount of mobile low-molecular components. Many of these compounds may affect the agricultural success or pose a potential risk upon release to environmental compartments. Due to their volatile or semi-volatile character headspace gas chromatography is a straight forward method for their characterisation.

In a survey, a number of biomass substrates including wheat straw, a biogas digestate and four different woody substrates were submitted to hydrothermal carbonisation (HTC). Process temperatures of 190, 230, 250, and 270°C, respectively, were applied in separate runs over six hours in order to generate hydrochars with gradually increasing degree of carbonisation. Headspace gas chromatography was combined with mass selective detection for the identification and flame ionisation detection for the quantification of individual hydrochar volatilome components.

The advantages of the analytical approach regarding sample preparation and the challenges regarding data significance and interpretation are discussed. The compositions of the respective hydrochar volatilomes are compared with regard to the original substrates. The alteration of hydrochar volatilomes with proceeding degree of substrate carbonisation is discussed. The significance of major substance classes including certain aldehydes, ketones, furans, aromatics and phenols is outlined with regard to process and product characterisation.

The presented analytical approach provides a tool for the characterisation of hydrochars regarding the quantification of potentially hazardous components, the assessment of carbonisation progress or the identification of substrate origin.

Potential socio-economic impacts of biochar on smallholder farmers in Kenya

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An array of studies are showing the potentials of biochar in improving soil fertility, reducing fuel demands and minimizing exposure to indoor pollution. In the context of smallholder farmers in Africa, the three aforementioned aspects are tightly related to poverty reduction and health improvement. However, new technology adoption requires the right socio-cultural conditions to take hold and succeed. In order to assess the need for and the feasibility of using biochar in smallholder systems we carried out a preliminary study that included 152 households in Embu, Kwale and Siaya counties in Kenya. Each household responded to a survey that includes 304 variables. The survey captures demographics and socio-economic conditions, current fuel energy and stove uses, availability and feedstock used, current fertilizer uses, crops grown and their marketization, as well as the labour division within the household. In addition to the survey, we carried out qualitative interviews with these households in order to capture their perceptions and willingness to adopt a technology such as biochar. Our data shows clearly that there is both the need for and the disposition of these communities to tackle the issues of soil fertility, fuel efficiency and exposure to indoor smokes. Besides the impacts that Biochar might have on the general economy and health of the household, there is a clear correlation between those activities that Biochar will have an impact on and those traditionally associated with female labour.

Compost vs. biochar amendment: a two-year field study evaluating soil C build-up and N dynamics in a semiarid olive orchard.

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Olive tree plantations are one of the most important crops in the Mediterranean basin. Most olive tree cultivated soils have low levels of organic matter and suffer from limited N availability. The regular application of organic amendments has been found to increase soil fertility, adding other positive environmental side-effects, like C sequestration and N₂O mitigation. This study evaluated the application of compost and biochar in a drip-irrigated organic olive orchard (*Olea europaea* L. cv. Arbequina) in South-East Spain. The experimental plots were organized as a randomized block design with four treatments (control, compost, biochar and a compost-biochar blend at 90:10 dry weight basis) and three replications. Amendments were applied in the spring of 2013 at a rate of 20 tons/ha, according to local farming practices. During two consecutive years, changes in soil total organic C concentration (TOC), $\delta^{13}\text{C}$, water soluble C (WSC) and N (WSN), mineral N (NH₄⁺ and NO₃⁻), water extractable PO₄³⁻, N₂O emissions and denitrification enzyme activity (DEA) were monitored. In addition, the nutritional status of the olive trees was evaluated by foliar analysis. Biochar showed the highest C sequestration potential, compared to compost or the compost-biochar blend. WSC and WSN in soil significantly increased in plots amended with compost or the compost-biochar blend, especially during the initial six months after soil amendment. Nitrogen cycling in soil followed a seasonal pattern, with the highest DEA and N₂O emissions during the summer. Compost and particularly the compost-biochar blend increased DEA in soil. However, no significant differences were found for soil mineral N and N₂O emissions, which were in general very low compared to other studies. Our results show that, in these N-limited agro-ecosystems, compost amendment has a clear impact on soil microbiological activity with a link to N availability, whereas biochar does not alter the N dynamics, but markedly builds-up soil C. The application of compost-biochar blend, while not having measurable short-term impact on total soil C stocks, combines both positive effects and could represent the best option in the long term.

Biochar does not exert structural control over soil N₂O and N₂ emissions

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Soil-borne N₂O emissions contribute significantly to terrestrial greenhouse gas emissions. Biochar additions to soils are a promising tool to reduce N₂O emissions, however, the exact mechanisms of these biochar-induced reductions are not yet fully understood. The objectives of this study are to investigate whether N₂O emission reductions persist after biochar incorporation in the field in the longer term.

