Ecological Questions 24/2016: 75 – 78 http://dx.doi.org/10.12775/EQ.2016.014

SHORT COMMUNICATION

Biochar and its importance in adsorption of antibiotic and heavy metals from aqueous solutions

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Abstract. This short communication relates to carbon-rich material referred to as biochar. In the subsequent sections, the text presents old and modern methods of production, physiochemical characteristics and miscellaneous applications of biochar in environmental protection, e.g. treatment of contaminated soil and water, as well as in agriculture for soil fertilization. The final part of the text deals with further possible, more extensive use of biochar in these two economic sectors, particularly to create carbon sink for CO_2 sequestration in land cultivation, and to remove heavy metals and pharmaceutical compounds from soil and water in environmental protection.

Key words: applications of biochar, biochar preparation, biomass pyrolysis, physiochemical characteristics, thermodynamics of biosorption.

Biochar is a carbon-rich material highly adsorbent and porous, similar in its appearance to charcoal and other carbon-rich materials but it is intentionally produced as soil amendment. Biochar is a solid coproduct of the biomass pyrolysis obtained heating organic materials at high temperatures without oxygen (anaerobic conditions). Biochar can be produced from almost any types of biomass feedstock such as agricultural wastes, forestry wastes, saw dust, rice husks, rice straw, bagasse, paper products, animal manures, and even urban green waste.

Pyrolysis produces 60-75 wt% of liquid bio-oil, 15-25 wt% of solid char, and 10-20 wt% of noncondensable gases, but exact proportions are largely dependent on the biomass feedstock used and process temperatures (Mohan et al., 2006).

Changing the conditions of pyrolysis it is possible to obtain different product characteristics. Pyrolysis at temperatures higher than 500°C produces biochars that are more resistant to weathering, due to their higher surface areas and aromatic structure, on the other hand, biochars produced at lower temperatures are better in retaining nutrients, and this coupled with their higher reactivity in soil, make them better to improve soil fertility (Kim et al., 2003).

In the Amazon Basin, indigenous people added biochar for thousands of years to produce highly fertile soils called *terra preta de índio*, or black soil of the Indian. These methods of adding charred biomass have been seen to increase crop production as well as maintain long-term soil fertility, even in areas that were known to have infertile soil. Agee (1993) and Atkinson et al. (2010) studied the wildfire occurrence and the development of Anthrosols (soils with long and intensive agricultural use) in the Amazon and demonstrated that charcoal can remain in the soil for hundreds to thousands of years.

However, the presence of biochar in the soil is highly desirable as it can increase the amount of organic carbon and improve the availability of nutrients and therefore enhance plant growth, agricultural productivity and soil physical, chemical, and biological properties (Lehmann et al., 2003; Rondon et al., 2007).

When biochar is incorporated into soils, it increases cation exchange capacity (CEC). Biochar is oxidized during its production and helps organic matter to adsorb to its surface. It has also been noted that as biochar weathers over time there is a further increase in CEC, which allows for cations, including nutrients such as NH_4^+, to be retained in the soils (Clough, 2010).

Biochar is extremely porous and has a huge surface area of about 300 m^2 per gram. Due to its high porosity, biochar can uptake water and dissolve nutrients up to five times its own weight (huge water holding capacity). Increases in soil fertility are attributable to biochar's unique properties of adsorption and stability. Additionally, biochar has been produced with pH values range between 4 and 12, depending on the starting biomass feedstock and pyrolysis conditions (Lehmann, 2007). Generally, low pyrolysis temperatures (< 400°C) yields acidic biochar, while pyrolysis at higher temperatures produces alkaline biochar (Cheng et al., 2006; Lehmann, 2007). Compared to other organic soil conditioners, biochar is much more effective in retaining nutrients and keeping them available to plants, it increases adsorption of ammonium, nitrate, phosphate, and calcium ions. It maintains a porous structure, attracting beneficial microbes, and giving areas for microorganisms to thrive, where they are protected from predators, the sorption to biochar particles makes microorganisms less susceptible to washing out from the soil. Biochar holds nutrients, retains moisture, increases fertilizer efficiency and enhances crop yield, while reduces the need to irrigate, reduces fertilizer runoff, especially nitrogen and phosphorus and total fertilizer requirements, and finally decreases emissions of nitrous oxide by 50-80%. History confirms biochar is much more stable in the environment than any other form of organic matter (Clough & Condron, 2010; Lehmann et al., 2011).

The microbial communities found in *terra preta* soils were quite different from untreated soils, communities incorporated in the charcoal were about 25% richer than the ones in forest soil, with 14 phylogenetic groups compared to only nine in forest soils. It was hypothesized by Atkinson et al. (2010) that biochars' low inorganic-N can provide a good habitat for Nitrogen-fixing bacteria, which has the enzyme nitrogenase and the ability to convert atmospheric N_2 into NH_3.

