Biochar amendment to coarse sandy subsoil improves root growth and increases water retention

Crop yields and yield potentials on Danish coarse sandy soils are strongly limited due to restricted root growth and poor water and nutrient retention. We investigated if biochar amendment to subsoil can improve root development in barley and significantly increase soil water retention. Spring barley (Hordeum vulgare cv. Anakin) was grown in soil columns (diameter: 30 cm) prepared with 25 cm topsoil, 75 cm biochar-amended subsoil, and 30 cm un-amended subsoil lowermost placed on an impervious surface. Low-temperature gasification straw-biochar (at 0, 0.50, 1.0, 2.0, and 4.0 wt%) and slow pyrolysis hardwood-biochar (at 2 wt%) were investigated. One wt% can be scaled up to 102 Mg/ha of char. After full irrigation and drainage, the in-situ moisture content at 30-80 cm depth increased linearly ($R^2 = 0.99$) with straw-biochar content at a rate corresponding to 0.029 m3/m3/%. The lab determined wilting point also increased linearly with char content ($R^2 = 0.99$) but at a much lower rate (0.003 m3/m3%). Biochar at concentrations up to 2% significantly increased the density of roots in the 40-80 cm depth interval. Addition of 1% straw-biochar had the most positive effect on root penetration resulting in the highest average root density (54% coverage compared to 33% without biochar). This treatment also resulted in the greatest spring barley grain yield increase (22%). Improving the quality of sandy subsoils has global potentials, and incorporation of the right amount of correctly treated residues from bioenergy technologies such as straw-biochar is a promising option. © 2014 British Society of Soil Science.
Biodegradation measurements confirm the predictive value of the O: C-ratio for biochar recalcitrance

Suitable predictors of degradability are sought to support the identification of biochars with large potential to increase C sequestration in soils. We determined the biodegradation of 9 chars from hydrothermal carbonization and pyrolysis in two agricultural soils. The 200- and 115-day degradation correlated strongly with the O:C- and slightly with the H:C-atomic ratio of 9 and 14 biochars, respectively. Highest temperature treatment and ash content did not show similar correlations.

© 2014 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

Effect of biochar on aerobic processes, enzyme activity, and crop yields in two sandy loam soils

Biochar added to agricultural soils may sequester carbon and improve physico-chemical conditions for crop growth, due to effects such as increased water and nutrient retention in the root zone. The effects of biochar on soil microbiological properties are less certain. We addressed the effects of wood-based biochar on soil respiration, water contents, potential ammonia oxidation (PAO), arylsulfatase activity (ASA), and crop yields at two temperate sandy loam soils under realistic field conditions. In situ soil respiration, PAO, and ASA were not significantly different in quadruplicate field plots with or without biochar (20 Mg ha−1); however, in the same plots, volumetric water contents increased by 7.5 % due to biochar (P = 0.007). Crop yields (oat) were not significantly different in the first year after biochar application, but in the second year, total yields of spring barley increased by 11 % (P <0.001), though the increase in grain yield was not significant. Field plots with cumulative biochar rates of up to 100 Mg ha−1, applied during two consecutive years, substantiated that biochar was not inhibitory to PAO and ASA as reference plots consistently showed lowest activities. For PAO, it was found that soil pH, rather than biochar rates, was a driving environmental variable. For ASA, the methodological approach was challenged by product sorption, but results did not suggest that biochar significantly stimulated the enzyme activity. Crop yields of maize in field experiments with 10–100 Mg biochar ha−1 were unaffected by biochar except for a negative effect of the highest annual rates of 50 Mg ha−1 in the first year after application. In conclusion, the present wood-based biochar poorly affected the measured microbial processes and generally resulted in similar crop yields in reference and biochar-amended soil plots.
Direct and Indirect Short-term Effects of Biochar on Physical Characteristics of an Arable Sandy Loam

