SCSC-PU-262
January 2024

BIOCHAR FOR SOIL IMPROVEMENT:
Everything you need to know and more

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What is biochar?

Biochar is a solid, carbon-rich material created from the decomposition of plant or other organic matter under conditions of high heat and low or no oxygen. It is charred matter of biological origin, hence the name biochar.

When plant matter (think wood in a fireplace) is burned in the presence of oxygen, combustion happens. Most of the carbon contained in the material combines with oxygen to form mostly carbon dioxide (CO_2) and some carbon monoxide (CO). A small amount of ash may remain. Ash from combustion is about 6 to 10 percent of the starting mass of wood and is made up of a small amount of carbon and many other minerals from the wood that do not turn into gas. Potassium is a major component of ash.

Combustion requires oxygen. However, when oxygen is limited during thermal decomposition, pyrolysis occurs. The absence of oxygen means that CO_2 and CO do not form, and carbon is instead condensed into more stable molecular structures. The remaining biochar can be 30 to 40 percent of the mass of the original material (feedstock). Biochar is so stable that it may last almost 10,000 years in soil before it decomposes.

Long-term stability is one of the most important properties of biochar. In general, the stability of carbon compounds varies widely (Fig. 1). Sugars may last only minutes in the soil environment. Crop residues and grasses may last months to a few years. Even humic acid, a famously stable form of soil carbon, is short-lived compared with biochar.

Biochar also has a lower density compared with its feedstock. This is an important property to consider when using biochar as a soil amendment.

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Most biochars will be less dense than 0.5 grams per centimeter cubed (g/cm^3). Water is very close to 1 g/cm^3. The bulk density of a soil is typically between 1.2 and 1.6 g/cm^3. This means that biochars will float in water and can be easily removed from soil surfaces by wind. Wood-based biochars are around 18 percent less dense than the wood from which they were created (Byrne & Nagel, 1997; Fig. 2). Biochars created from lower-density feedstocks, such as manures or crop residues, are even less dense.

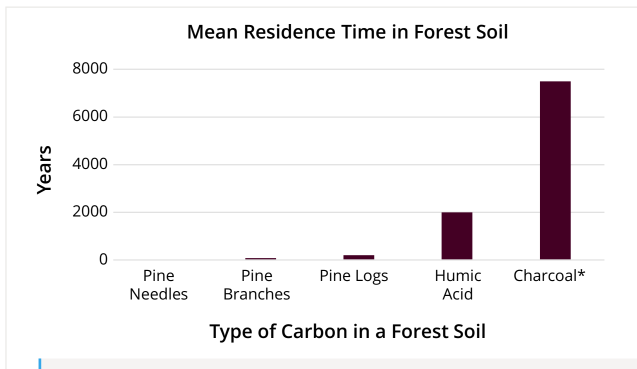

Figure 1. The length of time a plant material takes to decompose in forest soils. *Charcoal and biochar are very similar, but because of intended application as a fuel, charcoal is produced from only wood and under more narrow conditions. *Modified from DeLuca and Aplet (2008).*

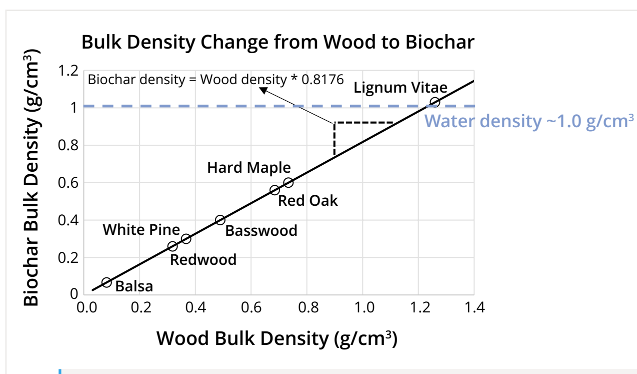

Figure 2. Bulk density of some biochars created from various wood feedstocks. Low densities lead to buoyancy in water and can be easily displaced by a light breeze or a little rain. *Modified from Byrne and Nagel (1997).*

Biochar is not new

Pyrolysis is a very old technology used to create what most of us recognize as charcoal. Ancient humans harnessed this approach to concentrate energy as much as 30,000 years ago. Anthropologists explain that the necessity to create and use charcoal arose from a number of factors. These include scarcity of wood and other fuels and the amount of work required to gather and transport fuel. Charcoal represented an important technological advance for early humans. It burned hotter and longer, was lighter to transport than raw wood, and could be stored for long periods.

