A DIFFERENT VIEW

BIOCHAR AND THE BIOMASS RECYCLING INDUSTRY

To realize its full potential as a tool for carbon cycle management and to sustainably increase soil productivity, biochar should be tested in combination with other organic waste streams.

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BIOCHAR, the high carbon content remains of organic biomass heated in the absence of oxygen, has been a topic of intense interest and growing experimentation in the past five years. The rediscovery of terra preta (or black earth) soils in the Amazon has sparked the imagination and curiosity of researchers around the world. These "human-built" soils are dark, productive deposits — a composite of charcoal (biochar), pottery shards and organic matter such as plant material, animal feces and fish and animal bones. Significantly, these soils are several thousand years old, yet continue to maintain high plant productivity and high soil carbon content despite existing in a region well known for low soil productivity and rapid organic matter decomposition. Charcoal presence is not unique to the tropics. U.S. farmland soils can vary in charcoal content from 10 to 35 percent of the total organic carbon (TOC), with charcoal-enriched areas in regions with a wildfire-dependent ecology (Skemstad *et al.,* 2002).

Much of the published terra preta research to date has focused solely on the biochar component. A full picture of "biochar-only" effects is yet to be fully understood. Most of the best-documented studies have used a single addition of biochar, which is intensively measured over a number of years, but data to date suggest a wide range of outcomes. Biochar additions have been seen to be positive, neutral and even negative. This wide range in outcomes may be due to differences in the specific biochar used, time since addition, the crop species tested and the particular starting soil properties/deficiencies.

Dr. Sally Brown's Climate Change Connections column in the April 2011 issue of BioCycle — "Carbon Cycling 101" — referenced research conducted by Seachar, a Seattle, Washington-based biochar advocacy group, which involved incorporation of biochar and compost alone, and then combined, on plots that then were seeded. Seachar invited Brown to tour the plots. Those same plots were analyzed by a USDA Agricultural Research Service scientist, who came to the University of Washington (where Dr. Brown is employed) to discuss his analysis. Wrote Brown in her BioCycle column, "from a scientific perspective, nothing significant happened on the Seattle plots with regard to the use of biochar."

Seachar's disappointment in the comments about biochar in Brown's April column ultimately led to BioCycle inviting Seachar to write an article in response.

Biochar is a by-product of pyrolysis and gasification. Large-scale flash pyrolysis systems convert 70 percent of the biomass to oil, 15 percent to gas and 15 percent to char. The char is sometimes consumed to heat the process. Gasification and staged combustion can be adjusted to produce more (15%) or less (2%) biochar. Pyrolysis systems vary in the amount of volatile nutrients like nitrogen, sulfur and potassium that are retained. Hydrothermal carbonization (HTC) is a new process that converts biomass to char under heat and pressure in aqueous solutions. It may be suitable for wet wastes like biosolids since it promises a higher retention of nutrients than dry pyrolysis.

Interest is rising in the biochar community to further explore the dynamic relationship between the known properties of biochar and the organic materials long used to build soil carbon and productivity. To realize the full potential of biochar as a tool for carbon cycle management and to sustainably increase soil productivity, biochar should be tested in combination with other organic waste streams, and in multiple applications over years.

PROPERTIES OF BIOCHAR

At least four properties of biochar make it a compelling opportunity for combination with composts, manures, green manures and biosolids:

Stability in the environment: Even the best composts decline in carbon percentage relatively rapidly after soil addition, especially in hot, humid environments. Academic research on potential long-term carbon sequestration and carbon credits requires identifying the recalcitrance of biochar-based carbon in soils. To date, upper bounds point from hundreds to thousands of years. However, from a landowner perspective, adding biochar to compost provides a carbon source that is functionally a permanent addition, and can be marketed as such.

