Biochar: a new soil management tool for farmers and gardeners

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**WHAT DO PEOPLE SAY ABOUT BIOCHAR?**

"We are pleased to add the NC Farm Center for Innovation and Sustainability field trials for evaluating biochar to the emerging information pool on the benefits of biochar amendments to the soil for enhancing productivity for row crops such as soybeans, corn, cotton and winter wheat. The Center's first year of 2009-2010 analysis substantiates the promise of biochar to increase yields and plant density despite a season of agricultural droughts."

- **Richard Perritt, Executive Director, North Carolina Farm Center for Innovation and Sustainability**

"No matter what type of soil you have, biochar has the potential to improve your soil quality through improving aspects such as water holding capacity and nutrient use efficiency. Just remember that not all biochars are equal, and we have a lot more to learn about what biochar types and application rates we should use."

- **Dr. Rory Maguire, researcher at Virginia Tech**

**INTRODUCTION**

Although biochar is a new concept to most, prominent environmentalists including Dr. James Lovelock, Bill McKibben and Dr. James Hansen have all talked about the promise of biochar as an amendment to improve soil fertility and sequester carbon in soil. More and more scientific research is published each year on biochar. Overall it seems biochar could be a useful tool in farmers’ toolbox, but as of yet it is difficult to find farmers who work with biochar, proven technologies to make biochar or biochar itself available for purchase. Indeed the biochar industry is in its infancy. The objective of this bulletin is to provide you with basic information on what biochar is and what it can do in soils. Some practical considerations on obtaining and working with biochar will also be covered. We hope that with this information you will be able to decide for yourself whether biochar could be a useful tool on your farm, and whether you should start testing it.

The idea to use biochar as a soil amendment may seem recent but it actually comes from the study of very old soils in the Amazon Basin. The so-called "Terra preta de Indio", or "black soil of the Indians" was formed by indigenous peoples centuries to thousands of years ago when they accumulated charcoal and other fire residues, and also nutrient-rich waste such as animal and fish bones, in waste piles near dwellings. Over time these wastes resulted in black colored human-modified soils which are up to two meters deep, while the surrounding soils are reddish to yellowish. Until this day Terra preta soils remain much more fertile than surrounding, unmodified soils. Scientists believe that the charcoal in these soils, or biochar, is what keeps them so fertile over such long periods in an environment that rapidly leaches nutrients out of soil and where organic matter decomposes very rapidly.

The deliberate use of rice husk biochar to improve soil fertility has been documented in Japan since 1697. Rice husks are an abundant
waste in many countries. Since the 1980’s, Japanese researchers have shown that wood and bark biochar can improve crop yields and also tree growth, and biochar is currently used in Japan for these and other purposes in commercial operations. In the USA, the 1846 book *A Brief Compend of American Agriculture* by R.L. Allen mentions applying charcoal to soil for fertility management, among many other uses.

**WHAT IS BIOCHAR?**

Biochar is a kind of charcoal made from the pyrolysis of a wide range of biomass feedstocks, including crop, wood and yard wastes, and manures. These wastes are heated in a closed container, where air flow is either prevented or kept very low. The biomass heats up to the point at which pyrolysis starts (about 350°C, or 660°F). At that point, the reaction becomes exothermic, which means it starts to produce heat and no longer consumes it.

The molecules in the biomass are reorganized to form black biochar, along with gases and volatile molecules which leave the biomass. These gases and volatiles are themselves fuels, which can be burned at once to produce more heat, or they can be used to produce electricity in more complex systems.

It is also possible to condense and refine the volatile compounds from the biomass, into liquid fuels (bio-oils). In other words, making biochar always involves producing renewable energy, in the form of heat and fuels. This heat and fuel can be used to replace fossil fuels in some situations, for example to heat a building.
The properties of biochar can vary considerably, depending on what the biochar is made from and how it is made. Some biochars can have characteristics which make them a good amendment in one soil but not another, or the biochar can be plain bad. Farmers must be aware of this, and this bulletin addresses the variability in biochar materials. Biochar retains the structure of the biomass it was made from, and can be very porous with a very large surface area.