Biochar application to cropland has been recommended as a strategy to reduce the release of atmospheric CO_2 and mitigate climate change. During the conversion of biomass into biochar, about 50% of the original biomass carbon is retained in the biochar, by storing organic carbon; biochar provides exceptionally long life storage for thousands of years, which offers considerable opportunity for creating a CO_2 sink (Lehmann, 2007; Song et al., 2016).

When biomass goes through the pyrolysis process, the carbon is sequestered in the formed biochar. This carbon is stable when applied to soil, making biochar a viable option for carbon sequestration where the release of carbon dioxide due to decomposition is greatly reduced, so, using biochar as a soil amendment can help to offset anthropogenic carbon dioxide emissions (Anderson et al., 2010; Clough & Condron, 2010). The use of biochar has the potential to improve significantly energy efficiency in a variety of ways. Poultry litter, paper mill sludge, and other organic matter are currently sent to landfills for disposal, and this transport is both money- and fuel-intensive. If these products are instead used to produce biochar, they become a valuable resource rather than an expensive waste product. The other products of the biochar manufacturing are syngas and bio oils that can be used to produce electricity or to replace a variety of fossil fuels (Lehman & Joseph, 2009; Hunt et al., 2010).

Biochar has a significant effect on heavy metal cycling in soil environments. Biochar particles can absorb aluminum and lead, at high toxic concentrations, limiting toxicity to both plant roots and soil bacteria (Maraseni, 2010; Lu et al., 2012).

Biochar is very effective in uptake and immobilize heavy metals like cadmium, copper, lead, and other pollutants. Adding 5% chicken manure biochar or green waste biochar into soils with heavy metal contamination can immobilize of cadmium, copper, and lead and reduce the levels of these metals in plants growing in the contaminated soils (Park et al., 2011). Biomass of the plants grown in chicken manure biochar amended soils was also greater than plants grown in control soils, probably due to the reduction in heavy metal concentrations due to the biochar (Park et al., 2011).

Biochar can be also used to remove organic pollutants. The chemical mobility of these pollutants, such as pesticides or herbicides, can be reduced by biochar (Jetten, 2008). Biochars from a variety of biomass feed stocks are noted to uptake organic pollutants, including Diuron, Atrazine, acetochlor, and terbuthylazine. The adsorption ability of biochar has been shown to exceed that of the natural soil organic matter by a factor of 10-100 in some cases (Cornelissen et al., 2005).

Water shortage and stress resulting from rapid population growth, global climate changes, and pollution are among the greatest environmental problems worldwide. Globally, around 20 million hectare of land are irrigated with treated waste water and this has become undoubtedly a key strategy to fight water shortage, but this water may be contain organic pollutants (Hochstrat et al., 2006; Hamilton et al., 2007; Li et al., 2009).

Many farmers and ranchers give antibiotics to their animals such as cattle and chickens not only for the treatment of infections, but also because antibiotics promote animal growth. Many ranchers feed antibiotics to their animals to prevent falling sick in unsanitary conditions, and studies have shown that as much as 90% of these antibiotics can be excreted, primarily through the feces, those antibiotics are transferred to us via meat, and even via the manure because animal manure is widely applied on agricultural lands as fertilizer. Therefore, antibiotic compounds can enter the food chain, imposing potentially adverse impacts on human health. Antibiotic resistance is one of the world's most pressing public health problems

It was reported that approximately 3300 metric tons of antibiotics were used for human medicine in the U.S. in 2011 (Mitchell et al., 2015), and 80 percent of total of all antibiotics used in the U.S. are used for animals.

Antibiotics residues, which are recognized as organic contaminants, are frequently detected in the discharge of treated wastewater. Occurrences of antibiotics in treated wastewater, surface water, and even in groundwater have been reported worldwide (Daughton & Ternes, 1999), so it is important to inhibit antibiotics leaching through the vadose zone to groundwater during irrigation, especially with waste water.

Using of biochar to remove antibiotics from aqueous solutions presents an innovative and promising technology. Adsorption by biochar of antibiotics has the big advantage of being low cost compared with the conventional techniques.

Finally, using biochar in agriculture as a soil amendment can effectively increase soil fertility and create a carbon sink for CO_2 sequestration and in addition, can be a low-cost adsorbent filter to mitigate pollutants migration in soils.

Although many previous studies have proved that biochars have strong ability in the adsorption of organic pollutants, a big effort is needed yet to explore the ability of this promising material to remove heavy metals and pharmaceutical compounds from soil and water.

