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Prospects for Biochar Use in Missouri

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Use of Biochar in Sustainable Food Production and Effects on Missouri Soils

by
Dr. M. R. Bayan
Principal Investigator of Research
Soil and Environmental Sciences
PhD in Agronomy: Soil Fertility/Chemistry
PhD in Geology: Coal Petrology/Mineralogy

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Overview

In recent years, the sustainable use of natural resources to produce food, feed, and fiber has received more attention (Committee on Twenty-first Century Systems Agriculture 2010; Brklacich et al., 1995). Biochar has been reported to improve soil quality by positively impacting its physical, chemical, and biological properties (Lehmann and Joseph 2009). Productive farms are normally highly integrated, and a holistic approach is used in their management (Altieri, 2004). It is within this holistic approach to sustainable food production that a biochar system can have a significant impact. This article describes and discusses aspects of proper production of biochar through slow pyrolysis. (Slow pyrolysis involves the heating of plant material in an oxygen-deprived environment.)

What is biochar?

Biochar is one of the oldest soil amendments. A soil amendment is a product that improves soil quality and fertility when it is properly applied. Biochar is a type of charcoal that is produced in a special way. It is made by heating air-dried plant material (biomass) in a setting without oxygen. The production process greatly affects how long the biochar remains in the soil; it also plays a large part in how effective the biochar is as a soil conditioner. Normally, a biochar that is made with the highest treatment temperature (HTT) above 750°F (400°C) is better than a char that is produced at a lower HTT (Downie et al., 2009; Bayan et al., 2014a). The charcoal produced at a higher thermal value has more total pore space; it is also safer to use than a charcoal produced below 570°F (300°C). When used correctly, biochar can improve soil quality and promote plant growth. This results in better yield. Biochar can store moisture and nutrients in the soil. Properly produced biochar provides a good environment for essential microorganisms (organisms that cannot be seen without using a microscope) to grow. These microorganisms play a major role in nutrient cycling within the soil environment. Nutrient cycling is a natural process by which nutrients in inorganic and organic material are used and recycled to produce living things.

Biochars are not the same. They can be roughly grouped based on two aspects. The first is the biomass that was used to make them. Biomass feedstock refers to plant material (either woody, such as trees, or herbaceous, such as grasses). Feedstock is the biological and renewable material that is used directly as a fuel or can be converted to another form as a fuel or energy product. The second is the way they are produced. This includes HTT, rate of heating, and exposure time to HTT. When used properly, biochar can enhance soil quality by improving its chemical, physical, and biological properties. Well-made biochar that is applied to a soil in need of amendment can reduce the use of agrochemicals in food production.

A charcoal created through a torrefaction process (explained later) is simply a char; it is not a biochar. A char that has not been properly made through the pyrolysis process might not be safe to use as a soil amendment.

To understand the potential of biochar use in agriculture and industry, a brief review of carbon in the environment is needed.

Carbon in the environment

Humans have known about the chemical element carbon for over five millennia. It is the key element of all living cells. It occurs in all parts of the environment: rocks, water, and air. In rocks, it mostly exists in the form of calcium carbonate, a major component of limestone. In fresh water, it exists as a carbonate ion (a charged atom or molecule). In air, it occurs as carbon dioxide (CO_2). Through a process called photosynthesis, plants produce food, feed, and fiber. To do so, they use the Sun's energy, carbon dioxide from the air and water, and nutrients, mainly from the soil. During Earth's history, much carbon dioxide was removed from the air (for example, during the Carboniferous period). The Carboniferous period lasted for 60 million years, ending about 300 million years ago. Coal deposits were created by the burial of plants through geologic processes. However, coal is not biochar; its properties also differ greatly from those of biochar.

It is important to realize that the carbon dioxide level in the atmosphere has varied over time. Recently, it has been increasing. Most climate scientists believe that human activities are the cause of much of the increase in atmospheric CO_2.

The carbon content of biomass versus the carbon content of biochar

The amount of carbon in dried biomass varies from 45 to 50 percent (Schlesinger 1991). Biochar has a higher carbon content than the carbon content of the biomass from which it is made. A biochar that is produced at 750°F (400°C) and higher always has more carbon than a char that is made at lower HTT values (Bayan 2014a). Biochars with more carbon are of higher quality. They are also more recalcitrant (resistant to decomposition) in the soil environment. This makes them better soil amendments. However, it is the ratio of hydrogen (H) to carbon (C) (number of hydrogen molecules divided by number of carbon molecules) in biochar that is used to classify the quality (Krull et al., 2009). Also, when produced by similar pyrolysis processes, one way that biochars differ is based on the feedstock used. Normally, biochar from herbaceous (non-woody plants) feedstock (e.g., switchgrass and giant miscanthus) has a higher hydrogen-to-carbon ratio than the ligneous (woody) biochars. There are a few exceptions. The H:C ratio of some biochars produced from woody plants, such as willow trees, comes fairly close to those of the herbaceous biochars that are produced under the same thermal conditions (Bayan 2014a). But, if a biochar is free of contaminant, then higher carbon means a higher quality biochar.

Are all biochars the same?

