An Introduction to Biochar and Its Application to Soils[1]

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Biochar is the solid by-product of organic matter (such as wood, crop debris, sewage sludge, manure, and yard trimmings) that has been heated in a closed container with little or no available oxygen. This process is known as *pyrolysis*. Both biochar and charcoal are produced by pyrolysis. The distinction between charcoal and biochar is in the intended use. Whereas charcoal is used as a fuel for heating and cooking, as a filter for adsorbing contaminants, as a reactant for making iron, or as a coloring agent, biochar is primarily used as a soil amendment.

The application of biochar to production fields is of current interest to the agricultural community because it reportedly increases water, nutrient, and carbon retention in soil. Recent scientific studies show that biochar offers the following two main benefits to soils:

1. Biochar is more stable than any other soil amendment.

2. Biochar has a higher capacity to hold nutrients than any other soil amendment.

In 2009, two scientific authorities on biochar, Dr. Joseph Lehmann and Dr. Stephen Joseph, wrote that, as a consequence of these two benefits, "biochar [is] not merely another type of compost or manure…but is much more efficient at enhancing soil quality than any other organic soil amendment" (4). To be clear, biochar is not a fertilizer. Biochar produced from some feedstocks can provide a small amount of nutrients to the soil, but this contribution to crop productivity is likely to be short term. Nevertheless, biochar's stability in soils, high water-holding capacity, and high nutrient (and soil organic matter) retention suggest that biochar has significant potential to increase irrigation and fertilizer efficiencies.

This publication introduces agricultural professionals to biochar and provides preliminary recommendations for on-farm applications. It must, however, be noted that endorsements for agricultural biochar use are not widespread. *Specific* recommendations are impossible to determine at this time because of insufficient data on the best biochar to use for different soil and crop types and the appropriate application rates. A major complication in developing recommendations is that biochar is a highly variable material dependent on the feedstock, the process conditions, and the production temperature. The biochar's age and whether or not it is "precharged" have also been shown to influence experimental results. Thus, while many studies demonstrate significant benefits, some of these benefits may (or may not) be translatable to other soil and crop systems. Therefore, caution is advised before large-scale application.

Current scientific research on biochar as a tool for countering climate change and improving soils on a global scale is a recent development, yet biochar has ancient origins. This renewal of interest in biochar was spurred by the discovery of high organic carbon and remarkably fertile soils in South America, specifically Amazonia, that have been termed Amazonian Dark Earths, or Terra Preta de Indio (Portuguese for "Black Earth of the Indians"). Remarkably, these soils have maintained high fertility for thousands of years—and this in a region of the world where soils

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are often characterized by low fertility and low nutrient-holding capacities. The fertility of Amazonian Dark Earths is believed to be largely a consequence of charcoal additions (biochar) by the indigenous people of the region. Biochar's positive effects have remained even hundreds of years after habitation.

Biochar Effects

The scope of biochar's expected benefits far exceed that of traditional soil conditioners and amendments. At least three other major benefits can serve to motivate the adoption of biochar technologies: 1) mitigation of climate change, 2) waste management, and 3) renewable energy production. Biochar's extreme longevity in soils means that the carbon that plants remove from the atmosphere and convert into biochar is sequestered in soil, thereby helping to reduce atmospheric carbon dioxide concentrations (a major greenhouse gas). Urban green waste, industrial organic waste, and animal and crop waste can be converted to biochar, facilitating the adoption of new waste management strategies. Moreover, sophisticated biochar production technologies permit the liquid and gaseous by-products of biochar production, "bio-oil" and "syngas," to be harnessed for use as renewable energy sources.

Soil conditioning benefits associated with biochar amendments are many and varied. Studies to date show evidence of the following:

1. Improvement of soil chemical properties

- *Liming effect / increases pH:* Biochar pH is typically greater than 7.0 and may provide benefits when applied to acidic soils. For example, Van Zwieten et al. (2007) reported a 30%–40% increase in wheat height when biochar was added to an acidic soil, but these effects were not evident in this study when the biochar was added to a neutral soil.

- *Increases cation exchange capacity (CEC):* CEC is an important measure of a soil's ability to retain nutrients and make them available to plants. Cheng, Lehmann, and Engelhard (2008) showed that this benefit increases as biochar ages. Because pH increases are related to CEC increases, this benefit can be interrelated to biochar's effect on soil pH.