Biochar addition to agricultural soil is reported in several studies to reduce climate gas emissions, boost carbon storage, and improve soil fertility and crop productivity. These effects may be partly related to soil physical changes resulting from biochar amendment, but knowledge of how biochar application mechanistically affects soil physical characteristics is limited. This study investigated the effect of biochar application on soil structural and functional properties, including specific surface area, water retention, and gas transport parameters. Intact soil cores were taken from a field experiment on an arable sandy loam that included four reference plots without biochar and four plots with 20 tons ha\(^{-1}\) biochar incorporated into the upper 20 cm 7 months before sampling. Water retention was measured at matric potentials ranging from wet (pF 1.0) to extremely dry conditions (pF similar to 6.8), whereas gas transport parameters (air permeability, k(a), and gas diffusivity, D-p/D-o, where D-p is the gas diffusion coefficient in soil and D-o is the gas diffusion coefficient in free air) were measured between pF 2.0 and 3.0. Water retention under dry conditions and measured specific surface area were not significantly greater in the biochar-amended soil than the reference soil probably because of the relatively low biochar application rate. Yet, the biochar-amended soil showed a significant decrease in soil bulk density and an accompanying increase in total porosity. Water retention and air-filled porosity (epsilon) were both markedly greater in the biochar-amended soil than in the reference soil between pF 1.0 and 3.0. Soil macroporosity (equivalent to >0.1 mm pore diameter) and the ratio of macroporosity to total porosity were also significantly greater in the biochar-amended soil. As a result, the level of the pore organization (PO, k(a)/epsilon) was greater in the biochar-amended soil. Across the tested matric potentials, biochar amendment caused average increases of 28 to 34% in epsilon, 53 to 161% in D-p/D-o, and 69 to 223% in k(a), with the most significant increases occurring around natural field capacity (pF 2.0). Overall, the results suggest that biochar application even at a relatively low rate can alter soil functional characteristics, especially under normal field moisture conditions.
Store perspektiver i biokoks på sandjord
Forsøg med tilførsel af halmkoks på sandjord tyder på, at jorden bliver mere løs og i stand til at binde mere vand. Det baner vejen for større rodnet og højere udbytter.

General information
Publication status: Published
Organisations: Department of Chemical and Biochemical Engineering, Ecosystems Programme, University of Copenhagen
Contributors: Petersen, C., Hansen, E., Johansen, J., Hauggaard-Nielsen, H., Bruun, E.
Pages: 34-36
Publication date: 2013
Peer-reviewed: Unknown

Publication information
Journal: Agrologisk
Issue number: 1
ISSN (Print): 0906-0081
Ratings:
Original language: Danish
Source: dtu
Source ID: u::6685
Research output: Contribution to journal › Journal article – Annual report year: 2013 › Communication

Effects of slow and fast pyrolysis biochar on soil C and N turnover dynamics
This study compared the effect of two principal pyrolysis methods on the chemical characteristics of biochar and the impact on C and N dynamics after soil incorporation. Biochar was produced from wheat straw that was thermally decomposed at 525 °C by slow pyrolysis (SP) in a nitrogen flushed oven and by fast pyrolysis (FP) using a Pyrolysis Centrifuge Reactor (PCR). After 65 days of soil incubation, 2.9% and 5.5% of the SP- and FP-biochar C, respectively, was lost as CO2, significantly less than the 53% C-loss observed when un-pyrolyzed feedstock straw was incubated. Whereas the SP-biochar appeared completely pyrolyzed, an un-pyrolyzed carbohydrate fraction (8.8% as determined by acid released C6 and C5 sugars) remained in the FP-biochar. This labile fraction possibly supported the higher CO2 emission and larger microbial biomass (SMB-C) in the FP-biochar soil. Application of fresh FP-biochar to soil immobilized mineral N (43%) during the 65 days of incubation, while application of SP-biochar led to net N mineralization (7%). In addition to the carbohydrate contents, the two pyrolysis methods resulted in different pH (10.1 and 6.8), particle sizes (113 and 23 μm), and BET surface areas (0.6 and 1.6 m2 g−1) of the SP- and FP-biochars, respectively. The study showed that independently of pyrolysis method, soil application of the biochar materials had the potential to sequester C, while the pyrolysis method did have a large influence on the mineralization-immobilization of soil N.

General information
Publication status: Published
Nitrogen and Carbon Leaching in Repacked Sandy Soil with Added Fine Particulate Biochar