All biochars are not the same. Biochar quality is affected by the following factors:
1. The biomass precursor (feedstock) from which the biochar is produced.
2. The pyrolysis conditions under which the biochar is produced. The process consists of the following: (a) the rate of heating, (b) the highest thermal treatment (HTT) in the chamber, and (c) how long the biomass is allowed to stay in the pyrolyzer (where pyrolysis occurs) at the chosen HTT.
3. Any handling that is done after production, such as exposing the biochar to water, residues from other processes, etc.

All biochars should be tested before they are incorporated into topsoil. This should be done by an impartial certified laboratory. Be sure that the lab specializes in testing products such as black carbon. If there is no regulation about biochar and its safe use, have vendors provide a legitimate certificate issued for their biochars from the International Biochar Initiative (IBI). The IBI is a nonprofit group that distributes information about biochar; it can be found at www.biochar-international.org. The emerging biochar industry usually has no issues getting a certificate from the IBI. This ensures the safety of their product, and it improves the quality and effectiveness of biochar for agricultural use.

If biochar is not properly made it can pollute soils with compounds such as PAHs (polycyclic aromatic hydrocarbons; see below), dioxins (toxic heterocyclic hydrocarbons), furans (cyclic flammable liquid compounds), heavy metals (metals or metalloids that present environmental problems), etc. The test should clearly show the level of the PAHs that are listed in the next section. It should also list the metal element contents. This would include the levels of arsenic, cadmium, lead, chromium, manganese, mercury, nickel, vanadium, etc. There might be other sources of pollution. It would depend on the precursor biomass that was used to make the biochar. It is important to use pure lignocellulosic biomass, without plastic or rubber contaminants. Lignocellulosic refers to substances that make up the main part of the cell walls of plants, composed of cellulose linked to lignin; lignin is found in and between plant cell walls. This will result in a biochar that should be safe when produced through slow pyrolysis. However, when biochar is co-produced with other products, they might introduce harmful levels of contaminants into the final product. A safe method for producing your own biochar is presented later in this report.

Potential contaminants of biochar (PAHs, dioxins, and furans)

Polycyclic aromatic hydrocarbons are also known as PAHs. They are a group of chemicals that form whenever an organic carbon source (e.g., lignocellulosic biomass) is exposed to heat in an oxygen-depleted environment. This type of biomass includes trees, shrubs, grasses, manure, etc. PAHs are hazardous chemicals (United States Environmental Protection Agency 2008). They are carcinogenic (cancer causing) and normally perservere in the soil environment. Charcoals that are produced through torrefaction (explained later on) might enhance soil fertility and promote plant growth; however, they can reduce the soil quality due to their PAH content (Bayan 2014). There are federal regulations to protect people from the possible health effects of eating, drinking, or breathing PAHs (Agency for Toxic Substances and Disease Registry [ATSDR] 1995). In a recent study (publication forthcoming), Bayan et al. found that the PAH content in charcoal produced from biomass feedstocks grown in Central Missouri increased as the production temperature fell below the lower limit of the slow pyrolysis process (750°F or 400°C). Table 1 shows the result of the PAH analysis. The PAH content refers to the sum of the following PAHs: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo (a) anthracene, chrysene, benzo (b) fluoranthene, benzo (k) fluoranthene, benzo (a) pyrene, indeno (1, 2, 3, c, d) pyrene, dibenz (a, h) anthracene, and benzo (g, h, i) perylene.

Table 1. PAH content of charcoal produced from three biomass feedstocks through torrefaction and slow pyrolysis

Biomass	Torrefaction 215-300°C mg/kg	Slow Pyrolysis 400-600°C mg/kg	Torrefaction divided by Slow Pyrolysis
Corn Stover	18	0.41	18/0.41 = 44
Switchgrass	3.5	0.19	3.5/0.19 = 18.4
Willow	6.4	0.96	6.4/0.96 = 6.7

The charcoal created by the torrefaction of corn stover included 44 times more PAHs (18 mg/kg) than the biochar produced through slow pyrolysis from the same biomass between 750° and 1110°F (400° and 600°C) (0.41 mg/kg) (the value for torrefaction divided by the value for slow pyrolysis). According to ATSDR (1995), "PAHs are present in tobacco smoke, smoke from wood fires, creosote-treated wood products, cereals, grains, flour, bread, vegetables, fruits, meat, processed or pickled food, and contaminated cow's milk or human breast milk. Food grown in contaminated soil or air may also contain PAHs. Cooking meat, or other food, at high temperatures, which happens during grilling or charring, increases the amount of PAHs in the food." The combustion of fossil fuels also produces these chemicals. Furans and dioxins may also form during biochar production especially when biomass contains chlorine or torrefaction and pyrolysis is not used to produce char.

For more information, please refer to: www.biochar-international.org/sites/default/files/IBI_White_Paper-Implications_of_Potential_%20Dioxin_in_Biochar.pdf.

How does biochar work in the soil environment?