2. Improvement of soil physical properties

- *Improves soil bulk density:* Biochar's innate porosity and very low bulk density have been shown to improve soil physical properties by decreasing soil bulk density and increasing water infiltration. It also provides related benefits, such as increasing root growth. These qualities might result in the need for less tillage, which would result in fuel, labor, and economic savings in addition to the agro-ecological benefits of reduced tillage.

- *Improves soil moisture retention:* Many studies showing the benefits of biochar to crop yield cite moisture retention as a key factor (Gaskin 2007; Sohi et al. 2009). This may be of greatest advantage in sandy soils.

3. Improvement of soil biological properties

- *Improves habitat for microorganisms and worms:* Biochar's many pores, the size of the pores, and its high surface area may offer plentiful habitats for microorganisms, provide protection from predation and drying, and offer microorganisms concentrated mineral and carbon sources (Lehmann et al. 2011). Microorganisms provide a host of beneficial ecosystem services, including plant disease suppression, nutrient cycling, and improved soil aggregation. Interestingly, worms have also shown preference for ingesting biochar particles (Topoliantz and Ponge 2003, 2005; Van Zwieten et al. 2010).

- *Increases mycorrhiza abundance:* Evidence shows that biochar has a strong positive effect on mycorrhiza abundance (Warnock et al. 2007). Mycorrhiza facilitate increased nutrient uptake by the plant roots.

The vast majority of biochar field trials, especially over the course of the most recent decade, showed positive results on crop yield and/or total plant biomass. However, Kishimoto and Sugiura (1985) and Mikan and Abrams (1995) both reported yield reductions in response to biochar additions. These scientists hypothesized that the increase in pH resulted in a decrease in the uptake of micronutrients, and that micronutrient deficiencies were responsible for the yield reductions.

Depending upon the feedstock from which the biochar is manufactured, some biochar might have high concentrations of heavy metals if, for example, it is made from sewage sludge or industrial waste products. Another concern is the release of harmful organic volatile compounds. Consequently, it is advisable to either avoid biochar produced from these feedstocks or to perform detailed testing in order to avoid possible field and/or crop contamination.

While biochar may adsorb nutrients, it also strongly adsorbs organic compounds and thereby may decrease the bioavailability, toxicity, and mobility of organic pollutants (Kasozi et al. 2010). This characteristic could result in reduced pesticide and herbicide efficacy. On the other hand, as biochar ages, the pore spaces (or charges) in the biochar particles can gradually become saturated, and the biochar may no longer sorb organic compounds. Thus, long term, biochar is not expected to significantly reduce pesticide or herbicide efficacy.

Examples of Biochar's Effects on Crop Yields Relative to Florida Agriculture

Field trials using biochar in the tropics or semitropics during the past decade have, when nutrients were managed appropriately, generally shown positive results on yields. Table 1 outlines the results of some biochar field studies published in peer-reviewed journals.

Additional Benefits

In addition to improving soil quality and fertilizer and irrigation efficiency, two additional potential benefits of biochar include:

1. Agricultural professionals may in the future be financially compensated for sequestering carbon in the soil in the form of carbon credits.

2. Numerous pilot projects in the United States and elsewhere have shown that biochar production (pyrolysis) can be designed to heat greenhouses or generate electricity, thereby allowing farmers to offset some of their energy costs.

Biochar Application

Biochar application in modern farming is still in its infancy; therefore, few recommendations are currently available, and none are from the land-grant university system. The following represents general suggestions based on our current knowledge of biochar's effects in agronomic systems.

Biochar Availability

Biochar is available commercially from a number of different suppliers at the approximate cost of $1 per pound, plus shipping expenses and, in some cases, additional costs for handling, container, and taxes. See Table 2 for information about where to purchase biochar.