Biochar amendment to soil may affect N turnover and retention, and may cause translocation of dissolved and particulate C. We investigated effects of three fine particulate biochars made of wheat (Triticum aestivum L.) straw (one by slow pyrolysis and two by fast pyrolysis) on N and C leaching from repacked sandy soil columns (length: 51 cm). Biochar (2 wt%), ammonium fertilizer (NH₄⁺, amount corresponding to 300 kg N ha⁻¹) and an inert tracer (bromide) were added to a 3-cm top layer of sandy loam, and the columns were then irrigated with constant rate (36 mm d⁻¹) for 15 d. The total amount of leachate came to about 3.0 water filled pore volumes (WFPVs). Our study revealed a high mobility of labile C components originating from the fine particulate fast pyrolysis biochar. This finding highlights a potential risk of C leaching coupled with the use of fast pyrolysis biochars for soil amendment on sandy soil. By contrast, C components from the slow pyrolysis biochar were fully retained in the topsoil. Contrary to our expectations, there were no overall effects of biochar amendment on the cumulative leaching of mineral N (NH₄⁺ plus NO₃⁻), that is, the biochars did not increase the N retention capacity of the soil. All three biochars caused a slight increase of NH₄⁺ leaching, while NO₃⁻ leaching was slightly decreased by addition of the fast pyrolysis biochars.
Application of Fast Pyrolysis Biochar to a Loamy soil - Effects on carbon and nitrogen dynamics and potential for carbon sequestration

Thermal decomposition of biomass in an oxygen-free environment (pyrolysis) produces bio-oil, syngas, and char. All three products can be used to generate energy, but an emerging new use of the recalcitrant carbon-rich char (biochar) is to apply it to the soil in order to enhance soil fertility and at the same time mitigate climate change by sequestering carbon in the soil. In general, the inherent physicochemical characteristics of biochars make these materials attractive agronomic soil conditioners. However, different pyrolysis technologies exist, i.e. slow pyrolysis, fast pyrolysis, and full gasification systems, and each of these influence the biochar quality differently. As of yet, there is only limited knowledge on the effect of applying fast pyrolysis biochar (FP-biochar) to soil. This PhD project provides new insights into the short-term impacts of adding FP-biochar to soil on the greenhouse gas (GHG) emissions and on soil carbon and nitrogen dynamics. The FP-biochars investigated in the thesis were generated at different reactor temperatures by fast pyrolysis of wheat straw employing a Pyrolysis Centrifuge Reactor (PCR). The carbohydrate content ranged from more than 35 % in FP-biochars made at a low reactor temperature (475 ºC) down to 3 % in FP-biochars made at high temperatures (575 ºC). The relative amount of carbohydrates in the FP-biochar was found to be correlated to the short-term degradation rates of the FP-biochars when applied to soil. Fast and slow pyrolysis of wheat straw resulted in two different biochar types with each their distinct physical structures and porosities, carbohydrate contents, particle sizes, pH values, BET surface areas, and elemental compositions. These different physicochemical properties obviously have different impacts on soil processes, which underscores that results obtained from soil studies using slow pyrolysis biochars (SP-biochar) are not necessarily applicable for FP-biochars. For example, the incorporation of FP-biochar (10 wt%) in a sandy loam soil improved the water holding capacity (WHC) by 32 %, while the SP-biochar reference only increased it moderately. Moreover, soil amendment of FP-biochar caused immobilization of considerable amounts of soil N, whereas SP-biochar resulted in a net mineralization of N after two months of soil incubation. Nitrogen immobilisation can be detrimental to crop yields, as shown in a Barley pot trial in this thesis, but may, on the other hand, constitute an advantage during e.g. fallow periods by preventing N leaching. Moreover, when it comes to the mobility of biochar in soil, FP-biochars acted considerably differently to SPbiochar. FP-biochar contained highly mobile carbon components (nm-scale), which followed the downward movement of water. By contrast, C components from slow pyrolysis biochar were retained in the topsoil. In summary, the research of this thesis shows that, compared to its more inert 'traditional biochar counter-part' made by slow pyrolysis, FP-biochar, in a number of ways, acts more like the original organic matter feedstock when added to soil. Yet, on the longer term the effects are likely a transient phenomenon, as the labile part is used up after a few months, leaving a much more recalcitrant FP-biochar. It is still too early to recommend - or discourage - FP-biochar for agronomic use, since field trials are needed in order to verify potential benefits or drawbacks on soil fertility and crop yields. However, this thesis has improved the mechanistic understanding of the effects of applying FP-biochar to soil, and shows that wheat-straw FP-biochar has properties beneficial for agricultural soil, e.g. it improves soil WHC, adds minerals, enhances microbial activity/biomass, and increases the N and C turnover dynamics.