During the past few years, there has been a focus on biochar in many scientific studies. The latest research shows that all biochars produced through slow pyrolysis have some nutrients essential for plant growth right after their production. Herbaceous biochars typically include more nitrogen than ligneous biochars. Plants, however, need more nitrogen than biochar can provide to grow optimally (Bayan 2014a, 2014b). Therefore, biochar is not considered a fertilizer.

All biochars contain some mineral matter (ash). All biochars that were produced through slow pyrolysis from the biomass available in Missouri have an alkaline pH (Bayan 2014a, 2014b). The neutralizing ability of biochar can increase nutrient availability in the soil environment close to plant roots (rhizosphere).

All biochars have a higher specific surface area (SSA) than their biomass precursors. The specific surface area is a property of solids in which the total surface area is divided by the mass or volume. This value is used to determine the type and properties of a material, such as soil.

The pores in biochar retain water and nutrients; they also provide the best place for beneficial microorganisms to grow. This is especially true when biochar contacts growing roots. The pore volume of biochar is affected by the way it is produced (Bayan et al., 2014a).

All biochars have surface charges (electrical) at lower pH values. These make biochars capable of retaining certain nutrients, such as potassium, calcium, magnesium, etc. (Bayan et al., 2014). All biochars can retain water in their cavities. This helps plants cope with drought (Joseph et al., 2009).

If used properly, biochars do not denature soil enzymes nor reduce their activity in the long run. Therefore, biochars do not harm nutrient cycling in the soil environment (Bayan 2013b).

Biochars can retain some nutrients. This prevents the nutrients from being lost to moving water or to the air in the soil environment. This could reduce the amount of fertilizer needed to achieve maximum yield.

Preparation for application

Biochar should be crushed to pass through a sieve of about 3/8 in. (1 cm) before applying it to soil (fig. 1). Before application to soil, the length of a herbaceous biochar piece can average about 3/8 in.

Figure 1. Biochar should be crushed before it is mixed with soil.

How to apply biochar to soil

Biochar should be mixed with the top 6-8 in. (15-20 cm) of soil. To maximize its amending effects, biochar should not be broadcast over the soil; it should be tilled or disked into the soil (fig. 2).

Before biochar application. **Sixty days after biochar application.**

Figure 2. Biochar should be mixed with the soil. It improves soil structure by promoting aggregate formation.

Effect of biochar on plant growth

When applied properly to the soil, biochar promotes plant growth and increases yield (Bayan, 2013a, 2014; Vaccari et al., 2011) (figs. 3 and 4). To be successful, crop production using biochar requires a good understanding of both soil and biochar. Other factors involved in plant growth must also be taken into account. Otherwise, biochar can reduce plant growth and decrease yield. For example, if biochar is used at higher rates than required, it could impair plant growth. If biochar is applied to a soil with a high pH and electrical conductivity (the ability to transmit an electric current), the biochar might reduce yield if water is limited. Hence, the positive effects of biochar can only be reaped when the farmer develops proper soil and crop management practices. These practices are based on an understanding of biochars, soils, and the needs of agronomic crops.