As mentioned earlier, biochars are highly variable, so farmers should consider the characterization of the particular biochar that they are considering purchasing. Depending on feedstocks and process conditions, biochars have widely varying pHs, ash contents, surface areas, C:N ratios, and other characteristics. Some biochars, particularly those made from animal manure, contain a higher percentage of ash and, consequently, a lower percentage of recalcitrant carbon. If purchasing biochar by weight, it is important to consider that some biochars are sold at higher moisture content than others. Some biochars are advertised as having certain added nutrients or beneficial inoculants. Currently, there are no established standards for characterizing biochars, such that scientists and consumers can easily differentiate and categorize different types. However, this may change as the market for biochar evolves and as scientific research progresses.

In summary, a few important questions to consider asking a biochar manufacturer before making a large purchase include:

1. What is your biochar made from?

2. Through which process and at which temperature is it made?

3. What is the moisture content?

4. What is the surface area / adsorption? CEC?

5. What is the ash content? Fixed carbon content? pH?

6. Is the biochar "charged" with inoculants, organic matter, or added nutrients?

7. Is the product uniform and consistent?

8. Is the product free from metals and harmful organic compounds?

9. Has your product been tested in horticultural/agricultural applications? If so, was the testing performed in-house or by third parties and published in scientific peer-reviewed journal(s)?

Making Your Own Biochar?

Before embarking on making your own biochar, consider equipment, time, amount needed, expense, and overall economic feasibility. For example, a backyard gardener can easily produce small quantities of biochar in a small woody debris burn pile in a shallow pit or in a 55-gallon drum, but larger quantities require advanced methods. As an analysis of biochar's benefits to Florida's farmers is not yet available, an accurate economic feasibility study of home biochar production is not available. Consult the resources listed at the end of this document for more specific ideas and guidelines for home biochar production.

Application Rates

Studies have tested rates from 5 tons/hectare to 60 tons/hectare, and almost all have shown benefits, with the higher application rates often showing even greater benefits. This is a very wide range and, because of the variation in data, soil, and biochar type, specific recommended application rates are not offered at this time. It is, however, recommended to consider that biochar-carbon varies greatly depending on parent material, so for future comparisons, it may be more appropriate to report application rates in terms of biochar-carbon per hectare as opposed to total bulk biochar per hectare. For example, biochar from manure contains much less fixed carbon per unit of biochar than biochar from woody materials; therefore, very different levels of carbon and ash are applied to a given soil depending on the source material of the biochar.

Application Frequency

Because of biochar's stability in soils, it does not need to be applied on an annual basis, like manures and composts. A single application can result in benefits over many years. The targeted total application rate; the availability of biochar, labor, and time; and the individual situation of the farmer will determine whether it is preferential to employ a large one-time application or several smaller, repeated applications. However, it is worth noting that some of biochar's benefits (pH and CEC effects) seem to increase as the biochar ages (Major et al. 2010). Therefore, it might be prudent for farmers to observe the effects over multiple seasons before reapplication.

Particle Size

It is not yet known if there are significant differences in effectiveness with different biochar particle sizes. The research to date suggests that this is not a significant factor, but that farmers should be conscious of particle size only so far as it pertains to effective application methods. After application, biochar particles have been observed to quickly break into smaller particle sizes.

Application Methods

Wind and water erosion can be problematic when adding many kinds of soil amendments, and biochar is no exception. In fact, biochar might be more susceptible to wind and water erosion because of its low density and sometimes fine particle size. A recent field trial conducted in Quebec, Canada, in 2008 by Blue Leaf Inc. estimated that 2% of biochar was lost when loading a spreader, 3% was lost during transportation, and 25% was lost during field application, for a total loss of 30% (Major 2010). In addition, heavy rains and sloping terrain can also result in biochar loss.

The recommended practice for avoiding loss by water erosion is to incorporate biochar into the soil. Various methods for doing so are discussed later in this section. Recommendations to avoid loss by wind erosion are 1) apply on a day with very little wind and at the time of day that typically has less windy conditions, or on a day with a light rain (to reduce dust); 2) apply water to biochar prior to spreading; and 3) mix biochar with manure or compost.

Biochar should be applied near the soil's surface in the root zone, where the bulk of nutrient cycling and uptake by plants takes place (Major 2010). In all farming systems, biochar should ideally be managed with traditional farm machinery and incorporated into routine field operations. This will help keep costs as low as possible.