**WHY IS BIOCHAR INTERESTING?**

Biochar is interesting because it has been demonstrated to improve soil quality and crop growth, while sequestering carbon in soil and providing other environmental benefits. As such, it represents a tool for managing soil quality on the long term, while mitigating climate change. Currently, scientific research on the agricultural and environmental benefits of biochar is being published at an increasing rate.

**Agricultural benefits**

In many pot and field studies, biochar has been shown to improve crop yields when compared to appropriate controls where biochar was not applied. Biochar has resulted in very high yield improvements on very poor soils such as acidic tropical soils, in some cases multiplying yields by factors of two or more. In more fertile soils, more modest improvements in the range of tens of percent are common. In some studies, neutral or negative effects on yields were also obtained. How do we make sense of this information?

It is important to understand that biochar is not an actual fertilizer, although biochar always contains some ash and ash can supply nutrients to plants, for example calcium, potassium, and magnesium. These nutrients are often limiting in very poor soils, and the ash from biochar could explain the strong effect biochar addition can have on yields in these soils soon after application. Biochar does not contain any appreciable amounts of available nitrogen, but does contain some decomposable carbon, (termed “unstable” carbon as opposed to the “stable” fraction of carbon in biochar). Thus, if biochar is applied and insufficient nitrogen is supplied, nitrogen immobilization can occur and reduce crop yields. This also happens with compost if the C:N ratio is too high, for example.

**Key points from this section:**

- biochar is a type of charcoal that is a useful soil amendment
- biochar is made through pyrolysis which also generates energy
- not all biochars are created equal, and farmers need to be aware of this
Biochar is a soil amendment that is to be used along with appropriate sources of nutrients, like green manures, animal manures, composts and/or fertilizers. It is not a substitute for these inputs. While the ash in biochar does supply nutrients to crops, many biochars contain only small amounts of ash. Also, any nutrients in ash not used by plants in the year after application are eventually lost from the soil, sometimes rapidly, for example by leaching.

Then how does biochar improve crop yields? Yield improvements with biochar have been attributed to the following effects:

1. Rise in pH. The pH of biochar is often high (e.g. > 9), and biochar can have a liming effect. This is beneficial in soil were the pH is lower than optimal for the intended use, but not if the pH is higher than optimal.

2. Direct addition of nutrients. The ash in biochar contributes some nutrients to soil, but this is a short-term effect.

3. Retention of nutrients. Over time, biochar surfaces develop an ability to retain nutrients in soil. This is a long-term benefit of biochar and sets it apart from other forms of organic matter in soil, which also help retain nutrients but decompose relatively rapidly. Biochar remains in soil for centuries to millennia, and during the years after it is applied to soil, its ability to retain nutrients added with manure, for example, increases.

4. Potential improvement of soil physical properties. Biochar has a very low density and is highly porous. It is thought to act as a sponge in soil and retain water, potentially making it available to plants in times of drought. Biochar can also improve water infiltration at the soil’s surface, and reduce soil compaction. Again, these improvements would be effective on the long term. The effect of biochar on soil physical properties will vary with soil texture. For example, it is expected that biochar added to sandy soil could improve water retention, while it could improve aeration of clay soils.

5. Biochar may provide appropriate conditions for beneficial soil microbes, such as nitrogen-fixing Rhizobia and mycorrhizal fungi. Other soil microbes may also find shelter inside the pores of biochar particles, and thus be protected from their predators. This is also a long-term benefit of biochar.

In short, biochar has the potential to provide benefits for soil quality both on the short and long term. The long-term benefits of biochar are unique to this soil amendment, since other organic amendments decompose rapidly in the years after they are applied.