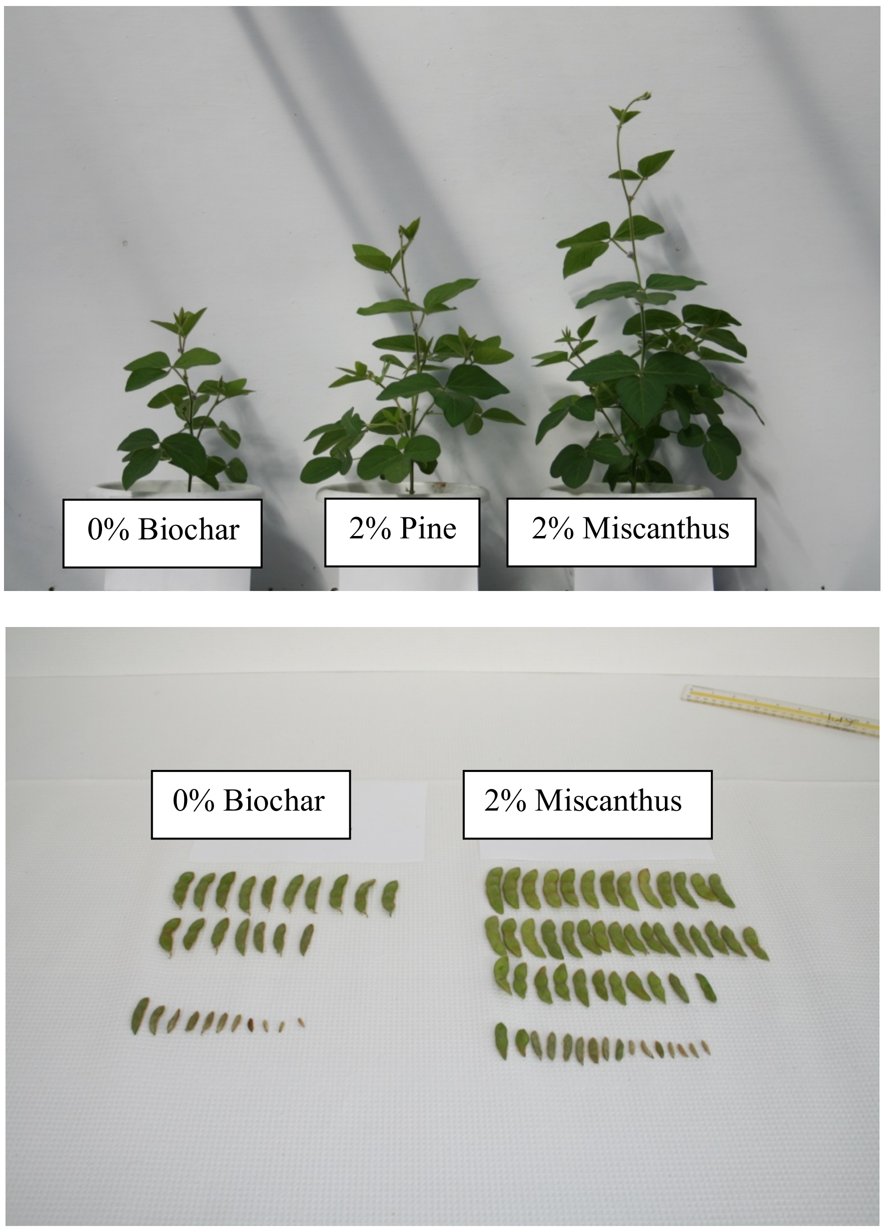

Figure 3. Soybean growth and yield increased significantly after a 2% application of giant miscanthus biochar in this greenhouse experiment (Bayan 2013a).

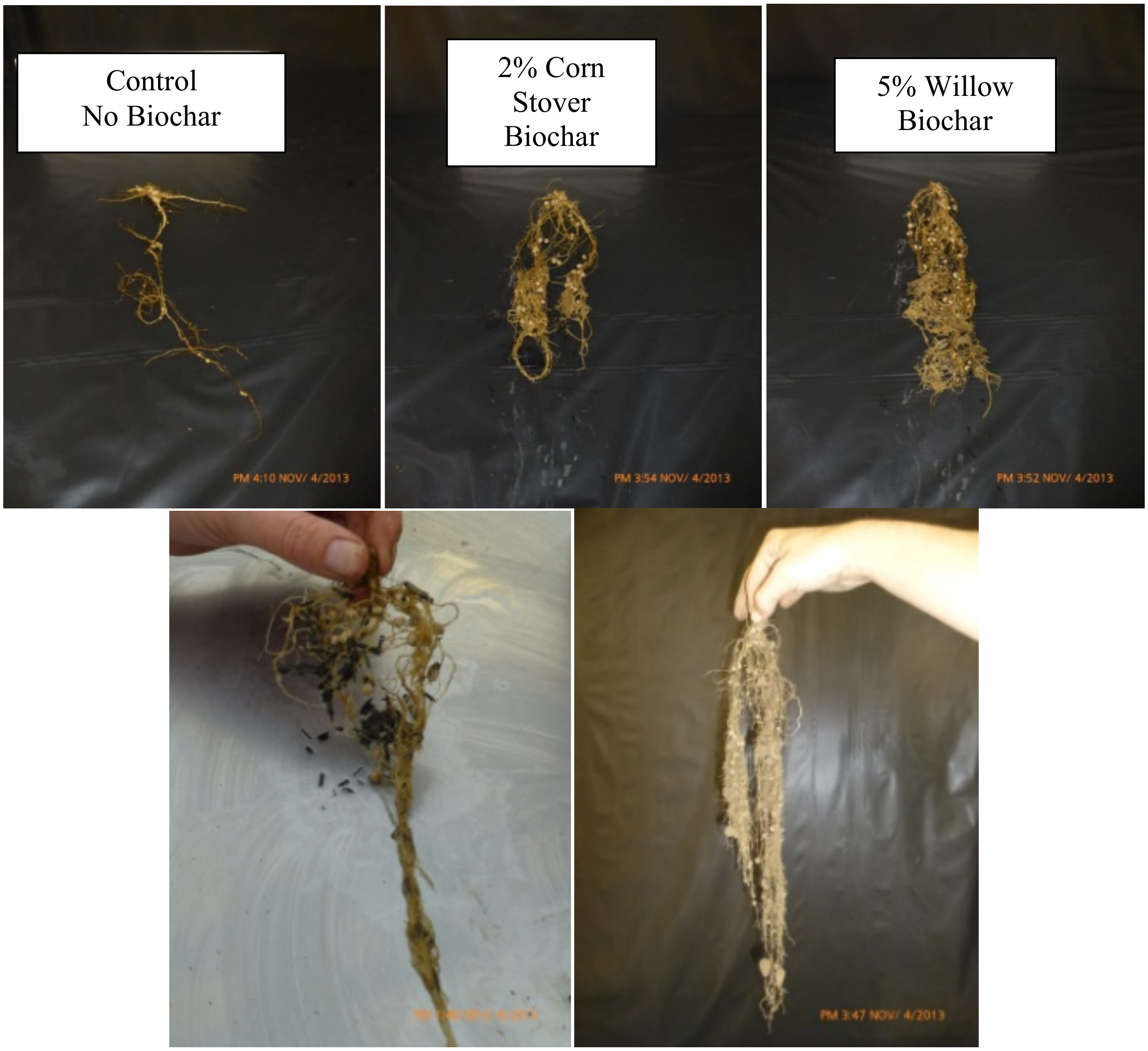

Figure 4. Applying biochar to soil improved root growth and nodulation, the process of forming nodules that contain symbiotic (mutually beneficial) nitrogen fixing bacteria, in this soybean plant. The roots grew toward and surrounded the biochar pieces to absorb water and nutrients (Bayan 2013a).