References

Agee J.K., 1993, Fire ecology of Pacific Northwest Forests, Island Press. Washington, DC.

Anderson C., Clough T., Condron L., Craigie R., Sherlock R. & Taghizadeh-Toosi A., 2010, Biochar incorporation into pasture soils suppresses in situ nitrous oxide emissions from ruminant urine patches, Journal of Environmental Quality 40: 468–476.

Atkinson C., Fitzgerald J. & Hipps N., 2010, Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review, Plant Soil 337: 1-18.

Cheng C.H., Lehmann J., Thies J.E., Burton S.D. & Engelhard M.H., 2006, Oxidation of black carbon by biotic and abiotic processes, Organic Geochemistry 37: 1477-1488.

Clough T. & Condron L., 2010, Biochar and the nitrogen cycle: Introduction, J. Environ. Qual. 39: 218-1223.

Cornelissen G., Gustafsson O., Bucheli T.D., Jonker M.T.O., Koelmans A.A. & Van Noort P.C.M., 2005, Extensive sorption of organic compounds to black carbon, coal, and kerogen in sediments and soils: Mechanisms and consequences for distribution, bioaccumulation, and biodegradation, Environmental Science & Technology 39(18): 6881-6895.

Daughton C.G. & Ternes T.A., 1999, Pharmaceuticals and personal care products in the environment: Agents of subtle change? Environmental Health Perspectives 107: 907-938.

Hamilton A.J., Stagnitti F. Xiong X.Z., Kreidl S.L., Benke K.K. & Maher P., 2007, Wastewater irrigation: The state of play, Vadose Zone Journal 6(4): 823-840.

Hochstrat R., Wintgens T., Melin T. & Jeffrey P., 2006, Assessing the European wastewater reclamation and reuse potential – a scenario analysis, Desalination 188(1-3): 1-8.

Hunt J., DuPonte M., Sato D. & Kawabata A., 2010, The basics of biochar: A natural soil amendment, Soil and Crop Management SCM-330, University of Hawaii at Manoa: 1-6.

Jetten M.S., 2008, The microbial nitrogen cycle, Environmental Microbiology 10(11): 2903-2909.

Kim H., Seagren E. & Davis A., 2003, Engineered bioretention for removal of nitrate from stormwater runoff, Water Environment Research 75(4): 355-367.

Lehmann J., 2007, Bio-energy in the black, Frontiers in Ecology and the Environment 5: 381-387.

Lehmann J., da Silva J.P. Jr., Steiner C., Nehls T., Zech W. & Glaser B., 2003, Nutrient availability and leaching in an archaeological anthrosol and a ferralsol of the central Amazon basin: Fertilizer, manure and charcoal amendments, Plant Soil 249(2): 343-357.

Lehmann J. & Joseph S., 2009, Biochar for Environmental Management: Science and Technology, Earthscan, the first edition, London.

Lehmann J., Rillig M., Thies J., Masiello C., Hockaday W. & Crowley D., 2011, Biochar effects on soil biota – A review, Soil Biology & Biochemistry 43: 1812-1836.

Li F., Wichmann K. & Otterpohl R., 2009, Evaluation of appropriate technologies for grey water treatments and reuses, Water Science and Technology 59(2): 249-260.

Lu H., Zhang W., Yang Y., Huang X., Wang S. & Qui R., 2012, Relative distribution of Pb2+ sorption mechanisms by sludge-derived biochar, Water Research 46: 854-862.

Maraseni T., 2010, Biochar: maximizing the benefits, International Journal of Environmental Studies 67(3): 319-327.

Mitchell S.M., Ullman J.L., Teel A.L. & Watts R.J., 2015, Hydrolysis of amphenicol and macro lide antibiotics: Chloramphenicol, florfenicol, spiramycin, and tylosin, Chemosphere 134:504-511. [DOI: 10.1016/j.chemosphere.2014.08.050].

Mohan D., Pittman C.U., Jr. & Steele P.H., 2006, Pyrolysis of wood/biomass for bio-oil: A critical review, Energy and Fuels 20: 848-889.

Rondon M.A., Lehmann J., Ramirez J. & Hurtado M., 2007, Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions, Biology and Fertility of Soils 43: 699-708.

Park J., Choppala G., Bolan N., Chung J. & Chuasavathi T., 2011, Biochar reduces the bioavailability and phytotoxicity of heavy metals, Plant and Soil 348: 439-451.

Song X., Pan G., Zhang C., Zhang L. & Wang H., 2016, Effects of biochar application on fluxes of three biogenic greenhouse gases: a meta-analysis, Ecosystem Health and Sustainability 2(2): e01202. [doi: 10.1002/ehs2.1202].