Four biochars were produced via slow pyrolysis from two feedstocks, namely swine manure digestate (D) and willow wood (W), at two different pyrolysis temperatures, 350°C and 700°C. In this way four biochar types were obtained: D350, D700, W350 and W700. These biochars were incorporated in a loamy textured cropland field at an application rate of 10 t ha⁻¹. After 7 months intact soil cores were sampled and taken to the laboratory to investigate the physical control of biochar on denitrification.

During a first experiment, we measured N₂O emissions via headspace analysis from undisturbed and disturbed (i.e. sieved (2mm) and grounded) soil cores. In this way we tested the hypothesis that biochar-induced improvements of soil aeration are responsible for decreased N₂O emissions.

Secondly, we looked into the mechanism of hot spot-creation in which complete denitrification from N₂O to N₂ would occur. N₂O and N₂ emissions were measured from undisturbed soil cores via the acetylene inhibition method. Observations of N₂O emission reductions from undisturbed soil cores sampled in the field seven months after biochar incorporation enabled us to refute two N₂O emission reduction mechanisms.

In the first experiment, there were very large and significant ($P < 0.05$) differences in the cumulative N₂O emissions between the control and all biochar amended soil cores in both disturbed and undisturbed treatments. Compared to the control cores, the cumulative N₂O emission in the biochar amended soil cores was between 72 and 85% lower in the undisturbed treatments, and it was between 50 and 90% lower in the disturbed treatments. These observations refute the hypothesis that biochar exerts a physical control over soil denitrification after several months of incorporation.

Secondly, the cumulative N₂O-N emission was about 8 to 10 times lower than the N₂-N emission in corresponding treatments. In all biochar amended soils both the N₂O-N and the N₂-N emissions were significantly ($P < 0.05$) lower than the emissions from the control cores, indicating that biochar does not stimulate the reduction step from N₂O to N₂.

In shortage of a denitrifier C substrate N_2O emissions did not differ between control and biochar treatments. However, when provoking availability of a C-source by glucose addition or disruption of soil aggregates pronounced N_2O emission reductions were manifested in the biochar amended treatments. Therefore we postulate adsorption of C-substrate to the biochar as a likely mechanism of N_2O emission reductions over longer time periods.

The effect of aged vs new biochar on soil N₂O emissions

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Scientific evidence is building that biochar additions to soil can significantly reduce nitrous oxide (N₂O) emissions. Parallel to the discussion on why biochar may be reducing N₂O is the question to whether an eventual effect will endure over time. Indeed, most studies to date use freshly produced biochar and measure N₂O over short periods of weeks or months. Therefore, in our study, we measured N₂O emissions from a field experiment where we added biochar in 2010 and compared these with N₂O emissions from new biochar plots that we added in 2012 and 2014. We hypothesized that the new biochar plots would produce less N₂O emissions than the old biochar plots

The field experiment was conducted on a clay loam at the Norwegian University of Life Sciences field station in Norway. The biochar was made from *Miscanthus giganteus* and sourced from Pyreg GmbH (DE) and applied to plots at a rate of 25 t C ha⁻¹. Soil N₂O flux measurements were taken between May and September of 2012 (n=10) and 2014 (n=16) from closed static chambers. To explain data variation we also took auxiliary measurements including soil NO₃, NH₄, pH, EC, soil water content, soil temperature, bulk density, and soil N₂O and CO₂ concentrations. We collected aged biochar from the field and characterized this together with the new biochar to explain potential differences in emissions from the treatments.

The main findings of the study were as following:

- Nitrous oxide fluxes were four times lower in 2014 than in 2012, due to a summer drought which limited N₂O via denitrification.
- In 2012, where wet weather prevailed, new and aged biochar reduced cumulative N₂O emissions by 34% and 12% respectively compared to the control. In 2014, during a drought period, new biochar stimulated N₂O emissions. This was not the case however for aged biochar which responded similar to the control.
- In 2014, when wetter conditions returned and denitrification was likely occurring, new and aged biochar reduced N₂O once again.
- Neither aged or new biochar altered the soil pH in 2014.

Our field observations over two seasons in a temperate clay-loam show that both new and aged miscanthus biochar generally reduce N₂O emissions but only during wet denitrifying periods. We observed that biochar's N₂O reducing effect weakened with field aging. However, the increased emissions attributed to biochar during drier periods were only stimulated by the new biochar and not aged.

N₂O suppression by biochar in soil; to what extent is this a pH effect?