Terra Preta and the recent revival of interest in biochar as a soil amendment

In the early 1960s, a Dutch soil scientist surveyed the soils of the Amazon Forest and noted that certain soils with characteristic black colorings in the upper horizon were much more fertile than surrounding soils without. Over the next few decades, Wim Sombroek visited and studied various sites in the Amazon Forest with these soils that came to be called Terra Preta. He explained that the dark deposits were the result of organic matter from charred materials (biochar). These deposits were associated with habitation areas, with the intent to improve soils and the reliability of food production for the people who lived there.

Because of this discovery, a number of researchers and entrepreneurs have promoted the production and benefits of biochar for the purpose of improving soil function and plant growth. *Everything old is new again.*

How can biochars improve soil and plant growth?

If you don't know what's in it, don't use it. The first thing you should know before using biochar is its composition. There is a wide range of properties that will influence its usefulness for soil and plant growth. Biochar chemical and physical properties are a function of both the feedstock properties and production process (i.e., temperature and duration). Some biochars are hydrophobic and repel water if created at very high temperatures (>1100°F). This hydrophobic property will interfere with the soil or potting media's water holding capacity and may very likely harm plants. Nutrients and/or toxic metals may become concentrated in ways that can damage or kill plants. Generally, temperatures of 350 to 900°F with durations of 30 to 90 minutes result in biochars that are useful for soil and plant growth. Only purchase biochars with total elemental analyses to ensure that high metal concentrations or excessively acidic or alkaline pH will not be a problem.

Biochars can provide many benefits to soils and plants. There is a body of science to support this idea. Biochars can supply nutrients, improve water holding capacity (most benefit is seen in sandy soils), supply carbon to feed and protect microorganisms, and stimulate root growth. Because of this, biochars with the right properties can provide visible benefits to plant growth.

The following are some of the more ideal properties to look for in a biochar

- **Particle size:** Small particle size provides greater surface area for reaction with plant-available water in soils and pots, while larger particles will have internal volumes unavailable for reaction.
- **Macronutrient content** (i.e., nitrogen, phosphorus, potassium, sulfur, magnesium, and calcium): If any of these are low or absent, additional fertilizer will be required to ensure optimal plant growth.
- **Micronutrient content** that is not excessive: Manganese, zinc, copper, boron, iron, and chloride are necessary for plant growth but can harm plants if levels are too high.
- **Low sodium** or other detrimental elements such as arsenic, lead, selenium, etc.
- **Hydrophilic:** Evidence of the ability to absorb water rather than repel it.

How much biochar should you use?

At this time, there are no good rules developed for the optimal amount of biochar to use in plant growth or soil improvement, but we can fall back on some existing fundamental advice. For instance, never apply biochar at a rate that will provide any amount of a nutrient that is more than the plant's requirement. For this reason, it is important to purchase only biochars that provide a total elemental analysis.

Proceed with caution. It would be better to add too little and cause no visible benefit than to add too much and watch your plant suffer harm. Worse yet, excess accumulation of micronutrients or toxins can lead to long-term plant growth problems. As you learn more, you can develop confidence with biochars for your soils and plants. For potted plants, a quarter cup of biochar mixed into a gallon of soil or media would be an example of a cautious beginning. Biochar may be reapplied every 6 to 12 months for perennial houseplants.