Application rate

Biochar is a soil amendment. It works well when the soil needs enrichment. When biochar is applied to a high quality soil, its benefits might not be obvious. The ideal rate of biochar for the soils in Central Missouri is from 2% to 4% by weight. Using 2% biochar, the application rate to a depth of 6 in. (15 cm) on a soil with a bulk density of 1.3 g/cm^3 is 17.4 short tons per acre. At this rate, 800 lbs. of biochar is needed for every 1000 square feet of land. There is no need to apply biochar to a Mollisol (soil that is high in organic matter content and base cations—ions with a positive charge). Note that application rates of less than 2% should not lower the yield if biochar is applied to a Mollisol. Vertisols are another order of soils that exist in a few Missouri counties (Mississippi, New Madrid, Pemiscot, and parts of Scott and Stoddard). Due to a high pH and base saturation in Vertisols, applying biochar might initially increase the osmotic pressure (which shows how easily a solution takes in water) in the rhizosphere (a small band of soil affected by root secretions). This would cause plasmolysis (where cells lose water) in meristematic (undifferentiated plant cells; the ones that grow) plant cells. To offset this, the biochar could be rinsed thoroughly before it is applied to Vertisols. Biochar lowers soil bulk density. It improves hydraulic conductivity (how easily water moves through fractures and/or pores). As such, it enhances the quality of soils with a claypan. A claypan is a layer with more clay than the layer above it; the soil is compact and impervious to water.

The following soils in Missouri will benefit from biochar use: most Entisols (soils that are young or recently formed); Inceptisols (more weathered soils than Entisols with some degree of horizon formation—this means that the soil layer differs from what is above and below); Alfisols (more developed soils than Entisols and Inceptisols that form under deciduous trees; these soils have been cultivated in many parts of Missouri); and Ultisols (more highly weathered, older soils, more acidic than Alfisols). For a description of these soil orders, refer to the Cooperative Soil Survey at http://soils.missouri.edu/tutorial/page4.asp.

Spot application of biochar

Before transplanting or seeding, biochar can be applied to an area of soil that is 4 square feet in size. Use a spade or shovel to remove the soil from this area to a depth of 6 to 8 in.(15-20 cm); transfer the soil to a wheelbarrow. Thoroughly mix 3.5 lbs. (1.6 kg) biochar with the soil in the wheelbarrow. Then backfill the pit with the soil mixture from the wheelbarrow (fig. 5).

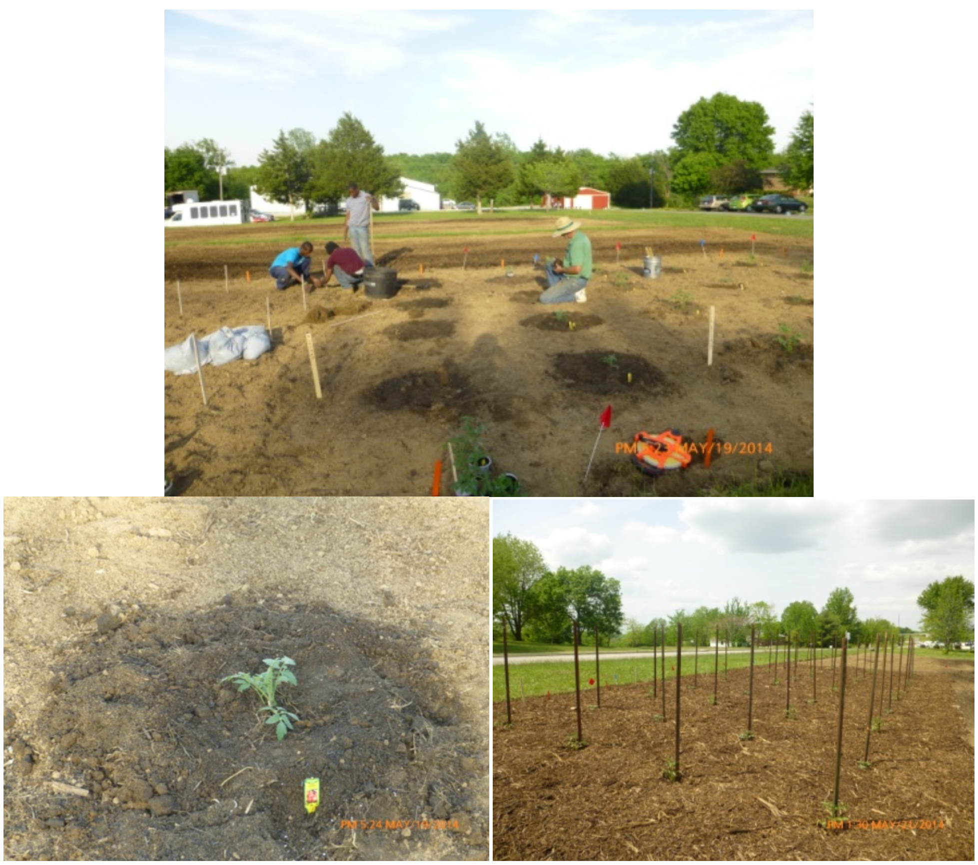

Figure 5. Spot application of biochar before and after tomato transplantation and mulching.