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Recent studies have shown that there are still many questions regarding the cause of the N₂O mitigation effect observed when biochar (BC) is added to soil. A number of hypotheses have been proposed for the biochar effect on N₂O emissions including physical sorption of NO₃⁻ and N₂O, biochar toxicity, stimulation of both nitrification and denitrification, increased availability of labile carbon (at least in the short term) and biological stimulation of N₂O reduction through redox effects of biochar. The role of pH has also been considered and is the focus of this study. We hypothesize that biochar can reduce N₂O emissions in acid soils by increasing soil pH, which reduces the inhibition of N₂O reductase, and supports more complete denitrification.

We used an automated incubation system to measure high-resolution NO, N₂O and N₂ kinetics in anoxic soil-slurries with and without biochar addition. Soil slurries were used to remove the matrix effect of the soil and to provide homogenous substrate availability for microbial growth. We chose to incubate samples of low pH soils known to produce significant N₂O emissions in the field as this would offer the highest N₂O mitigation potential when buffering acidity by addition of biochar. We compared a cultivated peat and an acid mineral soil representing contrasting buffer capacity and carbon availability. pH response and denitrification N-gas kinetics were studied for a series of well-characterised corncob biochars prepared at 250, 400, 600 and 800°C highest treatment temperature (HTT). Increasing amounts of the biochars were applied to characterize the dose response for each HTT biochar. NaOH treatments were included to examine whether pH treated soils followed the same trajectories as the biochar amended soils.

Our main findings are:

1. Biochar suppressed net NO & N₂O accumulation/timing in the kinetic experiments.
2. Suppression increased with increasing HTT, concomitant with its alkalinizing effect
3. The response to NaOH was similar to the high temperature biochars at equal effective soil pH.
4. The pH effect was confounded at lower pyrolysis temperatures. Low temperature biochars had a tendency to increase the N₂O product ratio that we tentatively attributed to their high content of volatile matter.
5. In the carbon poor mineral soil we hypothesise that denitrification was inhibited by lack of available carbon. In this soil low temperature biochars enabled more complete denitrification possibly due to the availability of volatile matter.

Our results show that not only do biochar properties have measurable effects on denitrification kinetics but that these effects are dependent on soil type. Our results also show that volatile matter can have significant implications for denitrification kinetics.

Impacts of empty fruit bunch biochar on nitrogen leaching and ^{15}N -labelled fertilizer recovery in maize on an oxisol

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The potential of biochar in retaining nutrients due to high surface area and porosity is an ideal amendment for highly weathered acidic soils in humid tropical region. A short-term pot experiment was conducted under rain shelter to determine the impact of oil palm empty fruit bunch biochar (EFBB) on recovery of ^{15}N -labelled fertilizer (80 kg N/ha at 2% a.e) by maize plant and N leaching at the rate of 0, 5, 10, and 20 Mg ha⁻¹ EFBB in a sandy clay soil. Watering was done daily and leachate was collected weekly to determine total volume of leachate and amount of mineral N ($\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$) leached until the harvesting of maize at 56 days after sowing. From the analysis of leachate, it shows that EFBB significantly reduced cumulative leachate volume by 29-52%, 24-51% in $\text{NH}_4^+\text{-N}$, and 25-59% in $\text{NO}_3^-\text{-N}$, when compared to the control. Soils applied with EFBB significantly improved N fertilizer recovery by 7-14% in maize and dry matter weight by 32-85%. Other nutrients like K, Ca, and Mg in tissue and in soil also significantly increased in pots added with EFBB. The EFBB was shown to be effective in reducing N leaching and improve N fertilizer recovery at an application rate up to 10 Mg ha⁻¹. Lower leachate volume and leached mineral N seems to indicate higher retention in the soil with EFBB, attributing to improvement of N fertilizer recovery in the plant. In conclusion, this study shows that EFBB has the potential to be applied on this highly weathered acidic soil as an amendment to improve fertilizer efficiency and crop growth. This justifies further studies of EFBB carried out under field conditions.

Effects of biochar on potential nitrification and LAS ecotoxicity in agricultural soil

