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The Basics of Biochar: A Natural Soil Amendment

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Biochar is a fine-grained, highly porous charcoal substance that is distinguished from other charcoals in its intended use as a soil amendment. Biochar is charcoal that has been produced under conditions that optimize certain characteristics deemed useful in agriculture, such as high surface area per unit of volume and low amounts of residual resins. The particular heat treatment of organic biomass used to produce biochar contributes to its large surface area and its characteristic ability to persist in soils with very little biological decay (Lehmann and Rondon 2006). While raw organic materials supply nutrients to plants and soil microorganisms, biochar serves as a catalyst that enhances plant uptake of nutrients and water. Compared to other soil amendments, the high surface area and porosity of biochar enable it to adsorb or retain nutrients and water and also provide a habitat for beneficial microorganisms to flourish (Glaser et al. 2002, Lehmann and Rondon 2006, Warnock et al. 2007).

Background

“Biochar” is a relatively new term, yet it is not a new substance. Soils throughout the world contain biochar deposited through natural events, such as forest and grassland fires (Krull et al. 2008, Skjemstad et al. 2002). In fact, areas high in naturally occurring biochar, such as the North American Prairie (west of the Mississippi River and east of the Rocky Mountains), are some of the most fertile soils in the world. Historical use of biochar dates back at least 2000 years (O’Neill et al. 2009). In the Amazon Basin, evidence of extensive use of biochar can be found in the unusually fertile soils known as Terra Preta and Terra Mulata, which were created by ancient, indigenous cultures (O’Neill et al. 2009). Due to the large amounts of biochar incorporated into its soils, this region still remains highly fertile despite centuries of leaching from heavy tropical rains. In parts of Asia, notably Japan and Korea, the use of biochar in agriculture also has a long history. Recently, heightened interest in more sustainable farming systems, such as Korean Natural Farming, has revived the use of biochar in Western agriculture.

Environmental impact

Biochar can be a simple yet powerful tool to combat climate change. As organic materials decay, greenhouse gases, such as carbon dioxide and methane (which is 21 times more potent as a greenhouse gas than CO_2), are released into the atmosphere. By charring the organic material, much of the carbon becomes “fixed” into a more stable form, and when the resulting biochar is applied to soils, the carbon is effectively sequestered (Liang et al. 2008). It is estimated that use of this method to “tie up” carbon has the potential to reduce current global carbon emissions by as much as 10 percent (Woolf et al. 2010).

Production of biochar

Biochar is created by heating organic material under conditions of limited or no oxygen (Lehmann 2007). There are many ways to achieve this result. The type of organic matter (or feedstock) that is used and the conditions under which a biochar is produced greatly affect its relative quality as a soil amendment (McClellan et al. 2007, McLaughlin et al. 2009). The most important measures of biochar quality appear to be high adsorption and cation exchange capacities and low levels of mobile matter (tars, resins, and other short-lived compounds) (Glaser et al. 2002, Liang et al. 2006, McClellan et al. 2007, McLaughlin et al. 2009). Production of biochar generally releases more energy than it consumes, depending on the moisture content of the feedstock (Lehmann 2007). Heat, oil, and gas that are released can be recovered for other uses, including the production of electricity. A sustainable model of biochar production primarily uses waste biomass, such as greenwaste from municipal landscaping, forestry, or agriculture (for example, bagasse).

Frequently asked questions

Can barbeque charcoals be used as biochar?

Generally, no. Charcoal briquettes are mostly made from de-volatilized coal and contain chemicals that can be toxic to plant growth and should not be used in soils (McLaughlin et al. 2009). Lump charcoals, such as those made from kiawe (mesquite) or oak, are designed for use as cooking fuel. Analysis of several such charcoals revealed variation in quantities of undesirable tars, resins, and polycyclic aromatic hydrocarbons (PAH) and, typically, lower adsorption capacities, thus lessening their ability to improve soil quality (McClellan et al. 2007, Mclaughlin et al. 2009).

Is there scientific research showing increased plant growth with applications of biochar?

Yes. Studies in both tropical and temperate climates have demonstrated biochar’s ability to increase plant growth, reduce leaching of nutrients, increase water retention, and increase microbial activity. In a study done on a Colombian Oxisol (a soil type also found extensively in Hawai‘i), total above-ground plant biomass increased by 189 percent when biochar was applied at a rate of 23.2 tons per hectare (Major et al. 2005). Research indicates that both biological nitrogen fixation and beneficial mycorrhizal relationships in common beans (*Phaseolus vulgaris*) are enhanced by biochar applications (Rondon et al. 2007, Warnock et al. 2007). In Brazil, occurrence of native plant species increased by 63 percent in areas where biochar was applied (Major et al. 2005). Studies have also shown that the characteristics of biochar most important to plant growth can improve over time after its incorporation into soil (Cheng et al. 2006, 2008; Major et al. 2010).

Production of biochar. Top, *Melochia* species logs (3–4 inches diameter) can serve as organic matter for biochar production. Center, biochar produced by heat treatment. Bottom, close-up of biochar particles; this material’s size is called ½$^-$ (“half minus”) because it consists of ½-inch or smaller particles.

Is there scientific research indicating negative effects of biochar on plant growth?