Effect of biochar on water retention by soil

Biochar will retain water in its pores. Before it can do so, it must be soaked with water for some time. When applied to the soil, dry biochar is hydrophobic (it repels water). However, after about a month, its pores become full of water. This creates a temporary water reservoir that plants can use during a drought.

Using soybeans as a test plant in a greenhouse experiment at Lincoln University in Missouri, the 5% application rate of biochar greatly reduced water use when compared to the control. The herbaceous biochars stored more water than the ligneous biochars. At the 2% application rate, however, the water-holding capacity was not significantly different from the control. When biochar is used to offset the negative effects of drought on plant growth, biochar should be applied at its maximum recommended rate. That rate is 4% by weight for soils in Missouri, except for Mollisols and Vertisols.

Can biochar be activated?

Using additives or extra chemical treatments, biochar can be altered after it is produced. Biochar can also be created to address special needs: agricultural, industrial, or environmental. It can be mixed with organic amendments. This is mainly helpful in organic farming and when growing vegetables. For this purpose, biochar can be mixed with compost or manure. Good results have been found for tomato plants using the following compost and biochar mixture rates: mix 3 quarts (about 3 L) of good quality compost with 3.5 lbs. (1.6 kg) of crushed biochar. In a wheelbarrow, add this compost/biochar mixture to soil that was removed from a 4-$ft.^2$ area (to a depth of 6 in.). Backfill the pit created by removing the soil; plant seedlings at the center of the area. Cover the soil with mulch; water as needed. This mixture should work with other vegetable crops. Do not use biochar near acid-loving plants unless it is thoroughly washed to remove alkalinity.

The relationship of biochar to bioenergy production

The process of pyrolysis that produces biochar also produces bioenergy (energy from biological sources, such as plants or animal waste). This bioenergy comes in two forms. One is biogas, a mixture of gases created in an oxygen-deprived environment after breakdown of organic matter. The other is a liquid that resembles crude oil. The non-condensable gases that are produced through pyrolysis are carbon monoxide, methane, ethane, hydrogen, etc. Fast pyrolysis of biomass makes less biochar than slow pyrolysis. Thus, the pyrolysis process can be fine-tuned to produce different proportions of byproducts: solids (biochar), gases (biogas), and liquids (tarry substances). Slow pyrolysis produces more biochar but less biogas or liquids.

Types of pyrolysis

Pyrolysis involves the thermal decomposition of biomass in a setting that lacks oxygen. There are three products of this decomposition: (1) gas; (2) condensable vapors—the source of bio-oil, a synthetic oil that differs from petroleum but might be a substitute for petroleum; and (3) biochar. In a similar process, torrefaction, charcoal is produced in some areas of the world, such as in Central Asia, the Caucasus, and the Middle East. Note that torrefaction is not the same as pyrolysis. There are two major types of pyrolysis: (1) slow pyrolysis, and (2) fast pyrolysis. Torrefaction is excluded from this list. However, some refer to torrefaction as "mild pyrolysis" (Shankar Tumuluru et al., 2011).

What is torrefaction?

Torrefaction is the slow heating of biomass, at less than 120°F per min. or <50°C min^{-1}. It occurs in an oxygen-deprived environment between 400° and 570°F (200°-300°C), not exceeding 570°F. This process creates charcoal that resembles biochar. It has many of the properties of biochar; however, it lacks the potency of biochar. It might also contain pollutants. These might be PAHs, furans, and dioxins. Charcoal that is produced through torrefaction helps plant growth and has positive effects on soil. However, there is the risk that it might contain pollutants. Also, charcoal is not as recalcitrant as biochar because it has a shorter half-life (the time for half of a substance to decay or be eliminated) in the soil environment. Its chemical and physical properties are also not as good as the biochar made through pyrolysis. The product created by the torrefaction of woody (ligneous) biomass that is made in Central Asia, the Caucasus, and the Middle East is called charcoal. It is mainly used for heating and cooking. This char should not be confused with biochar. For more information about torrefaction, see Shankar Tumuluru et al. (2011).

What is slow pyrolysis?

During pyrolysis, biomass feedstock is heated in an oxygen-deprived environment between 750°F (400°C) and 1110°F (600°C). This thermal range should result in clean and more effective biochar if the biomass is dry. As mentioned before, the quality of biochar is also affected by other factors such as the biomass feedstock, the rate of heating (how fast the temperature rises to the HTT), and how long the biomass stays at the highest treatment temperature.