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Biochar is a recalcitrant and persistent char product synthesized by pyrolysis of plant- or animal-based biomass and intended for soil amendment. Suggested ecosystem services of biochar include increased soil fertility, carbon sequestration and decreased nutrient leaching. Further, large specific surface area of biochars has the potential to decrease bioavailability of toxic organic contaminants in the soils, through sorptive processes. Still, however, toxic compounds present in the feedstock (heavy metals) or generated during pyrolysis (e.g., polycyclic aromatic hydrocarbons, PAH) necessitates precautionary measures before wider environmental application of biochar. The aim of this study was to test the ecotoxicity of biochars in agricultural soil towards potential nitrification as a microbial bioindicator and to test for potential mitigation of the ecotoxicity of the widespread organic contaminant linear alkylbenzene sulphonate (LAS) in the presence of biochar. Under laboratory conditions, six types of biochar derived from straw (2 types), wood (3 types), and animal bones (1 type) were amended to a sandy loam soil in concentrations from 0.4 to 36.8% (wt/wt) and incubated for up to three weeks. Assays of potential nitrification after 1-2, 7-8 and 21-22 d showed that two of the three wood-based biochars either caused no effect or even stimulated potential nitrification. For the other biochars, dose-responses were modeled and initially (1-2 d after amendment) showed 10% effect concentrations (EC_{10}) in the range of 1.3 to 23.8%, but with significant recovery potential observed with the for biochars causing largest inhibition of potential nitrification (i.e., EC_{10} increasing from 1.3 to 3.6-4.2% within 1 week). All biochars were found to potentially increase soil pH although at varying degree; such pH effects would likely stimulate nitrification in the soil. LAS ecotoxicity in the presence of 1.1% biochar in the soil showed diverging results for the tested biochars (2 from straw and 2 from wood). Modelled EC_{10} values for potential nitrification were derived both above ($EC_{10} = 61.9 \text{ mg LAS kg}^{-1}$) and below ($EC_{10} = 35.5 \text{ mg LAS kg}^{-1}$) the EC_{10} in reference samples, where LAS ecotoxicity was tested in the absence of biochar ($EC_{10} = 42.8 \text{ mg LAS kg}^{-1}$). We conclude that the six biochars increased soil pH to varying degree, but did not cause severe inhibition of potential nitrification. Thus, based on comparison of ecologically relevant doses and effects on the tested microbial bioindicator, the current biochars had an ecologically acceptable profile. However, no clear effect of LAS sorption to biochar was observed, which could potentially have mitigated LAS ecotoxicity in the soil.

Impact of biochar on the population structure of soil biota

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Changes in microbial abundance and community structure due to the amendment of biochar were explored by using taxon-specific qPCR (ecotyping). For this purpose, DNA was extracted from soil samples derived from a long term field experiment (3 years) located in Berge, Germany. The ecotyping was suitable to detect and resolve impacts of two biochars from different feedstock (wood and maize) on the soil microbial community structure. On the other hand, the high variability of control plots prevented a clear distinction. Due to significant local differences found in the control plots, the field site was separated into two areas with significantly diverging microbial community structures. Significant differences in the abundances of specific taxa were only found 10 months after application of chars, while after 22 months the microbial community had returned to control level. Analogue shifts of the population structure were also detected by incubation experiments under laboratory conditions but with higher biochar concentrations. Three taxon-specific reaction types were derived: type i) shifting to a constant relative abundance, type ii) matching the control fraction, and type iii) exhibiting a constant change rate. It was further found that earthworm distribution patterns were subject to the identical local separation found in microbial populations. Biochar impact was seen in one of the two areas. Here, mean abundance and biomass of earthworms were significantly higher in biochar plots; however the proportion of juvenile worms was significantly higher in the control plots. As seen in the microbial populations, biochar had the highest impact on the earthworm population 10 months after application.

Effects of biochar and digestate on the nematode community and the soil food web in an agro ecosystem

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Nematodes are the most abundant and ubiquitous metazoa in soil ecosystems. They have established functional groups at all trophic levels of the soil food web and indices derived by nematode faunal analysis provide bioindication of soil health and disturbance and of soil food web conditions. The aim of the study is to elucidate if digestate and different char materials, with varying feedstock and production processes, have different effects on the nematode community, the soil health and the soil food web conditions.

The study was performed in cooperation with the project “Biochar in agriculture perspectives for Germany and Malaysia”. The field experiment is located in Berge (Brandenburg, Germany) on a loamy sand soil. The experiment has a randomized block design with the three factors biochar, digestate and N-fertilization. Three different char materials were tested. For HTC-char the feedstock maize silage was processed by batch-wise HTC at 210°C and 23 bar for 8h. Maize silage continuously pyrolysed at 600°C for 30 min formed pyro-char. For pyreg-char screenings from wood chip production were continuously pyrolysed at 850°C for 30 min. For the digestate the same maize silage as for the char materials was digested by a batch-wise solid-state process at mesophilic temperatures (approx. 35°C).

Nematode sampling took place three times in 2013, representing different stages of development of the arable crop winter wheat: In the beginning of March (spring; beginning growth), at the end of April (late spring; growth phase with high root exudation) and at the end of October (autumn; after harvest). Nematodes were determined to genus level and assigned to feeding types according to Yeates et al. (1993). The nematode faunal analysis concept (Ferris et al. 2001) was applied to assign soil energy pathways (Channel Index, CI) and food web conditions (Enrichment Index, EI, and Structure Index, SI).