**Environmental benefits**

Studies have found that biochar stays in soil for centuries to millennia. This is because the bulk of the material is highly resistant to decomposition by microbes. During pyrolysis, the molecular structure of the biomass is rearranged, to a form that is highly stable in soil. Carbon that was in the atmosphere gets incorporated into biomass by plants, plant residues are pyrolyzed, and biochar placed in the soil. Thus biochar can be used as a tool to sequester carbon in soil in a safe way. Not only is there no chance that the carbon in biochar will suddenly “leak” back into the atmosphere, but having biochar in soil also provides benefits in terms of soil quality. Biochar can also provide other environmental benefits, including:

1. Reduce nutrient pollution in water bodies.
   Since biochar retains nutrients in the root zone, it reduces their leaching through the soil profile and into water bodies. Agriculture is an important source of nutrient pollution
in many areas, especially nitrogen and phosphorus.

2. Biochar may reduce the production of greenhouse gases by soil. Research has shown that the production of nitrous oxide and methane, two extremely potent greenhouse gases, was reduced under certain conditions when biochar had been applied to soil.

3. Biochar can reduce the bioavailability and mobility of heavy metals and pesticides in soil. This property, combined with other effects of biochar on soil quality, can make biochar a useful tool for the revegetation of contaminated or degraded soils. It can also have negative implications in some cases where farmers rely on pesticide activity in the soil.

**Key points from this section:**
- biochar will likely have a greater effect on poorer soils than it will on more fertile soils
- biochar is not an actual fertilizer
- biochar has long-term impacts on soil quality, and this sets it apart from other organic soil amendments
- there are several mechanisms by which biochar can improve soil quality, including chemical, physical and biological
- biochar sequesters carbon in soil on the long term
- biochar provides other environmental benefits, such as reduced pollution of water bodies and potentially reduced greenhouse gas emissions from soils

**HOW IS BIOCHAR MADE?**

Biochar can be made in pyrolysis units which span a wide range of scales and design complexity. In all cases, biochar makers should strive to protect their own health and that of the environment by ensuring they make biochar in a clean and safe manner. Some traditional ways of making charcoal, for example in earthen mounds, are not safe and are poorly efficient. Indeed, they produce large amounts of smoke which represents a health hazard and is an environmental pollutant, and one obtains only small amounts of biochar from the initial biomass. Here are some examples of clean pyrolysis units.

*Biochar-producing cookstove, locally made from clay in a village in Kenya. This stove burns clean and produces small amounts of biochar with each meal prepared. Finely divided crop residues can be used as a biochar feedstock. This is known as a two chamber batch process unit: a retort chamber in the stove is loaded with biomass, and it is unloaded only after pyrolysis is complete and the stove has cooled down. Photo by D. Torres.*
Mobile, continuous-flow pyrolysis unit marketed by Biochar Engineering Corp. This unit is transported and operated on a trailer. It is a continuous flow process, meaning that an auger provides feedstock into the unit and biochar flows out in a continuous fashion. This unit also produces no smoke. Photo provided by Biochar Engineering Corp.

Retort kilns made from 55 gallon drums. In operation, the drums are enclosed in a brick kiln and a small wood fire is built underneath to provide the initial heat source. The piping ensures that the gases and volatiles coming off of the biomass are burned, thus avoiding the production of smoke. This is also an example of a batch process. http://www.twinoaksforge.com/BLADSMITHING/MAKING%20CHARCOAL.htm

New England Biochar, LLC makes this batch retort kiln in both a stationary and a mobile version. It is a modified version of a design developed by Chris Adam for producing clean and efficient charcoal in Africa. Photo provided by New England Biochar, LLC.

Stationary, continuous flow pyrolysis unit built by Pacific Pyrolysis Pty Ltd. This unit produces biochar and electricity from waste biomass. It is connected to the grid, and biomass must be brought to the facility. Photo provided by Pacific Pyrolysis Pty Ltd.
Several designs are available on the internet for pyrolysis units that gardeners and small farmers could adapt for use. Whether you build your own unit or obtain one from someone else, always be aware of the important safety issues when making biochar, and comply with all applicable fire regulations. It is a good idea to work closely with others who have experience making biochar, to learn how to safely and efficiently produce it.

The actual pyrolysis process can only begin once the biomass feedstock is dry. If it is not dry, more heat will need to be supplied during the initial phase of the process, because water needs to be driven off in order for the biomass to reach the pyrolysis temperature. Since heat is produced during pyrolysis, it can potentially be used to dry the next batch of wet feedstock. Generally speaking, the biomass should have a moisture content no greater than 15% before it is submitted to pyrolysis.

