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What Is Biochar and How Different Biochars Can Improve Your Crops

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Introduction

Biochar is a charcoal-like material that is produced from plant materials such as grass, agricultural and forest residues that are decomposed at high temperatures, often during renewable energy production. During the process, the physical and chemical properties of the plant material change into a highly porous, stable, carbon-rich material known as biochar. Recent research suggests it has the potential to be used as a soil conditioner and as a container substrate amendment in agriculture and horticulture, and it may improve several soil and substrate physical, chemical and biological properties.

Wood feedstock material (left) and biochar product (right).

Potential Use of Biochar as an Amendment

Adding biochar to soil or container substrate has several potential benefits, such as modifying soil physical and chemical properties by:

- Increasing cation exchange capacity (CEC).
- Increasing surface area.
- Increasing pH.
- Increasing plant nutrient availability.
- Enhancing water-holding capacity.

Biochar can increase the water-holding capacity, thereby reducing water and nutrient leaching. Minimizing nutrient losses through leaching can improve grower profits and sustainability by increasing fertilizer use efficiency, reducing fertilizer costs, and avoiding the need for the enforcement of water-quality regulations for nonpoint source pollution. Additionally, by increasing water retention, biochar can decrease irrigation requirements and make it possible to expand production on limited water supplies. When combined, the above benefits modify the root-zone habitat for plants and the surrounding microbial community, often leading to greater microbial abundance and activity, and can also increase crop yields. Some studies report that biochar improved plant growth and some report no effect or a negative effect of biochar on plant growth (Table 1). Not all biochar looks or behaves the same; different types of biochars produced from different feedstocks are shown below. The potential for beneficial use of biochar relies on its chemical and physical properties, which depend on how it is made and the type of plant used as the feedstock, as well as the crop and cropping system to which the biochar is applied.

Switchgrass biochar (left) and hardwood biochar (right), both produced at approximately 1,000 C.

Table 1. Examples of the effects of biochar amendment to soil or substrate on plant growth.

Biochar Source Material	Soil/Substrate	Effect on Plant Growth	Crop
Citrus wood	Coconut fiber: tuff substrate	Increase	Pepper (*Capsicum annuum* L.) and Tomato (*Solanum lycopersicum* L.)
Gasified rice hulls	Peat	Decrease Increase	Geranium (*Pelargonium ×hortorum* 'Maverick Red') Tomato (*Solanum lycopersicum* 'Megabite')
Hardwood	Soil	Increase	Maize (*Zea mays* L.)
Hardwood pellets and pelletized wheat straw	Peat moss	Little or no effect	Tomato (*Solanum lycopersicum* L.) and Marigold (*Tagetes erecta* L.)
Mixed hardwood	Pine bark	Increase	*Hydrangea paniculata* 'Silver Dollar'

Biochar Production Conditions Influence Its Properties

The temperature used to heat the feedstock and length of time the plant material is exposed to that temperature strongly influence the biochar's physical and chemical properties, so it is important to know about the production process for each biochar that you use. The production vessel plays a significant role in the particle size as well. The heating process can be fast or slow depending on the heating rate and exposure duration. If the heating process is fast and the plant material is heated to a high (> 650 C/1,200 F) temperature for only a short time, the biochar product typically has very fine particles. Likewise, a slow process that subjects the plant material to lower temperatures (450-650 C/850-1,200 F) and slower heating rates produces larger biochar particles. Higher production temperatures not only result in small but also more porous biochar particles that have a proportionally greater surface area, CEC and a higher pH.

Table 2. Fast and slow biochar production processes and resulting biochar characteristics.

Heating Process	Temperature	Exposure Time	Biochar Particles Size	Physical Properties (Surface Area and CEC)	pH
Fast	High (> 650 C/1,200 F)	Short (seconds)	Fine and porous	Greater	Higher
Slow	Low (450-650 C/ 850-1,200 F)	Long (minutes or hours)	Large	Smaller	Lower

Initial Plant Material Affects Biochar Characteristics

The physical and chemical properties of biochar products vary widely due to differences among the production processes and the plant species used. Even when the same manufacturing process is used, biochar produced from different plants may have different chemical properties. Biochar pH can range from 4.6 to 9.3, depending on the initial plant species and the production temperature. In general, as the biochar production temperature increases, the resulting biochar pH also increases.