Results from the first sampling show a lower nematode population density with digestate and a higher with pyro-char and pyreg-char application, while HTC-char had no effects on nematode numbers. With digestate, HTC-char and pyreg-char proportion of bacterial-feeding nematodes were lower and of plant parasites were higher compared to the control. The energy transfer was predominantly in the bacterial channel of the food web, which is reflected by a high bacterial to fungal feeder ratio in all treatments. Moreover, the food web was enriched (high EI) and disturbed (low SI), with many r-strategists within bacterial and fungal feeders and few *K*-strategists such as omnivores or predators.

Effects of different biochars on soil meso- and macrofauna in a field trial

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We investigated the soil macro- and mesofauna, with a special focus on the Collembola community, at an arable field where different biochars have been amended in 2012. Soil fauna was collected from the top 10 cm of the loamy sand soil. In a three factorial design the effects of biochar application solely and in interaction with nitrogen fertilizer on crop growth, crop quality, soil properties and soil fauna were analysed. Therefore soil samples were taken in March, April and October 2013 in plots without amendment, with application of pyrolysed maize biochar (Pyro), pyrolysed wood biochar (Pyreg) or maize biochar produced by Hydrothermal Carbonisation (HTC) and with HTC biochar fermented with digestate (fermented HTC). Soil fauna was extracted using a high gradient extractor and preserved in ethanol. The impact of the different soil amendment on population density and community composition were assessed.

In total, 18 taxa from 5 faunal groups were detected in the arable soil. Dominant was the mesofauna with Acari and Collembola, followed by the members of the group Insecta. The macrofauna mainly comprised the groups Annelida, Coleoptera and Myriapoda. Population density of the soil fauna showed no differences according to treatments but seasonal variation, with numbers in March significantly higher than in October. The effects on Collembola, as major fungal feeders in arable soils, were investigated in more detail. However, again no significant differences were observed in the population density. Up to 12 Collembola species were detected at the different plots. Hemiedaphic life forms were the most dominant with five species, followed by epedaphic life forms with three to five species and euedaphic life forms with one to three species. The most dominant Collembola species were *Isotoma viridis* (epedaphic), *Folsomia* sp. (hemiedaphic), *Xenylla* sp. (hemiedaphic) and *Willemia anophthalma* (euedaphic). Compared to March and April, less species were detected in October, which resulted in lower species richness values. Shannon-Wiener diversity index showed the highest diversity of Collembola in April.

The clumped distribution of the soil fauna resulted in a high variation of data, which hampered the statistical analyses and only some trends could be assigned. Nevertheless, no negative impact of the investigated biochars on the soil meso- and macrofauna were apparent across the first vegetation period after amendment in an arable land.

Stability in soil of miscanthus biochar of light industrial scale: chemical tests, laboratory incubations, and 4-year field experiment.

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Biochar stability in soils is generally estimated through laboratory incubations, while mineralization rates in the field remain more uncertain. The main objective of the present research was to investigate the stability in soils of biochar produced from miscanthus feedstock with a semi-industrial pyrolysis method. Sub-objectives were to: 1) precisely determine the mineralization kinetics of the biochar in laboratory incubations, 2) determine if chemical oxidation and biomarker laboratory tests are consistent with incubation results, 4) estimate the stability of the biochar in a 4-year field experiment, 4) assess if soil microbial activities have been modified by biochar addition in the field.

Here we conducted chemical stability tests, laboratory incubations and a four-year field experiment with ¹³C isotopic tracing on a miscanthus biochar, which was produced in Germany by Pyreg GmbH in a continuous slow pyrolysis machine of light industrial scale.

The semi-industrial biochar produced at an estimated temperature of 600°C proved highly resistant to oxidations and contained more BP6CA than slow pyrolysis chars made in the lab with the same feedstock at 800°C. In a 90-day incubation, C mineralization was 45% for the miscanthus feedstock and 0.10% for the derived biochar. In the lab, miscanthus biochar generated a slight positive priming effect, but not larger than that of the miscanthus feedstock applied at one tenth of the rate. In the field, application of up to 25 t C biochar did not significantly increase growing-season CO₂ efflux. Isotopic tracing suggests that miscanthus biochar decomposed at less than 0.5% per growing season. Microbial biomass and functional diversity were not significantly modified two years after biochar application in the field, which suggests little impact of biochar on decomposer populations.

The four-year field experiment confirmed evaluations from stability indicators and laboratory incubations that the semi-industrial biochar is persistent in soil with little effect on microbial functions and therefore appears appropriate for long-term C storage in soils.

A long-term incubation study of the microbial decay of hydrothermal carbonized materials from sewage sludge in soil: linking chemical and biological effects

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The use of biochars in agriculture and forestry is gaining increasing interest in terms of mitigating emissions of greenhouse gases and improving the soil and plant growth. Beside direct plant derived biomass also carbon rich sewage sludge can be included into strategies that rely upon the biochar concept. The benefits of chars produced by hydrothermal carbonization (HTC) incorporated into soils depend on their long-term stability and on the improvements of soil chemical and biological properties.

