



IBI Research Summary:

Biochar for soil remediation and land reclamation

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Land reclamation and soil remediation

Land reclamation generally relates to the improvement of soils degraded by human activities, for example construction and certain forms of agriculture. Soil remediation refers to the process of removing, neutralizing or reducing the toxicity of certain compounds, often left by human activities such as mining and industry. Each degraded and/or contaminated site is potentially unique in its characteristics such as the presence of any specific contaminants, land form topography, climate, watershed dynamics, proximity to vulnerable populations etc. For this reason, whether biochar can be a tool to help with reclamation and remediation will be situation-specific. Biochar can potentially facilitate the revegetation of degraded soils through several mechanisms, and sorb a variety of compounds in soil. These multiple potential benefits, combined with the fact that biochar can potentially be a relatively low-cost and environmentally friendly tool for soil reclamation, provides incentive for more research. Data presented here does not include the effects of activated carbon (AC) on soil properties, although this has been widely studied. Biochar is the precursor to making activated carbon, which typically requires an additional step for activation, for example exposure to a chemical solution or gases. Depending on how they are made, some biochars may approach the sorption properties of AC.

Biochar as a tool for revegetation

The potential for biochar to improve crop yields is receiving much attention. Often, the goal is to facilitate the establishment of spontaneous vegetation on degraded soils which are acidic and have low organic matter contents. Soil may become degraded due to human activities such as mining and industrial activities as well as the use of certain pesticides in agriculture. Some biochar materials have a high pH and can act as liming agents, to increase soil pH (e.g. Chan *et al.*, 2007; Novak *et al.*, 2009; Major *et al.*, 2010). In cases where organic matter and clay levels in soil are low and soil is coarse textured,

moisture retention may help the establishment of vegetation. Biochar can help with this (see the IBI Research Summary, Impact of Biochar on Soil Moisture). Nutrient leaching can also be reduced by biochar application to soil (Lehmann *et al.*, 2003; Major *et al.*, 2009; Novak *et al.*, 2009; Singh *et al.*, 2010).

Biochar and the sorption of heavy metals

Biochar has been found to sorb a variety of heavy metals, including lead (Pb), arsenic (As) and cadmium (Cd). A dairy manure biochar made at 350°C sorbed several times more Pb than AC (Cao *et al.*, 2009). In this case, sorption by biochar was attributed mostly (85%) to the Pb reacting with ash present in the biochar, and also to direct surface sorption (15%) on biochar surfaces. The authors of this study conclude that the ash in the manure biochar was predominantly responsible for reducing Pb concentrations in water, as is also evident by the fact that AC (very low ash) sorbed much smaller amounts of Pb than did manure biochar.

Mohan *et al.* (2007) also worked on the removal of heavy metals in an aqueous solution by biochars made from pine and oak wood and bark, at 400-450°C. Due to its greater surface area and pore volume, oak bark biochar outperformed all others and removed similar amounts of Pb and Cd from solution as did a commercial AC material (~100% for Pb and ~50% for Cd). Oak bark biochar also removed ~70% of the As in solution. Other biochars, at pH values in the range of those of most agricultural soils (5-7) removed ~5-25% Pb, ~0-10% Cd and ~0-10% As from solution. These authors concluded that metal adsorption by biochars occurred by ion exchange mechanisms.

Biochar applied at 1% on a weight basis was found to reduce amounts of leachable metals in contaminated soils containing phenanthrene, resulting in better decomposition of phenanthrene and better plant growth. In this experiment, soil treatment with iron filings also reduced metal mobility and improved phenanthrene degradation, but did not allow the restoration of plant cover (Sneath *et al.*, 2009). Because biochar has been shown to have several different properties that enhance plant growth (Laird 2008), this suggests that applying biochar to contaminated soils will provide other benefits, beyond heavy metal sorption and enhanced decomposition of organic contaminants (e.g. phenanthrene). In another study, soil amended with 0.1 and 0.5 % (w/w) pine biochar sorbed more phenanthrene than non-amended soil, although the authors found that the amount of this contaminant sorbed by biochar varies with the properties of the biochar, soil characteristics and contact time between biochar and soil (Zhang *et al.*, 2010).