Adsorptive properties: Like its more refined cousin, activated charcoal, biochar has been shown to adsorb gases, odors, nutrients and environmental contaminants. In the developing world it has been added to composting toilets to reduce odors. Documented reductions in nitrous oxide (a potent greenhouse gas) were observed when biochar was applied to dairy pasture (Taghizadeh-Toosi *et al.,* 2011). Increased nitrogen, copper and zinc retention was observed in mixed sludge-biochar composts (Hua *et al.*, 2009).

There is ongoing research on the appropriate use of biochar for metals stabilization (Beesley, 2010). Uchimaya *et al.* (2011) concluded that biochar must be engineered to have high stability (high fixed carbon content) and high metal ion coordinating functional groups for long-term stabilization of heavy metals such as lead and copper. But for agricultural use, biochars having high ash contents can induce higher pH and release elements having nutrient value (nitrogen, phosphorus and potassium) (Chan, 2008). Combining biochar with soils, compost or biosolids, pre or post treatment, may therefore be a potent method to reduce uncontrolled and rapid escape of nutrients, heavy metals, toxins and GHG into the environment.

Soil porosity, water holding capacity and bulk density: While much of the physical structure of compost degrades, biochar is far more stable. During pyrolysis, the physical structure of cell walls is largely retained. Surfaces of biochar do weather/oxidize over time, but the macro structure remains, enhancing soil bulk density, water holding capacity and soil porosity. For compacted clay soils a positive change in these soil physical attributes can greatly improve plant growth.

Potential secondary product and revenue streams: Commercial technologies make it possible for biochar to be made as a primary product or coproduct depending on the source and value of the biomass. Sources of biomass for making biochar include clean urban wood waste, agricultural and forestry processing residues, and forest and crop residues.

Fly ash, a waste product from traditional low efficiency wood boilers' flues, is often pure char with low ash, and is a potent liming agent due to its high pH. It is sometimes available just for the cost of removal from industrial plants. Fly ash has been used directly by nurseries as a soil amendment or in composting. One manufacturer, Ecotrac Organics, combines fly ash with green manures as a pelletized product.

ICM Inc. processes 200 tons/day of urban wood wastes into biochar and gas in a commercial prototype at the Harvey County Landfill in Kansas. Its staged gasification reactor is intended to convert up to 400 tons/day of wood or crop residues to direct heat or power while producing up to 15 percent biochar as a coproduct.

Oversized wood waste screened from compost that is now sold to biomass plants as fuel could be carbonized and combined with waste to be composted, or combined with the finished compost. Biochar has been shown to enhance the effectiveness of low impact development (LID) filter socks for storm water management. One nursery has successfully incorporated biochar in compost to completely replace peat and vermiculite in growing media, reducing peat consumption and saving money. A biochar producer on Cape Cod combines 50 percent biochar with 50 percent compost by weight. Compost is made from yard trimmings and food waste. The product, "Terra Codda," is used by gardeners, farmers, golf courses, the New York City parks department and green roof contractors (Hirst, 2011). Recent studies have tested the effects of adding biochar to manure compost (Steiner, 2011; Dias, 2009; Hua, 2009).

Various companies have developed small-scale commercial prototypes for processing pits, nuts, shells, poultry litter and manures to biochar. Frye Poultry in Wardensvile, West Virginia, uses a gasifier to heat a poultry house while producing biochar (Gaume, 2007). Forest residues are available at low cost from forest restoration treatments. Small-scale, mobile systems for forest use are under development. These units have provided biochar for product testing and development but no commercial systems are available for high volume production.

Biochar and compost share many of the above stated positive attributes. The benefit of having biochar as part of the mix is due to its chemical and structural stability that provides unique long-term product value, not unlike the unique microbial and nitrogen fertilization that compost provides in the short term. Table 1 summarizes the list of benefits that compost and biochar offer individually, and then combined.

MICROBIAL DESERT OR A TERRESTRIAL REEF?