We aimed at analysing the long-term effects of HTC chars and their feedstocks in an incubation experiment for 24 months – complimentary to the field experimental design within the CARBOWERT project. HTC chars of different carbonization degree and their feedstocks (sewage sludge and straw) were compared to a control and a control with mineral nitrogen addition.

The incubation experiment consists in total of 297 units and is subjected to discontinuous samplings at 9 time intervals: experimental start, 10, 30, 90 days and 6, 9, 12, 18 and 24 months. Because of a higher resolution of the carbon transformation - complimentary to the long-term a short-term incubation experiment of 50 day was performed with the same design measuring the carbon dioxide release hourly using an automated respirometer (Respicond). The used materials were mixed on a 50 mg C basis to 100 g of a sandy soil. All materials were characterized for their physicochemical characteristics and potential stability (e.g. pH, TOC, TN, H, O, volatile and fixed organic matter, midDRIFTS peak area analysis).

The feedstock and process parameters of the hydrothermal carbonization determined the percentage of volatile and fixed organic matter. Elemental ratios H/C and O/C clearly decreased with the degree of carbonization. Additionally the feedstock and process parameters showed an increase of the relative areas of aromatic C=C vibration and stretching bands as well as for the aromatic C-H vibrations of the midDRIFTS peak area analysis. The microbial utilization of carbon of the materials in the short- and long-term experiments depended on their physicochemical properties. After about 20 to 50 days the decomposable carbon of the materials was depleted, hence microbial biomass then used predominately the labile carbon originating from the soil organic matter. The decay of the materials by microbial biomass (SIR-BMC), its dynamics and enzymatic activities

depended on the availability of nitrogen in the soil mixtures resulting either in a mobilization or immobilization of mineral nitrogen. In the long-term, trends of nitrogen remobilization could be expected for selected materials.

The peculiarity of our interdisciplinary approach within the CARBOWERT project are complementary experiments at different scales in terms of space and time applying a broad spectrum of biogeochemical analytics for getting more insight into the expected long-term benefits of hydrochar application in agro-ecosystems.

Short-term response of soil respiration and microbial communities after addition of chars – effect of nitrogen and readily available carbon

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Two chars in soil mixtures and their effects on soil respiration have been studied in 10-day incubation experiments. The focus was on the impact of fermentation post-processing and of readily available nitrogen and carbon sources on the CO₂ release and on its dynamics.

We used a pyrolysis char and a HTC char derived from maize silage, both raw and fermented. Calcium ammonium nitrate was used as nitrogen source and glucose as additional carbon source. Soil respiration was assessed using a multi-channel infra-red gas analysis system. An ecotyping analysis was performed to inspect the evolution of the population of fungi, Acidobacteria, Actinobacteria, α - and β -Proteobacteria.

All treatments with char decreased soil respiration compared to unmodified maize straw. Respiration in soil-HTC char mixtures was higher than in soil-pyrolysis char mixtures, but the fermentation was effective in reducing the CO₂ release. HTC char showed a two-step decay kinetics, which could not be explained with a simple double-pool model. Nitrogen addition did not increase overall CO₂ release in soil-char mixtures, but effects were evident in the respiration dynamics.

Respiration in soil-char-glucose mixtures was higher compared to soil-straw or soil-char mixtures without glucose amendment, but lower compared to the soil-glucose mixture. Thus, an inhibition effect of char upon glucose metabolism was evident, which was higher for HTC than for pyrolysis char. Ecotyping analysis reported an increase in Actinobacteria (+4.6%) and a concurrent decrease in fungi (-4.6%) and Acidobacteria (-3.9%) after the addition of glucose. Glucose and pyrolysis char in combination reacted like the glucose only variant except for fungi, which reacted neutral to the combination but negative to either single addition. HTC+glucose showed a clear combination effect which was most pronounced for fungi, where the HTC specific reaction was tripled.

The short-term incubation approach allowed highlighting differences in degradation dynamics between the considered soil-substrates mixtures, and confirmed the effectiveness of the charring process to increase the stability of organic substrates in soil. Ecotyping allowed revealing a major role of Actinobacteria in soil respiration and of fungi in the degradation of HTC char.

Biochar stability: effects of pyrolysis temperature, feedstock and soil

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Long-term stability remains an outstanding issue in the development of biochar as a carbon storage technology. Experimental investigations into the oxidative breakdown of biochar in soil are generally hampered by difficulties in discriminating carbon fluxes of biochar origin from those of endogenous soil organic carbon (SOC). We present preliminary results from an array of biochar-soil microcosm experiments in which carbon isotope labelling was used to distinguish carbon sources in microcosm CO₂ effluxes.