General information
Publication status: Published
Organisations: Ecosystems, Biosystems Division, Risø National Laboratory for Sustainable Energy
Contributors: Bruun, E.
Number of pages: 114
Publication date: Mar 2011

Publication information
Place of publication: Roskilde
Publisher: Technical University of Denmark. Risø National Laboratory for Sustainable Energy
ISBN (Print): 978-87-550-3910-0
Original language: English (Risø-PhD: No. 78(EN)).
Keywords: Environment and climate, Risø-PhD-78(EN), Risø-PhD-78, Risø-PhD-0078
Electronic versions:
ris-phd-78.pdf
Source: orbit
Source ID: 276895

Application of biochar to soil and N2O emissions: potential effects of blending fast-pyrolysis biochar with anaerobically digested slurry

Soil applications of recalcitrant biochar offer the possibility of mitigating climate change effects through long-term carbon sequestration and potentially also by reducing emissions of the potent greenhouse gas nitrous oxide (N2O). This
laboratory study examined the effect of combining a fast-pyrolysis biochar at small (1% by mass) and large (3%) concentrations with anaerobically digested slurry on soil N2O and carbon dioxide (CO2) emissions over a period of 55 days. The results showed that fast-pyrolysis biochar applied on its own increased N2O emissions from soil. However, when biochar was applied together with slurry, the larger biochar concentration decreased N2O emissions by 47%, relative to those from the slurry treatment with the smaller biochar concentration. Reduced N2O emissions coincided with enhanced soil microbial activity and immobilization of nitrogen. A combined application of biochar and anaerobic digested slurry could therefore be beneficial for cropping systems in terms of soil nitrogen retention while concurrently mitigating N2O fluxes and sequestering carbon in soil.

General information
Publication status: Published
Organisations: Ecosystems, Biosystems Division, Risø National Laboratory for Sustainable Energy
Contributors: Bruun, E., Müller-Stöver, D. S., Ambus, P., Hauggaard-Nielsen, H.
Pages: 581-589
Publication date: 2011
Peer-reviewed: Yes

Publication information
Journal: European Journal of Soil Science
Volume: 62
Issue number: 4
ISSN (Print): 1351-0754
Ratings:
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.44 SJR 1.471 SNIP 1.283
Web of Science (2011): Impact factor 2.34
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Original language: English
Keywords: Environment and climate
DOIs: 10.1111/j.1365-2389.2011.01377.x
Source: orbit
Source ID: 279508
Research output: Contribution to journal › Journal article – Annual report year: 2011 › Research › peer-review

Influence of fast pyrolysis temperature on biochar labile fraction and short-term carbon loss in a loamy soil
Production of bio-oil, gas and biochar from pyrolysis of biomass is considered a promising technology for combined production of bioenergy and recalcitrant carbon (C) suitable for sequestration in soil. Using a fast pyrolysis centrifuge reactor (PCR) the present study investigated the relation between fast pyrolysis of wheat straw at different reactor temperatures and the short-term degradability of biochar in soil. After 115 days incubation 3–12% of the added biochar-C had been emitted as CO2. On average, 90% of the total biochar-C loss occurred within the first 20 days of the experiment, emphasizing the importance of knowing the biochar labile fraction when evaluating a specific biochars C sequestration potential. The pyrolysis temperature influenced the outputs of biochar, bio-oil and syngas significantly, as well as the stability of the biochar produced. Contrary to slow pyrolysis a fast pyrolysis process may result in incomplete conversion of biomass due to limitations to heat transfer and kinetics. In our case chemical analysis of the biochars revealed unconverted cellulosic and hemicellulosic fractions, which in turn were found to be proportional with the short-term biochar degradation in soil. As these labile carbohydrates are rapidly mineralized, their presence lowers the biochar-C sequestration potential. By raising the pyrolysis temperature, biochar with none or low contents of these fractions can be produced, but this will be on the expense of the biochar quantity. The yield of CO2 neutral bio-oil is the other factor to optimize when adjusting the pyrolysis temperature settings to give the overall greatest climate change mitigation effect.