Uchimiya *et al.* (2010a) found that adding broiler litter biochar to soil enhanced the immobilization of a mixture of Pb, Cd and nickel, and the authors attributed this effect mostly to the rise in pH brought about by the biochar. In a different study, Uchimiya *et al.* (Uchimiya *et al.*, 2010b) tested the effect of “natural” (non-biochar) organic matter and the biochar’s unstable carbon fraction, on heavy metal immobilization by biochar. They found that these materials improve Cd immobilization by biochar, had no clear effect on immobilization of Ni, and actually lead to greater mobility of Cu in biochar-amended soil with very high pH (>9). Both high-ash and low-ash biochars had the ability to reduce the

mobility of Cd, Cu and Ni in this soil, and treating the biochars with phosphoric acid to increase their negative surface charges improved the biochars' immobilization capacity. Over a 60 day pot study using contaminated field soil and charcoal made for cooking, Beesley et al. (2010) found that biochar was much more efficient than compost (on a volume basis) in reducing the bioavailability of Cd and Zn, mostly due to the fact that biochar raised the soil's pH more than compost did. The availability of metals such as these in soil decreases as pH rises.

Biochar and the sorption of pesticides and other organic molecules

Organic contaminants include many agricultural pesticides and industrial contaminants. Biochar and the ash contained in biochar have a high affinity for sorbing different organic compounds. Charred organic matter (i.e. biochar, soot, activated carbon) generally sorbs 10 to 1000 times more organic compounds than does un-charred organic matter (reviewed by Smernik, 2009). Indeed, the sorption of many organic molecules in soils and sediments, including polycyclic aromatic hydrocarbons (PAH), has been attributed to the presence of biochar or similar materials in these soils (e.g. materials resulting from vegetation fires or from fossil fuel combustion). Sorption of organic molecules on biochar may be less reversible than sorption on other forms of organic matter, i.e. the probability is lower that a sorbed molecule will later detach itself. The sorption of organic molecules on biochar likely occurs by adsorption directly onto biochar surfaces, thus the greater the surface area and porosity of a biochar, the greater its potential for sorption of contaminants. While biochar is recalcitrant in soil, many other compounds in soil can also sorb to biochar and saturate or "block" its surfaces. Thus, more research is needed to determine the longevity of the effects of biochar on the sorption of organic molecules (Smernik, 2009).

Although sorption dynamics are affected by pH and other factors in soil, many studies have found that adding biochar to soil improved the sorption of pesticides. Cao et al. (2009) found that biochar made from dairy manure sorbed more atrazine (herbicide) in an aqueous solution than un-charred manure. Similar results were obtained by Zheng et al. (2010) for atrazine and simazine, another herbicide. A study where diuron (herbicide) sorption was compared in biochar amended vs. non-amended soils found that amended soil sorbed more diuron (Yu *et al.*, 2006). Similarly, Spokas et al. (2009) found that soil to which mixed wood chip biochar was added sorbed more atrazine and acetochlor (herbicides) than unamended soil, but organic matter applied to soil at the same rate as biochar would sorb more of these herbicides than the fast-pyrolysis biochar they tested. In contrast, Wang et al. (2010) found that wood biochar sorbed more terbutylazine (herbicide) than biosolids (digested or raw), and the herbicide was also more strongly sorbed by wood-based biochar than by biosolids, in soil.

Yu et al. (2009) studied the microbial degradation of insecticides chlorpyrifos and carbofuran in soil amended with wood-based biochar, and found that their degradation decreased with increasing amounts of biochar applied, while the uptake of the insecticides by onion plants also decreased with greater biochar application rates. This indicates that while the insecticides remained in soil longer, their bioavailability to plants

was reduced. Similarly, Yang et al. (2010) worked with soil-applied insecticides chlorpyrifos and fipronil and found that cotton straw chip biochar applied at 0.1 to 1% (w/w) reduced the losses of insecticides from the soil, while the uptake by Chinese chive plants was also reduced. The authors suggest biochar could be used to sequester these insecticides in a location while reducing their uptake by plants.

Yu et al. (2010) found that eucalyptus wood biochars made at 450 and 850°C were both in the range of 100 times more efficient at sorbing the fungicide pyrimethanil than was an Australian soil. The biochar made at the higher temperature sorbed more fungicide and released less of it after washing.