Biochars are not all created equal. The difference comes down to pyrolysis conditions and source material. Time and temperature of the pyrolysis step are of paramount importance for both the physical and chemical properties of the biochar, as well as its stability over time (Keiluweit *et al.,* 2010). Source of material also has some influence on biochar properties, but is a clear second to pyrolysis conditions. Biochars produced at low temperatures are very near pH 7, while high temperature biochars are closer to pH 8 to 10, and can be potent liming agents for acidic soils. Biochar produced under lower temperature retains some labile (microbially digestible) hydrocarbons, which may allow more rapid microbial colonization, but may also result in some short-term nitrogen tie up (not unlike some incomplete composts).

Biochar created under higher temperatures lacks these hydrocarbons, which may result in slower colonization, but may be less likely to induce a microbial bloom. Biochar is often discredited for being "sterile" due to its recalcitrance to microbial breakdown. When first produced, biochar is indeed devoid of microorganisms, and its value as a carbon food for microorganisms is limited. It is largely a soil amendment, and certainly not a nitrogen fertilizer. However, other nutrients such as phosphorus, potassium and calcium are well retained after heat treatment and release to the soil over time (Novak *et al.,* 2009). Biochar may provide stable spaces for soil microorganisms to inhabit, with some research suggesting it may take up to a year to establish functioning microbial populations following oxidation of its surfaces. Oxidation of biochar surfaces over time increases cation exchange capacity.

Therefore, agronomic outcomes with biochar depend on the biochar's properties and raw material source, soil characteristics, crop being grown, biochar volume applied and time since application. Biochar will generally help where soil carbon is low, where drought and soil compaction are significant issues, or where liming is required. Its benefits may be negligible in nutrient-rich soils with high organic matter, high water retention and crop-appropriate pH. Outcome may be negative where soils are already alkaline, and for crops with acidic soil requirements.

In principle, there should be selectivity in the biomass used to create biochar. Since pyrolysis strips off nitrogen, biomass that is low in nitrogen, woody and difficult to compost should be the targeted resource stream for biochar production. Wood chips are one logical source. Where there is significant excess manure, such as large dairy or chicken farms, some on-site biochar production/heat cogeneration activity using manures may be an attractive, environmentally friendly alternative. Biochar can be used to reduce nutrient loss of the manure before field application, or to create a valuable secondary phosphorus fertilizer for sale. Again, the most appropriate sourcing for biochar production will depend on the situation. However, under all circumstances, a deliberate consideration of the environmental value of the waste stream selection should occur, and specifically, what the net potential nitrogen and carbon loss and gain will be.

PATH FORWARD

A retail market to drive the capital required to reach scale remains a key current limitation for biochar. In the meantime, development of new and engaging uses and applications for biochar could spur demand. With the 2009 collapse of the negotiations on carbon credits by the United Nations Framework Convention on Climate Change, which would have provided immediate economic value for biochar, the value proposition for biochar must now be mostly centered upon its agronomic value. On the technical science side, work is being done by the International Biochar Initiative (IBI) and others to accurately and precisely characterize biochar, so that effects in various environments can be better forecast, and the most efficacious application rates can be identified and prescribed.

The *BioCycle* and biochar communities should work together to explore potential benefits and pitfalls of various combinations and market applications. The nascent biochar community has much to gain from the well-established infrastructure of the composting and biosolids industries. Conversely, adding the durability, environmental benefits and related income streams (such as cogeneration of heat and bio-oils) from biochar production may help drive the development of new products and market strategies for organic waste recyclers. Individuals from both areas need to step out of their comfort zones, develop new partnerships and collaborations, and think outside the box. ■

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Table 1. Potential level of benefit from compost, biochar and compost-biochar mixes

Soil Benefit	Compost	Biochar	Compost + Biochar
Stability in environment	*	*****	****
Water holding/absorption	***	***	***
Nutrient holding/adsorption	**	****	****
Nitrogen source	****	*	****
Microbial loading	****	*	****
Microbial habitat	***	***	***
Soil tilth/bulk density	***	****	****
Reduced N_2O off gas	*	***	***

* = minimum value, **** = high value

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