Broadcast and incorporation: The majority of biochar field trials have broadcasted and incorporated biochar into soil, just as manure or compost is applied to fields. Depending on the scale of the enterprise, broadcasting can be done by hand or, on larger scales, by using a lime/solid manure spreader or broadcast seeders. Wet biochar may work better with manure spreaders than with lime spreaders. Incorporation can be done with any implement that is typically used to incorporate manure, lime, or other amendments, such as hand hoes, animal draft plows, harrows, chisels, or spaders.

Incorporation with composts and manures: When added to the composting process, biochar has been shown to help the mixture retain more nitrogen (N), reduce odors, increase the number of microorganisms, and speed the composting process (Dias et al. 2009; Steiner et al. 2010). Moreover, applying a biochar-compost mixture reduces biochar loss to wind and water erosion. The final mixture can be applied via broadcasting and incorporation, as a topdressing, or through banding.

Banding: Banding minimizes soil disturbance and is appropriate for perennial crops and pastures, or for application after crop establishment. The total amount of biochar that can be applied by banding is less than that achieved by broadcast and incorporation. If banding by hand, a trench can be hoed open and the biochar deposited manually.

Mixing biochar with liquid manures and slurries: Although there is currently no published evidence of this technique's success, this strategy might be used to reduce odor, retain

N and phosphorous (P), and control dust. Fine biochars are most suitable for this application method.

Topdressing: When mechanical access is either impractical or undesirable, such as in cases of no-till cropping or established pastures, or in between fruit trees or in forest gardens or other perennial systems, biochar can be top-dressed. This method of application leaves the amendment at higher risk of erosion, and yet incorporation has been observed through earthworm activity, rainfall, leaf fall, and microfaunal activity, suggesting significant vertical transport (Gathorne-Hardy, Knight, and Woods 2008).

Organic Certification

According to the National Organic Program of the United States Department of Agriculture, biochar is considered a "nonsynthetic allowed" material, so long as it is made from plant biomass and not animal manures, since ash from manure is prohibited (Major 2010). As biochar becomes more common, it will almost certainly be more regulated as a soil amendment, and because of its high degree of variation, it is likely that each particular biochar will have separate certifications. Farmers are encouraged to check with their certifying agencies before applying biochar.

Safety

Charcoal, particularly in fine particulate form, poses a fire hazard because of its tendency to spontaneously combust on occasion. Care is required to minimize this risk, and national regulatory agencies typically regulate this type of risk. However, if one is producing biochar at home or storing large amounts of purchased biochar, it is important to be aware of this danger and take steps to avoid the possibility of spontaneous combustion. Water is often used to minimize the risk of fire, but the biochar must be saturated for the water to definitively prevent combustion.

Rice husk biochar, if made at temperatures above 550°C, can contain crystalline materials (cristobalite and tridymite) that are known to be toxic to humans and should be either avoided or used with caution. The dust fraction of any biochar can have negative effects when inhaled; therefore, it is prudent to wet biochar prior to applications and/or wear protective masks when handling.

Additional Resources

Further Reading

Bates, Albert. 2010. *The Biochar Solution: Carbon Farming and Climate Change*. Gabriola Island, BC, Canada: New Society Publishers.

This book is written for the general reader, and emphasizes biochar as a tool for mitigating climate change.

Bruges, J. 2009. *The Biochar Debate: Charcoal's Potential to Reverse Climate Change and Build Soil Fertility.* Vermont: Chelsea Green.

This book provides a basic introduction to the general concept and science behind biochar use and biochar's potential for mitigating climate change.

Lehmann, J., and S. Joseph. 2009. *Biochar for Environmental Management: Science and Technology.* London: Earthscan.

This is a scientific text that compiles peer-reviewed scientific literature on all aspects of biochar for soil applications, biochar systems, and economics and policy.

Websites

The International Biochar Initiative (www.biochar-international.org) is a website for biochar-related information and for connecting with the latest research, news, projects, and more. Another website is Biochar Farms (www.biocharfarms.org), which has referenced information, videos, and PowerPoints on the site, and under "Network" it offers a list of contact information for researchers, companies, and experts. A site with a detailed and extensive FAQs on gardening with biochar is located here: http://biochar.pbworks.com/w/page/9748043/FrontPage. There are, of course, many more sites with biochar-related information, one example of which is AirTerra (www.airterra.ca), a nonprofit organization committed to poverty reduction by promoting use of inexpensive biochar-producing stoves in the developing world.