Several studies assessed the effect of biochar-containing ash on the sorption of pesticides. Yang et al. (2006) found that wheat straw ash containing 13% C added to soil at 1% resulted in 7-80 times more diuron sorption than in un-amended soils, and the amount of diuron remaining after 10 weeks was slightly greater in amended vs. unamended soil. Thus, the bioavailability of diuron was decreased with ash/biochar as demonstrated by a greater survival rate and biomass of barnyard grass. Yang et al. (2003) also showed that wheat straw ash was 600-10000 times more effective at sorbing diuron than unamended soil, up to 12 months after application. This has important implications for weed management, where reduced herbicide activity is undesirable. Similar results were obtained for benzonitrile (solvent) sorption by ash/biochar in soil (Zhang *et al.*, 2006) and for MCPA (herbicide), where ash/biochar amended soil was 90-1490 times more effective at sorbing MCPA than unamended sandy soils (Hiller *et al.*, 2007).

Polycyclic aromatic hydrocarbons (PAH) are potent contaminants which are produced by fuel burning. Total PAH contents and PAH bioavailability in a contaminated field soil over 60 days was found to be reduced more by biochar than by compost (compared on a volume basis), although not all treatment comparisons were statistically significant (Beesley *et al.*, 2010).

Biochar and the sorption of hydrocarbons

Laboratory work using crude oil contaminated desert soil showed that of 12 materials tested, coconut charcoal was most efficient in promoting oil biodegradation. (Cho *et al.*, 1997).

Conclusions

Biochar has the ability to sorb a variety of contaminants. The results shown here indicate that different biochar materials will be best suited for different contamination problems, hence supporting the concept of “designer biochar”. While laboratory studies have provided very promising data, the extent to which biochar and its ash can impact the mobility of heavy metals, organic contaminants and hydrocarbons in soil in the field has not been studied to date. Such studies are needed to better determine the potential of biochar as a tool for soil remediation and land reclamation, and these studies should take place on the long term. Biochar should be studied alongside other soil amendments which

can mitigate contamination problems, to determine the advantages and disadvantages of each.

References

- Beesley, L., Moreno-Jimenez, E., Gomez-Eyles, J.L., 2010. Effects of biochar and greenwaste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. *Environmental Pollution* 158, 2282-2287.
- Cao, X.D., Ma, L.N., Gao, B., Harris, W., 2009. Dairy-Manure Derived Biochar Effectively Sorbs Lead and Atrazine. *Environmental Science & Technology* 43, 3285-3291.
- Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A., Joseph, S., 2007. Agronomic values of greenwaste biochar as a soil amendment. *Australian Journal of Soil Research* 45, 629.
- Cho, B.H., Chino, H., Tsuji, H., Kunito, T., Nagaoka, K., Otsuka, S., Yamashita, K., Matsumoto, S., Oyaizu, H., 1997. Laboratory-scale bioremediation of oil-contaminated soil of Kuwait with soil amendment materials. *Chemosphere* 35, 1599-1611.
- Hiller, E., Fargasova, A., Zemanova, L., Bartal, M., 2007. Influence of wheat ash on the MCPA immobilization in agricultural soils. *Bulletin of Environmental Contamination and Toxicology* 79, 478-481.
- Laird, D.A., 2008. The charcoal vision: A win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. *Agronomy Journal* 100, 178.
- Lehmann, J., da Silva, J.P., 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 and Soil* 249, 343.
- Major, J., Rondon, M., Molina, D., Riha, S.J., Lehmann, J., 2010. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil* 333, 117-128.
- Major, J., Steiner, C., Downie, A., Lehmann, J., 2009. Biochar Effects on Nutrient Leaching (Chapter 15). In: Lehmann, J., Joseph, S. (Eds.), *Biochar for Environmental Management: Science and Technology*. Earthscan, London, UK, p. 271.
- Mohan, D., Pittman, C.U., Jr., Bricka, M., Smith, F., Yancey, B., Mohammad, J., Steele, P.H., Alexandre-Franco, M.F., Gomez-Serrano, V., Gong, H., 2007. Sorption of arsenic, cadmium, and lead by chars produced from fast pyrolysis of wood and bark during bio-oil production. *Journal of Colloid and Interface Science* 310, 57.
- Novak, J.M., Busscher, W.J., Laird, D.L., Ahmedna, M., Watts, D.W., Niandou, M.A.S., 2009. Impact of Biochar Amendment on Fertility of a Southeastern Coastal Plain Soil. *Soil Science* 174, 105-112.
- Singh, B.P., Hatton, B.J., Singh, B., Cowie, A., Kathuria, A., 2010. Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils. *Journal of Environmental Quality*.
- Smernik, R.J., 2009. Biochar and Sorption of Organic Compounds (Chapter 16). In: Lehmann, J., Joseph, S. (Eds.), *Biochar for Environmental Management: Science and Technology*. Earthscan, London, UK, p. 289.
- Sneath, H., Wingate, J., Hutchings, T., De Leij, F., 2009. Remediation of metal, arsenic and phenanthrene contaminated soil using charcoal and iron filings. *Geochimica Et Cosmochimica Acta* 73, A1243-A1243.
- Spokas, K.A., Koskinen, W.C., Baker, J.M., Reicosky, D.C., 2009. Impacts of woodchip biochar additions on greenhouse gas production and sorption/degradation of two herbicides in a Minnesota soil. *Chemosphere* 77, 574-581.
- Uchimiya, M., Lima, I.M., Klasson, K.T., Chang, S.C., Wartelle, L.H., Rodgers, J.E., 2010a. Immobilization of Heavy Metal Ions (Cu-II, Cd-II, Ni-II, and Pb-II) by Broiler Litter-Derived Biochars in Water and Soil. *Journal of Agricultural and Food Chemistry* 58, 5538-5544.
- Uchimiya, M., Lima, I.M., Klasson, K.T., Wartelle, L.H., 2010b. Contaminant immobilization and nutrient release by biochar soil amendment: Roles of natural organic matter. *Chemosphere* 80, 935-940.
- Wang, H.L., Lin, K.D., Hou, Z.N., Richardson, B., Gan, J., 2010. Sorption of the herbicide terbuthylazine in two New Zealand forest soils amended with biosolids and biochars. *Journal of Soils and Sediments* 10, 283-289.