General information
Publication status: Published
Organisations: Rise National Laboratory for Sustainable Energy, Ecosystems, Biosystems Division, CHEC Research Centre, Department of Chemical and Biochemical Engineering, Biomass Gasification
Pages: 1182-1189
Publication date: 2011
Peer-reviewed: Yes

Publication information
Journal: Biomass & Bioenergy
Volume: 35
The potential of pyrolysis technology in climate change mitigation – influence of process design and parameters, simulated in SuperPro Designer Software

This report investigates whether or not it would be possible to produce carbon-negative energy from pyrolysis of wheat straw in a series of Danish agricultural scenarios. A combination of process simulation in SuperPro Designer software, correlations derived from literature studies and experimental work, and overall balance calculations has been applied in the process. The study deviates from other studies of pyrolysis and biochar production by the inclusion of substitution energy impact on the overall carbon-balance. Substitution energy is integrated to account for the gap between the energy production from the pyrolysis and the full energy potential of the biomass, quantified by complete conversion in either combustion or gasification systems. It was concluded that it is feasible to produce carbon-negative energy under a variation of different settings, but also that the negative carbon-balance is only robust for the slow pyrolysis scenario. The CO2 benefit of the most carbon-negative slow pyrolysis process is estimated to be around 10 % of the atmospheric carbon stored in the original biomass when natural gas is applied for energy substitution. This process avoids the emission of around 150-200 kg CO2/ton wheat straw with substitution energy with a Denmark 2007 average carbon-intensity. This result is weighted against the net emissions of the carbon-“neutral” process of conventional combustion. This emission is in this report estimated to be around 50 – 150 kg CO2/ton straw depending on scenario settings. The final results of the study have been compared to another study with convincing results. Results concluded that the primary force of the pyrolysis technology is the recalcitrant char product and not the pyrolysis oil. Based on this, the study suggests that despite the trend in commercial pyrolysis technology that focuses on fast pyrolysis processes with maximized bio-oil production, the twin challenge of climate mitigation and sustainable energy production is most efficiently addressed with a combination of slow pyrolysis and complete biomass conversion through combustion or gasification instead.

General information
Publication status: Published
Organisations: Biomass Gasification, Biosystems Division, Risø National Laboratory for Sustainable Energy, Ecosystems
Contributors: Thomsen, T., Hauggaard-Nielsen, H., Bruun, E., Ahrenfeldt, J.
Number of pages: 115
Publication date: 2011

Publication information
Place of publication: Roskilde
Publisher: Danmarks Tekniske Universitet, Risø Nationalallaboratorium for Bæredygtig Energi
ISBN (Print): 978-87-550-3877-6
Original language: English
(Denmark. Forskningscenter Risoe. Risoe-R; No. 1764(EN)).
Keywords: Bio systems, Thermal gasification of biomass, Risø-R-1764, Risø-R-1764(EN)
Electronic versions:
ris-r-1764.pdf
Source: orbit
Source ID: 274130
Research output: Book/Report › Report – Annual report year: 2011 › Research

Bio-char investigated by analytical flash pyrolysis and GCMS

General information
Publication status: Published
Organisations: Biomass Gasification, Biosystems Division, Risø National Laboratory for Sustainable Energy, Ecosystems, Department of Chemical and Biochemical Engineering, CHEC Research Centre
Biochar soil application to mitigate climate change

Production of energy carriers (oil, gas) and biochar from pyrolysis of biomass is by many considered a promising technology for combined production of bioenergy and recalcitrant C suitable for sequestration in soil. The mechanism behind biochar-C sequestration is straightforward: Due to its recalcitrant characteristics the microbial decomposition of biochar is much slower in comparison to the mineralization of the original feedstock. Conversion of organic residues like household waste or cereal straw to biochar is hence proposed a way to withdraw CO2 from the atmosphere and sequester it on a long term basis in the soil. The experiments presented here illustrate the C sequestration potentials of biochar originating from fast pyrolysis of wheat straw. It is documented that after 47 days in soil 95 % of the added biochar-C is still present in the soil as compared to only 56 % if straw is applied untreated to the soil. The type and settings of pyrolysis influence the chemical quality of the biochar produced significantly. Biochar chemical analysis revealed that the degradation of biochar in soil appears to be proportional with the biochar cellulosic and hemicellulosic fraction. Furthermore, the pyrolyzer temperature settings strongly influence the proportion of cellulose and hemicellulose remaining in the biochar. As these biochar fractions relatively rapidly are mineralized to CO2 by microbial respiration they are – in climate mitigation perspective - unwanted. At the upcoming Climate Conference in Copenhagen (COP15) December 2009, the use of biochar as a mitigation tool will be on the agenda and for the time being (July 2009) 20 countries and Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have made submissions to the UNFCCC seeking the inclusion of biochar as a climate mitigation and adaptation tool.
Capel, E. L., Examiner
Technical University of Denmark
01/03/2008 → 29/06/2011
Award relations: Carbon Sequestration in Soil with Bio-Char: Effects on Carbon-Nitrogen Dynamics and Plant Growth
Project: PhD