Nine distinct ¹³C-labelled biochar were produced from three enriched biomass feedstocks with pyrolysis temperatures ranging from 300 to 800 °C. These labelled biochar were used in 27 unique microcosm experiments involving two contrasting soils (temperate anthrosol vs. tropical ferralsol). Microcosm CO₂ effluxes were measured during a 200-day incubation period and partitioned into biochar and SOC derived CO₂ via a two-end-member isotope mixing model. Analysis of biochar-CO₂ fluxes established biochar oxidation as a first-order kinetic process. Rate equations for biochar carbon decay were thus constructed and extrapolated to provide estimates of biochar longevity in soil.

In our experimental conditions, biochar carbon mean residence times ranged from 13.4 to 209 years – approximately two orders-of-magnitude longer than their raw biomass feedstocks (26 to 131 days). Statistical analysis resolved production temperature as the key production variable controlling biochar carbon stability, with higher temperatures generally increasing stability. However, instances of divergent results across soil types (higher biochar production temperature decreasing stability in some ferralsol experiments) demonstrate that biochar oxidation is a multi-factorial phenomenon, partly determined by interaction between biochar properties and soil geochemistry.

Analysis of pore space characteristics of different biochars and potential as microhabitat

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Biochar is considered a promising means to improve soil fertility by enhancing microbial processes relevant for plant nutrition. However, contradicting results have been found regarding biochars' direct impact on soil microbial communities, indicating great specificity of every biochar. The present study aims to contribute to a better understanding of biochars' impact on microbial communities both in soil and during the process of biological activation of biochars. We systematically investigated potential and actual habitat provision of two biochars of pyrolytic origin and different feedstock to microorganisms, also addressing the alteration of habitat quality by microbial colonisation. On the long run, this study aims to contribute to the recent „biochar by design“ debate by systematically assess and compare different chars' properties and habitat qualities.

We compared two biochars of different feedstocks (*Wood* and *Miscanthus*) with respect to microbes present on the surface after two years of storage under field conditions. Furthermore, native and fungal colonised particles of both biochars were subjected to μ -CT analysis of pore space performed using soft X-rays to investigate changes in habitat quality by fungal colonisation. The two biochars were compared with respect to porosity, internal surface, connectivity in surface, volume, and direction and isotropicity. To figure out the parameters most important for biochar physical structure, all parameters obtained in μ -CT analysis were fitted to a Generalised Linear Model (GLM).

From both biochars, fungi and spore-forming high-GC and low-GC gram-positive bacteria could be isolated, with more overall microorganisms being isolated from the wood-derived biochar.

Interestingly, while no differences between the two biochars could be observed in porosity and internal surface area, large differences could be found regarding connectivity values. Surface connectivity, which was 4.73% in wood-derived and 9.92% in *Miscanthus*-derived biochar, corresponding to 6.44% volume connectivity in wood-derived biochar and 13.0% volume connectivity in *Miscanthus*-derived biochar.

While volume connectivity in the biochars was mostly explained by volume (30.4% of deviance) and biochar (18.2% of deviance), colonisation was also found to significantly change pore space (12.8% of deviance, $p = 0.02$). Moreover, differences in the volume connectivity/direction connectivity relationship according to biochar feedstock were found.

From our results we conclude that biochars obtained by pyrolysis of different feedstocks under comparable conditions differ greatly and are by no means comparable with differences mainly related to plant anatomic structure. With higher porosity and higher connectivities being found in *Miscanthus*-derived biochar, results suggest better habitat quality of this biochar compared to wood-derived biochar. However, data from isolated microorganisms and numerous practitioners' reports suggest the contrary. Therefore we suggest that habitat provision by biochar to microorganisms cannot be influenced by physical properties alone. Further studies must relate biochars' surface chemical properties to physical parameters in order to comprehensively explain microbial colonisation of biochar.

Influence of charring biomass on soil microorganisms and phosphorus availability under cocoa agroforest in South Cameroon

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Biochar a carbon rich material obtained after heating a biomass under low oxygen content has retained recently attention due its benefits as soil amendment and its contribution in mitigating climate change. Biochar have also been shown to change soil microbial community.

In order to quantify the effect of biochar and its feedstock on soil microorganisms, one year incubation experiment was carried out using mesh bags (25µm) on soil under a cocoa agroforest. Chicken manure and tree pellet were pyrolysed à 450°C to obtain the respective biochar. The experiment consist of seven treatments: chicken manure, chicken biochar, tree pellet, tree pellet char, tree pellet char amended with M medium, local charcoal and control soil. Treatments were mixed with soil (typical ferrasols) 10% (v/v) before filled into mesh bag and buried at 10 cm depth around 8 randomly selected cocoa trees. Afterward soil mesh bags were removed, then bacteria growth was quantify using leucine incorporation meanwhile, lipids biomarkers for arbuscular mycorrhizal (NLFA 16:1ω5) and PLFA were quantified for soil microbial groups. Next to soil biological analysis the change in soil extractable phosphorus was also investigated.