- Yang, X.B., Ying, G.G., Peng, P.A., Wang, L., Zhao, J.L., Zhang, L.J., Yuan, P., He, H.P., 2010. Influence of Biochars on Plant Uptake and Dissipation of Two Pesticides in an Agricultural Soil. *Journal of Agricultural and Food Chemistry* 58, 7915-7921.
- Yang, Y.N., Sheng, G.Y., 2003. Pesticide adsorptivity of aged particulate matter arising from crop residue burns. *Journal of Agricultural and Food Chemistry* 51, 5047-5051.
- Yang, Y.N., Sheng, G.Y., Huang, M.S., 2006. Bioavailability of diuron in soil containing wheat-straw-derived char. *Science of the Total Environment* 354, 170-178.
- Yu, X.-Y., Ying, G.-G., Kookana, R.S., 2006. Sorption and desorption behaviors of diuron in soils amended with charcoal. *Journal of Agricultural and Food Chemistry* 54, 8545.
- Yu, X.Y., Pan, L.G., Ying, G.G., Kookana, R.S., 2010. Enhanced and irreversible sorption of pesticide pyrimethanil by soil amended with biochars. *Journal of Environmental Sciences-China* 22, 615-620.
- Yu, X.Y., Ying, G.G., Kookana, R.S., 2009. Reduced plant uptake of pesticides with biochar additions to soil. *Chemosphere* 76, 665-671.
- Zhang, H.H., Lin, K.D., Wang, H.L., Gan, J., 2010. Effect of *Pinus radiata* derived biochars on soil sorption and desorption of phenanthrene. *Environmental Pollution* 158, 2821-2825.
- Zhang, P., Sheng, G.Y., Feng, Y.H., Miller, D.M., 2006. Predominance of char sorption over substrate concentration and soil pH in influencing biodegradation of benzonitrile. *Biodegradation* 17, 1-8.
- Zheng, W., Guo, M.X., Chow, T., Bennett, D.N., Rajagopalan, N., 2010. Sorption properties of greenwaste biochar for two triazine pesticides. *Journal of Hazardous Materials* 181, 121-126.