Yes. Most cases of decreased plant growth due to biochar application can be attributed to temporary levels of pH, volatile or mobile matter (MM), and/or nutrient imbalances associated with fresh biochar (McClellan et al. 2007). Biochar often can have an initially high (alkaline) pH, which is desirable when used with acidic, degraded soils; however, if soil pH becomes too alkaline, plants may suffer nutrient deficiencies. "Mobile matter" refers to tars, resins, and other short-lived substances that remain on the biochar surface immediately after production and can inhibit plant growth (McClellan et al. 2007, McLaughlin et al. 2009). Good production practices can decrease the amount of MM in the biochar. Microbial activity can decompose and transform the carbon-rich MM into nutrients for plants; however, in the process, the microorganisms require nitrogen and other soil elements, rendering them temporarily unavailable for uptake by plants. These transitional imbalances are later corrected as MM decays, pH neutralizes, and unavailable nutrients are released.

What kind of biochar is the best?

The most important measures of biochar quality include adsorption, cation exchange capacity, mobile matter (tars, resins, and other short-lived compounds) and type of organic matter feedstock used. Over time, adsorption capacity of biochar decreases, whereas its cation exchange capacity increases (Cheng et al. 2008, McLaughlin et al. 2009). Mobile matter can block porosity and initial adsorption but is highly susceptible to biological decay, which can mitigate those effects. The physical structure of the feedstock, mainly its pore size, which greatly determines surface area, water retention, and biological utilization of the biochar produced, is essentially locked into form during "thermal modification." While a greater proportion of micro-pores may yield a higher surface area, and thus greater nutrient retention capability, many soil microorganisms are too large to utilize such small spaces and benefit from some amount of larger pore sizes (Warnock et al. 2007). In terms of increasing plant growth, biochar with various pore sizes may be best suited to enhance the physical, chemical, and biological characteristics of soils.

The process by which a biochar is produced is an important factor influencing its quality. While some methods have consistently produced low-quality biochar, other processes, when done properly, can yield high-quality biochar.

How long does biochar last?

Research on the Amazon Basin's Terra Preta soils and naturally occurring biochar from forest and grassland fires implies that biochar can persist for millennia with very little decay. Laboratory studies using the latest technology estimate that biochar has a mean residence time in soils on the order of 1300–4000 years (Cheng et al. 2008, Liang et al. 2008).

How much biochar should be applied?

The optimum application rate for biochar depends on the specific soil type and crop management. Formal scientific studies with Hawai'i's soils to answer this question have not yet been done. Informal observations of crop growth after biochar applications of between 5 and 20 percent by volume of soil have consistently yielded positive and noticeable results (see photos). Some research indicates that much lower application rates yielded positive results (Glaser et al. 2002). Biochar can also be applied incrementally and incorporated with fertilizer regimens or compost applications.

How is biochar applied to soil?

Biochar is most commonly incorporated into the soil. First, evenly spread the desired amount onto the soil, then till it in with machinery or by hand. In some cases, such as fruit orchards and other perennial crops where tilling is not an option, biochar can be (1) applied to the soil surface and, preferably, covered with other organic materials, (2) applied mixed with compost or mulch, or (3) applied as a liquid slurry if finely ground (on a large scale, this could be done with a hydromulcher). When planting trees or other potted plants, biochar can be mixed with the backfill material. Deep banding can also be been used under appropriate conditions.

Biochar as a component of compost can have synergistic benefits. Biochar can increase microbial activity and reduce nutrient losses during composting (Dias et al. 2010). In the process, the biochar becomes "charged" with nutrients, covered with microbes, and pH-balanced, and its mobile matter content is decomposed into plant nutrients.

Regardless of the application method, it is important to be cautious when handling dry biochar, which is very dusty and should not be spread in windy conditions. This

The biochar being applied in these photos weighed approximately 500 pounds per cubic yard. It should be spread evenly over the soil in a layer ¼–¾ inches thick (equivalent to 8.4–25.2 tons per acre). Hand tillage or a tractor-drawn rotavator can be used to incorporate it into the soil.

can be easily remedied by wetting the biochar before application. Respiratory protection (e.g., dust mask) should be worn when handling the dry material.

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Effect of biochar application on plant growth. Both the untreated and treated plots received fishbone meal at a rate of 5000 pounds/acre. Biochar (size ½ inch) was applied in a ½-inch layer and tilled into the treated plot prior to planting (Hilo, Hawai‘i, "canewash" soil [mixed Andisols], approximately 300 ft elevation). Above, green bean plants, 3 weeks old, untreated (left) versus biochar-treated. Below, bok choy plants, 2 weeks old, untreated (left) versus biochar-treated.

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For more information on biochar, visit the International Biochar Initiative, www.biochar-international.org.

Photo credit: All photos by Josiah Hunt.

Disclaimer: The early plant growth results illustrated in this publication were obtained in an unreplicated field demonstration trial done by the first author. Scientific studies on biochar as an amendment have not as yet been done by CTAHR soil scientists, agronomists, or microbiologists. Until further, formal experiments are done to analyze the effects of biochar application on soils and plants and assess its efficacy in increasing crop yield and quality, information provided here should not be considered as a recommendation for agricultural use of biochar by CTAHR, despite the promise that the material seems to hold as a soil amendment for sustainable agriculture.