The total concentration of mineral nutrients in biochar is higher than that found in the initial plant material; therefore, biochar may increase the soil or substrate nutrient concentration and availability due to its initial nutrient concentration and high CEC. For example, hardwood biochar has low nitrate levels, acceptable levels of phosphorus (between 3 and 5 mg kg^{-1}), and high levels of potassium. The mineral concentration can vary widely among different types of biochar and may allow biochar to act as a nutrient source. Thus, biochar amendments could be produced and prescribed based on meeting the needs of a specific crop, or soil or substrate. Different biochar nutrient properties are shown in Table 3.

Table 3. Nutrient characteristics of different types of biochar.

Initial Plant Source Used to Create Biochar	Macronutrient Source*
Biosolids and green waste	P*
Corn straw and rice straw	P and K
Gasified rice hulls	P and K
Hardwood	K
Pelleted agricultural or forestry residues	P and K
Switchgrass	P and K
Timber harvest residues	P and Mg

*The abbreviations stand for magnesium (Mg), phosphorus (P) and potassium (K).

Biochar's Effect Depends on the Crop System

Biochar's effect on crop yield and nutrient availability is much more evident in tropical acidic soils due to their low fertility and, consequently, limited productivity. In Tennessee and neighboring states, it is likely that biochar application will improve poor-quality soils, sandy soils and soils with low organic matter and low CEC, which is common in many of the red clay soils, especially in eastern Tennessee. Likewise, due to the low CEC of most container substrate components (such as pine bark), biochar may be a particularly useful amendment in nursery and greenhouse production. The type of biochar used can be matched to the soil or substrate and crop requirements to achieve the desired results. For example, biochar stability and persistence in soil increases by increasing production temperature, which means that higher temperature biochar products are more stable in soil and lower temperature biochar products are less stable and decompose more rapidly. Lower temperature products could be used in mineral soils with low nutrient content and act as a source of nutrients by decomposing, and high-temperature biochar with long-term residence time could be used in soils rich in organic carbon and improve soil quality. Also, fast process biochars, which are highly porous materials, can be applied to compact soils to increase soil porosity and reduce soil bulk density. In general, biochar mineralizes in soils much more slowly than its feedstock. Most biochars do have a small, easily decomposed fraction of carbon, but typically a much larger stable fraction of carbon will persist in soils for decades.

Biochar's Cost

Biochar amendment to a field soil or container substrate could provide additional value by reducing crop production costs and providing long-term environmental benefits. For example, by reducing phosphorus and potassium fertilizer expenses, limiting irrigation requirements, and reducing nutrient losses, biochar can provide financial returns for farmers. Applications of biochar can provide beneficial effects over several growing seasons. Therefore, biochar does not need to be applied with each crop.

Currently, there are some private and public manufacturers in Tennessee, such as Proton Power and the City of Lebanon. As more companies enter into the energy sector, it is likely that biochar will become more readily available and the costs will likely be reduced. Also, biochar can be derived from different plant-based materials, so it has the potential to be locally available and, consequently, have low freight costs. The production cost of biochar is mostly related to the cost of the initial plant material and production process.

Considerations for Biochar Application

Understanding the type of biochar you are using is important to match its properties with your intended use. Ask the biochar manufacturer about the feedstock and production conditions. Test biochar in addition to conducting a soil test before use to establish the biochar's characteristics and better anticipate its effect on your soil or substrate. Also, it is important to handle biochar outdoors and keep it in sealed containers or bags, as well as have employees wear a dust mask while handling it to protect them from potential health concerns due to inhaling its dust. Mix biochar with soil rather than surface application to prevent biochar movement by wind.

Conclusion

Biochar can improve the physical and chemical properties of agricultural and horticultural soils and substrates and provide cost benefits by reducing water and nutrient losses. Biochar is produced under different production process and therefore has the potential to be produced and prescribed for a specific crop, soil or substrate. Biochar can be made from a variety of plant-based materials, so it has the potential to be produced locally. Have a lab test the biochar(s) available to you before using them and try them on a small scale to determine what biochar and what amendment rate maximize the benefit to your crops.

Pyrolysis: Decomposition of plant material at high temperatures in the absence of oxygen.

Container Substrate: Soilless potting media such as pine bark and peat.

Cation Exchange Capacity (CEC): A soil's or substrate's capacity to hold exchangeable cations (cation is a positively charged ion) and supply nutrients for plant uptake. Biochar increases cation exchange capacity, which improves soil fertility.

Surface Area: Total area of soil particle's surface. Biochar increases soil and substrate surface area relative to their mass due to its fine particles and porous structure. Smaller particles have greater surface area than larger particles.

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