Facts about slow pyrolysis:

- It has been used for thousands of years and is still used worldwide.
- Feedstock is air-dried and chopped or shredded into smaller pieces before pyrolysis.
- Normally, cedar or a small part of the load is combusted for the initial heat input.
- The biomass is exposed to heat over a long period of time; it is also exposed to the highest thermal treatment (HTT) for a longer time (e.g., for over 30 minutes and up to several hours).
- The rate of heating (how fast the temperature increases) is slow; the entire process can take six hours or longer.
- The biomass is exposed to heat ranging from 750°-1110°F (400°-600°C).
- More biochar is produced with this method than by other processes; in the experiments conducted at Lincoln University, the biochar generated through slow pyrolysis amounted to 25 to 31 percent of the original air-dried weight of the biomass.

Facts about fast pyrolysis:

- The biomass is exposed to an HTT of about 900°F (about 500°C or higher) for seconds.
- The rate of heating is fast; the entire process takes minutes to complete.
- The biomass must be dried (less than 10% moisture) and reduced in size to 1/16-1/8 in. (1.5-3 mm) before pyrolysis.
- Compared to slow pyrolysis, less biochar is made (about 12 percent of the original weight of the biomass).
- 60 to 75 percent of the biomass weight is converted into oil.

How to build a double-barrel slow pyrolyzer

The following is an improvement upon the double-barrel designs found on the Internet. Here is a list of materials needed:

1. An 85-gallon outer steel drum, cam lock closure included ($209 each*); about 321 L, 23.5 in. (59 cm) in diameter with lid. Cut out a 4-in. (10.2-cm) circular portion of the lid.
2. A 30-gallon inner steel drum, cam lock closure included ($138 each*); about 114 L, 19.25 in. (49 cm) in diameter (fig. 6).
3. A galvanized gas vent, 4 in. x 18 in. (10.2 cm x 46 cm) ($10*).
4. A galvanized hood connector ($7.70*).
5. Trim coil, 24 in. x 50 ft. ($97 per roll*). Use one-quarter roll per unit.
6. HomeSaver FlexWrap™ insulation. 1 in. x 24 in. x 50 ft. at $187 per roll*; use one-half roll per unit.

(*approximate cost at the time of this publication)