Online Discussion Groups

To connect to the broader biochar online community, visit http://biochar.bioenergylists.org/discussion. This site offers an introduction and links to various online biochar discussion groups. Alternatively, look into joining a regional biochar group near you – a list is maintained here: http://www.biochar-international.org/network/communities. Or you can work with your local county Extension agent to establish a new group in your area.

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Table 1. Summary of selected biochar field experiments

Authors	Researched area	Results summary
Glaser, Lehmann, and Zech (2002)	Improving physical and chemical properties of highly weathered soils in the tropics with charcoal – a review (Cowpeas on xanthic ferrasol)	Char additions increased biomass between 150% and 200% over controls.
Lehmann et al. (2003)	Nutrient availability and leaching in anthrosol and a ferrasol of the Central Amazon basin: fertilizer, manure, and charcoal amendments (includes greenhouse research)	Biochar additions significantly increased biomass production from 38% to 45%.
Oguntunde et al. (2004)	Compares corn yields between disused charcoal production sites and adjacent fields in Ghana	Grain yields were 91% higher and biomass yields were 44% higher at the charcoal site than the control.
Rondon, Ramirez, and Hurtado (2004)	Charcoal additions improve yield and quality of cash crops (carrots and beans) in Andean hillsides of Columbia	Increased biomass between 100% and 30% of fertilized controls.
Yamato et al. (2006)	Corn, cowpea, and peanut trial in an acidic soil of low fertility (Indonesia)	Biochar (+fertilizer) treatments had ~50% greater yields than fertilizer alone; also, large increases in mycorrhizal fungi colonization.
Rondon et al. (2007)	Bean responses (nitrogen fixation) from biochar additions (greenhouse study)	Bean yields increased between 39% and 46%.
Steiner et al. (2007)	Four cropping cycles with rice and sorghum	Biochar doubled grain yields when used in conjunction with NPK mineral fertilizer and increased retention of total soil organic matter.
Kimetu et al. (2008)	Comparison of corn yields in degraded soils in Kenya, with and without biochar additions	Biochar additions resulted in doubling of crop yields, from 3 to 6 tons/hectare.
Van Zwieten et al. (2008)	Corn and fava beans in a ferrasol with paper mill waste biochar and poultry litter biochar	Corn showed 51% yield increase at 10 tons/hectare, and 109% increase at 50 tons/hectare. Beans showed highest yields in biochar + fertilizer treatment.
Major et al. (2010)	Corn yield and nutrition 4 years after biochar application	The increases in grain yield in the 20 tons biochar/hectare lots over the control were 28%, 30%, and 140% for 2004, 2005, and 2006, respectively. The availability of nutrients such as calcium and magnesium were greater with biochar.

Table 2. Selected commercial biochar manufacturers

Name	Product details	Contact info
Biochar Solutions, Inc.	Fixed carbon: 90%–98% Adsorption: 100–330m^2/g BET surface area pH: 7.5–10 Moisture in biochar: 0%–3%	PO Box 2048 Carbondale, CO 81623 Phone: 970.510.6677info@biocharsolutions.comwww.biocharsolutions.com
Carbon Brokers International	This company is a broker and, therefore, does not manufacture the char.	Phone: 720.924.1750 www.carbonbrokersinternational.com
Carbon Char	This company does not manufacture biochar at this time. It sells a product (a bio-inoculant) that has char as one of the proprietary ingredients.	Phone: 828.254.7418 sales@carbonchar.com www.carbonchar.com
Dynamotive Energy Systems	% Moisture 2.01 % Ash 10.85% Volatile matter 23.42 % Fixed carbon 63.72 Via fast pyrolysis	Grosvenor Building Suite 800 - 1040 West Georgia Street Vancouver, BC, V6E 4H1 Phone: 1.800.852.0938 www.dynamotive.com
Genesis Industries	Minimum purchase amount at this time is 1 ton. Contact company for details.	212 Yacht Club Way A-12 Redondo Beach, CA 90277 Phone: 310.392.5050 Fax: 310.697.3032 http://egenindustries.com/