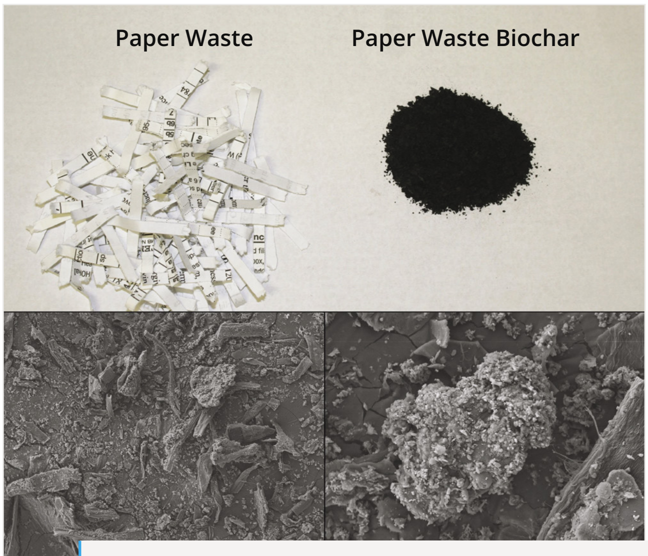

Figure 3. Paper waste can be a feedstock for biochar: Paper, which has very little structure to begin with, results in a flaky biochar product with little pore space for water holding capacity (bottom left, 330x magnification). Some salt crystal formation is evident at 2,000x magnification (bottom right).

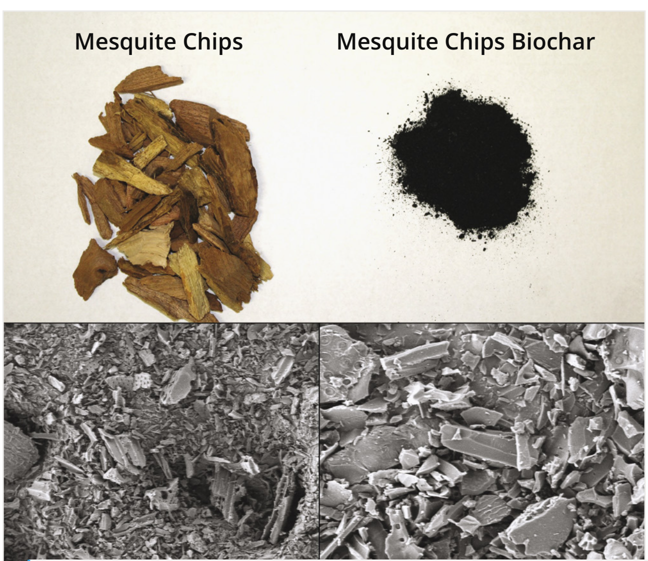

Figure 4. Mesquite chips: A hardwood feedstock such as mesquite will preserve porous properties during pyrolysis. These pores are associated with cell wall structures supported by cellulose and lignin. The larger starting size of the chips also aids in the preservation of porosity, which is helpful for increasing water holding capacity.

For a garden, a quarter cup per plant will not result in overapplication. You can reapply if no response is visible. Because of the low density of biochar, surface application should be avoided. Mixing it into the soil is the best practice to prevent displacement and loss from wind and rain. Blanket application and tillage of biochars in a way similar to compost should also be avoided as these amounts may easily exceed the recommended levels of nutrients or metals.

Figure 5. Cedar shavings: Softer wood feedstocks are intermediate in structure preservation between paper and hardwood. Starting with thinner shavings means less is preserved than with the mesquite.

Figure 6. Cotton gin trash: Gin trash is a mix of burrs (material that surrounds the boll), stems, leaves, seeds, and unrecovered lint. It contains a mixture of structured and less structured materials that result in a mixed biochar with respect to porosity. Seeds and woody bracts preserve some of their structure. This gin trash biochar shows evidence of salt crystallization (bottom right, 2,500x magnification).

Conclusion

- Biochars can benefit soil function and plant growth.
- Biochars differ widely based on what they are made from (feedstock) and how they are produced.
- There are no blanket recommendations to follow because of the variability in chemical and physical properties.
- Buy biochar with a laboratory analysis whenever possible, or send your biochar for mineral analysis to the Texas A&M AgriLife Extension Service Soil, Water and Forage Testing Laboratory using the *Biosolid/Manure Submittal Form* (*http://soiltesting.tamu.edu/*).

Citations and Credits

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All pictures courtesy of Madison Haynie. All electron microscope images collected at the Texas A&M Materials Characterization Facility by Madison Haynie.