**WHAT DO FARMERS NEED TO KNOW ABOUT BIOCHAR?**

**What is in biochar?**

Biochar contains ashes, stable matter, unstable matter and moisture. Ashes contain plant nutrients which can benefit plant growth in the short term. The amount of ash in biochar can vary a lot. Biochars made from animal manures generally contain large proportions of ash, compared to biochars made from plant parts. Care must be taken when working with high-ash biochars. It is possible to induce salt stress in the crop if too much is applied at once.

Stable matter in biochar remains in soil over the long term and provides nutrient retention and other benefits to soil quality. Unstable matter decomposes in the months and years after biochar is added to soil. The relative proportion of these fractions can vary in biochar, and no widely accepted tests yet exist to determine the size of these fractions.

Water is often applied to biochar to quench it after it comes out of the pyrolysis unit. If you make biochar yourself, it is a good idea to quench it with water as soon as you take it out of the pyrolysis unit, since it could spontaneously combust when it comes in contact with air. If you are purchasing biochar by weight, remember that biochar can hold up to 3 times its own weight in water, and it can contain a lot of moisture without looking like it does.

**How much biochar to apply?**

At this time there is insufficient data available to allow the determination of ideal biochar application rates in different soils and cropping systems. The fact that biochar materials themselves vary a lot, and no standard biochar classification systems exist also makes it difficult to give specific recommendations.

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**Key points from this section:**

- biochar can be made in simple or complex pyrolysis units
- biochar can be made in your backyard or on your farm
- there are personal and environmental safety issues to be aware of when making biochar
- local rules relating to fire must be followed at all times
- get help from experienced people as you learn how to make biochar
In field trials published to date, rates of 5-50 t/ha (2-22 t/ac) have given positive results. The upper end of this range may not be practical in terms of biochar sourcing and incorporation to the soil.

Applying biochar to an experimental plot on a farm in Virginia. Photo by K. Revell.

Applying biochar to an experimental plot on a farm in Virginia. Photo by K. Revell.

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Tilling biochar into the soil in Estrie, Québec. Photo by B. Husk.

Tilling biochar into the soil in Estrie, Québec. Photo by B. Husk.

How to apply it, and when?

Remember that biochar has a long-lasting effect in soil, and that beneficial effects improve over time. This means that biochar can be applied once with benefits over several years, and it is not uncommon to only start seeing benefits in the second and further years following the first one after application. Alternatively, if only small amounts of biochar are available over time, it can be applied regularly in smaller amounts. Biochar can be applied to soil by hand or using conventional machinery such as lime and manure spreaders, and should be thoroughly incorporated into the soil by tillage. Alternatively, the biochar could be applied in bands or in planting holes at transplanting.

The objective is to ensure the biochar is protected from erosion by wind and water at the surface of the soil, and that it is located in the root zone where plants are taking up nutrients.

In terms of timing, biochar can be applied whenever the soil is being tilled, in the spring or in the fall. Fall applications will allow more time for the biochar to “weather” in soil before the first crop is planted, and may be desirable.

How to obtain biochar and how much it costs

Biochar is a new product, and it can be very hard for farmers to find it in larger quantities, at an affordable price. Several businesses offer biochar for sale on the internet, but often for 1 $/lb, excluding handling and shipping. Since the market for biochar is an emergent one, prices have not yet stabilized to an actual market value.

Also, as of yet anyone can sell anything as biochar. This is why farmers and gardeners must be aware that biochar can have a range of characteristics, and can potentially have positive, neutral or negative effects in their soil. It is recommended that you obtain as much information as possible from the provider, including results of any plant growth tests they have done, and how these tests were conducted.

When working with any new biochar material you should start small, and ensure that you
build your test in a way that will allow you to draw valuable and adequate conclusions.

The International Biochar Initiative offers a technical bulletin (#101) on testing the safety of biochar before applying it to soil, a technical bulletin (#104) on testing biochar in soil, and a more complete Guide to biochar trials, for free on their website at www.biochar-international.org.