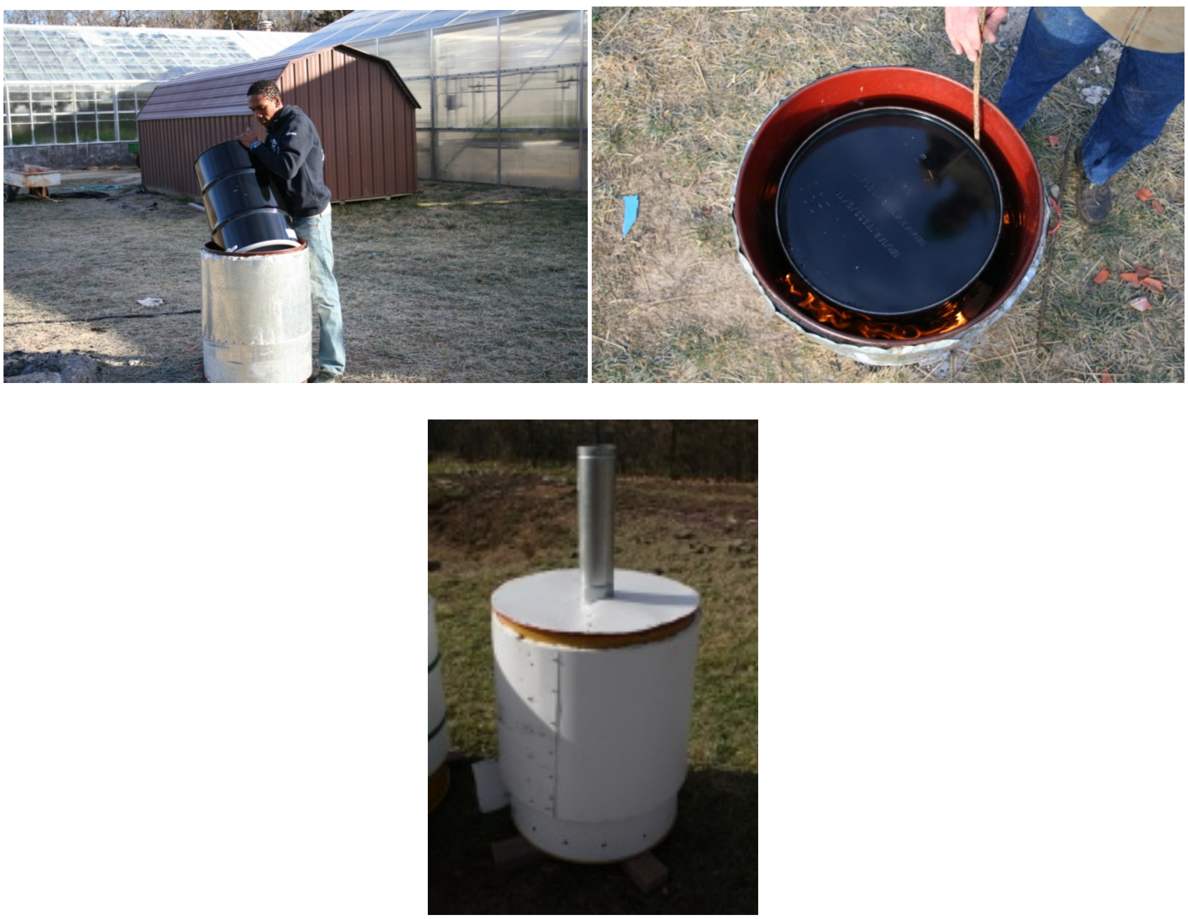

Figure 6. The inner drum fits inside the outer barrel leaving enough space for the initial woody fuel.

For easier handling, the height of the 85-gallon drum can be cut from 38.5 in. (98 cm) to 31.5 in. (80 cm). Air intake holes 9/16 in. (1.4 cm) in diameter should be drilled 4 in. (10.2 cm) from the bottom of the outer barrel on a line every 6 in. (15 cm). Note that 9/16-in. holes (to outgas the biomass) should be drilled on the lid of the 30-gallon drum. These holes will release the gases from the biomass to enter the larger drum to burn up. This sustains the pyrolysis process until it is finished. Also note that the small drum positioned with its lid facing down in the larger barrel.

The 30-gallon barrel is filled with air-dried chopped or shredded biomass. It is then inverted inside the 85-gallon barrel and centered. The space between the smaller barrel and the larger barrel is filled with dry wood (preferably cedar) and ignited. The lid is positioned and secured on the top of the larger barrel. The stack is then placed on the top, covering the circular hole.

This pyrolyzer will produce about 18 to 24 lbs. (8-11 kg) of biochar from 60 lbs. (27 kg) of dry wood. The design includes an optional thermocouple equipped with a type K probe. There is also a 1-in. (2.5-cm) thick fiberglass blanket wrapped and secured by sheet metal (aluminum) to insulate the outer surface of the larger drum.

A cyclone effect pulls the air through the lower holes into the flue on the larger barrel. This results in clean combustion, producing heat > 750°F (400°C). The heat pyrolyzes the biomass in the inner barrel. The combustible gases that escape from the biomass will also burn cleanly; they sustain the temperature between 750°-1110°F (400°-600°C). The process is complete in a few hours.

Other uses of biochar

Scientists and engineers are finding new uses for biochar. For example, biochar is being used in the poultry industry to control disease and odor. It is being used in livestock farming as a feed supplement. In metalworking, it is a reducing agent. Biochar is being used to clean water and to absorb odor. It is used in batteries and as a building material. A Swiss biochar scientist, Hans-Peter Schmidt, has found “55 uses for biochar and counting” (2008).

The economic relevancy of the biochar system

What is a biochar system?
A biochar system is a plan for using biochar in agriculture and industry. One goal is cost-effective production. Another is to promote the sustainable use of resources while preserving the environment (Lehmann and Joseph 2009).

Can a biochar system contribute to economic growth?
The biochar system can lead to economic growth. This can occur if biochar is produced sustainably as a co-product of the bioenergy being made from the biomass. Biochar production should be seen as one part of a larger design: biochar is one of its products but not the sole product. As biochar is used more in agriculture and industry, its value will grow. The biochar industry will succeed when biochar systems are custom tailored for a region. This is based on that area’s specific needs. It is also essential that biochar be produced sustainably as a carbon negative practice (see below).

What is a carbon negative practice?
An example of a carbon negative act is when biomass (e.g., in the swamps) was buried due to cataclysmic events in Earth’s history. The carbon from the atmosphere was sequestered (contained) through photosynthesis. In so doing, a key component of biomass was buried in the earth. Although biochar properties are completely different from those of coal, when biochar is mixed with the topsoil (0-6 in.; 0-15 cm), the carbon is effectively

removed from the atmosphere. It is buried in the soil, helping plants grow better. The biochar can remain in the soil for hundreds of years. Carbon negative processes are beneficial for the planet.

What is a carbon positive practice?
A carbon positive practice occurs when carbon that had been permanently removed from the atmosphere and buried in the earth is combusted. An example is the combustion of coal and hydrocarbons. This creates greenhouse gases and is harmful.

What is a carbon neutral practice?
When a tree dies or parts of it die, the fallen parts disintegrate, decompose, and over time, change into carbon dioxide. This gas is returned to the environment. In other words, the carbon that was temporarily removed from the atmosphere by photosynthesis is quickly returned to the atmosphere. Hence, there is no net change in atmospheric carbon. This is a carbon neutral process. Burning wood in a fireplace is a carbon neutral practice. When biochar is made in a double-barrel pyrolyzer as explained above, a minimal amount of biomass is combusted to start the pyrolysis process. The combusted biomass is carbon neutral. However, the resulting biochar, if mixed with the soil, constitutes a carbon negative practice. A biochar system normally includes all of these processes, but the net result is carbon negative.

Acknowledgements

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