In spite of the variability observed with the fungi biomarker results revealed that treatments with the original biomass gives the highest amount of the fungi biomarker 16:1ω5 compared to treatments with biochar. With respect to bacteria growth, treatments with chicken manure char and tree pellet char were substantially higher ($p < 0.05$) than those amended with their corresponding feedstock.

It was found that all treatments amended with biochars irrespective to the type had shown a decrease in abundance of all microbial soil biomarker groups (gram-positive, gram-negative, actinomycetes, fungi and protozoa) compared to treatment with their original biomass. The abundance of actinomycetes, fungi and protozoa decreases with biochar treatments compared to control soil. With regard to soil chemical, in addition to change in soil pH, no significant effect on available phosphorus was found between treatments with tree pellet char and its original biomass. However a substantial difference ($P < 0.01$) was found with soil amended with chicken manure char and its feedstocks. Sixteen times higher phosphorus available found in soil amended with chicken char compared to soil amended with chicken manure.

It was concluded that in soil depleted with carbon source the addition of pyrolysed charcoal might decrease the activity of soil microbial groups and chicken manure biochar may enhance phosphorus availability from tropical soil which could be benefit for agriculture.

Effects of biochar on nutrient availability, pH and crop yield in acidic tropical soils.

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The impact of biochar on soil physical and biogeochemical properties is controlled by the quality and quantity of biochars combined with intrinsic soil properties. Here we present four publications from different biochar projects in Zambia and Indonesia based on laboratory studies and field trials. Sorption isotherms of PO₄-P, NH₄-N and NO₃-N on cacao shell and corn cob biochars revealed small biochar binding capacities of PO₄-P and NO₃-N but a certain extent of NH₄-N binding (1). A subsequent experiment investigating whether the adsorption capacity of NH₄-N in acidic soils increased upon the addition of biochar revealed no significant increases or decreases in aqueous NH₄-N concentrations but an increase in concentrations of NO₃-N. The experiment confirmed that biochar has the ability to release essential plant growth nutrients, increase pH and thus alleviate Al toxicity (2). Increased pH upon the addition of biochar was further supported in another study of 31 different acidic soils from Indonesia. The addition of three types of biochar from cacao shell, oil palm shell and rice husk caused a significant increase in mean soil pH with the strongest effect observed for the cacao shell biochar. The most important finding of this study is that it is rather the CEC than the soil pH that is decisive for the alkalizing effect of biochar addition (3). Farmer-led field trials from three regions of Zambia with contrasting soils (sandy soils and loamy soils) showed positive effects (up to 200% increase) of maize cob biochar addition on crop yields in the sandy soils if biochar was combined with fertilizer. Biochar significantly increased concentrations of K and P in maize stover. The fraction of plant available water (Vol.-%), cation exchange capacity, pH, and exchangeable K significantly increased upon the addition of biochar in all three regions (4).

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Loss of nutrient retention capacity of biochars after seven-month in-situ field incubation

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Biochars are characterised by a high adsorption capacity, i.e., they may retain nutrients such as nitrate and ammonium in soils. Therefore, a hypothesized and desired goal to be achieved via the amendment of biochar to agricultural soils is the reduction of leaching losses of nutrients. However, it is well known that physico-chemical properties of biochar strongly depend on production process and so may the effects that biochar has in the soil.

We investigated the potential of biochar from pyrolysis (pyrochar; produced at 750°C) and from hydrothermal carbonization (hydrochar; produced at 200°C) from *Miscanthus* as feedstock for sorption of nitrate, ammonium and phosphate as well as the influence of biochar degradation in the field using a 7-month' in situ field incubation at three experimental sites (two sandy loams and one loamy sand). Sorption experiments with soil-char-composites were carried out right after application (T0) and after 7 months in the field (T1).

Pyrochars showed the highest ability to retain nitrate, ammonium and phosphate at T0. Ammonium and phosphate adsorption of pyrochars was affected by the soil type of the soil-biochar mixture. We found some ammonium and phosphate retention on sandy loam soils, but no effect of pyrochar or even ammonium and phosphate leaching from the loamy soil-pyrochar mixture. Application of hydrochars to agricultural soils caused little, and often not significant, effects on nutrient retention. In contrast, some hydrochars did alter the leaching of nutrients in comparison to the non-amended control soil. We found a surprisingly rapid loss of the pyrochars' adsorption capacity after seven-month field application of the biochars. For all sites and for hydrochar and pyrochar, the adsorption capacity at T1 was reduced by 60-80%.

Our results cast doubt on the efficiency of biochar applications to temperate zone soils to minimize nutrient losses via leaching.

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