**Making biochar: some considerations**

It is outside the scope of this bulletin to give details about techniques to make biochar, but some information that biochar makers need to be aware of include the fact that while pathogens, weed seeds and pesticide residues are destroyed by pyrolysis, heavy metals are not. Thus if certain woods treated with heavy metals are pyrolyzed, the resulting biochar will not be appropriate for applying to soil. Most jurisdictions have rules pertaining to acceptable amounts of heavy metals in soil amendments.

During the pyrolysis process, part of the biomass rearranges into gases and volatile compounds. For this reason, the mass loss in biochar is usually around 50% or more, meaning that your biochar yield will be half or less by weight than the amount of feedstock you pyrolyzed.

**Working with biochar**

Biochar can be very dusty, and a dust mask should always be worn when handling it. Dustiness can also be a problem when applying and incorporating biochar to soil. Some biochar users have estimated 30% losses of fine particles during handling, transport and application of dry biochar.

Such losses can be avoided by moistening the biochar, either with water or by mixing it with compost or manures. Apart from reducing dust, compost and manure provide nutrients to the plants which biochar might not.

**Key points from this section:**

- Ideal biochar application rates are not known, but it may be a good idea to start testing rates of 2-5 t/ac.
- Biochar contains moisture, ash, stable and unstable matter and each plays a role in soil.
- Biochar can be applied by hand or using machinery, but it should be incorporated into the soil as much as possible.
- At this time it can be difficult for farmers to find biochar for purchase at an affordable price.
- Biochar can be very dusty; it should be moistened by wetting or mixing with compost or manure before handling.
- Information bulletins are available from the International Biochar Initiative for testing biochar for safety and efficacy.
GLOSSARY

C:N ratio:

Represented the carbon to nitrogen ratio of a soil amendment. This is determined by analyzing the elemental carbon and nitrogen content of a material. The ideal C:N ratio for a soil amendment is in the range of 20 or less. The higher the C:N ratio, the more likely it is that nitrogen immobilization will occur.

Limiting nutrient:

Plants require several things to grow, including mineral nutrients from soil. They ideally need each nutrient in a certain amount and these amounts can vary over time. A nutrient is said to be limiting if it is not available to plants in sufficient amounts, at any given time.

Nitrogen immobilization:

Nitrogen immobilization occurs when there is an imbalance in the soil in the amounts of carbon and nitrogen that are available for microbes to decompose. Microbes need to consume carbon and nitrogen in given proportions, dictated by the proportions of these elements inside their organisms. If they are decomposing a material that contains lots of carbon but little nitrogen, microbes will compete intensely for nitrogen in the soil. When microbes thus “immobilize” nitrogen, it is not available for plants to use. Supplying more available nitrogen alleviates this effect.

Pyrolysis:

The pyrolysis process involves heating biomass in the presence of little or no oxygen. Since oxygen is limiting, the biomass cannot burn to ashes. Once a certain temperature is reached, the biomass decomposes into gases, volatile compounds and solid biochar. Pyrolysis also produces heat.

Surface area:

Relates to the amount of exposed area a solid object has. A very porous substance has a higher surface area than a less porous one.

Weathering:

Refers to the physical and chemical alterations of rocks and soils as they are exposed to atmospheric elements.
RESOURCES

- The website of the International Biochar Initiative (www.Biochar-International.org) provides up-to-date information about the science and technology of biochar, profiles of biochar projects around the globe and the latest news about biochar. The IBI publications page has a collection of technical bulletins and Guides for farmers, gardeners and researchers that contain useful information about how to test biochar in soil, methods for applying biochar, and principles for designing and commissioning biochar pyrolysis plants.

- The website of the United States Biochar Initiative (www.biochar-us.org) provides US-specific information about biochar.

- Several books on biochar intended for the general public, gardeners and farmers were recently published:


  *The Biochar Debate: Charcoal’s Potential to Reverse Climate Change and Build Soil Fertility* (The Schumacher Briefings) (2010) by James Bruges, Chelsea Green Publishing (available on Amazon.com)

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