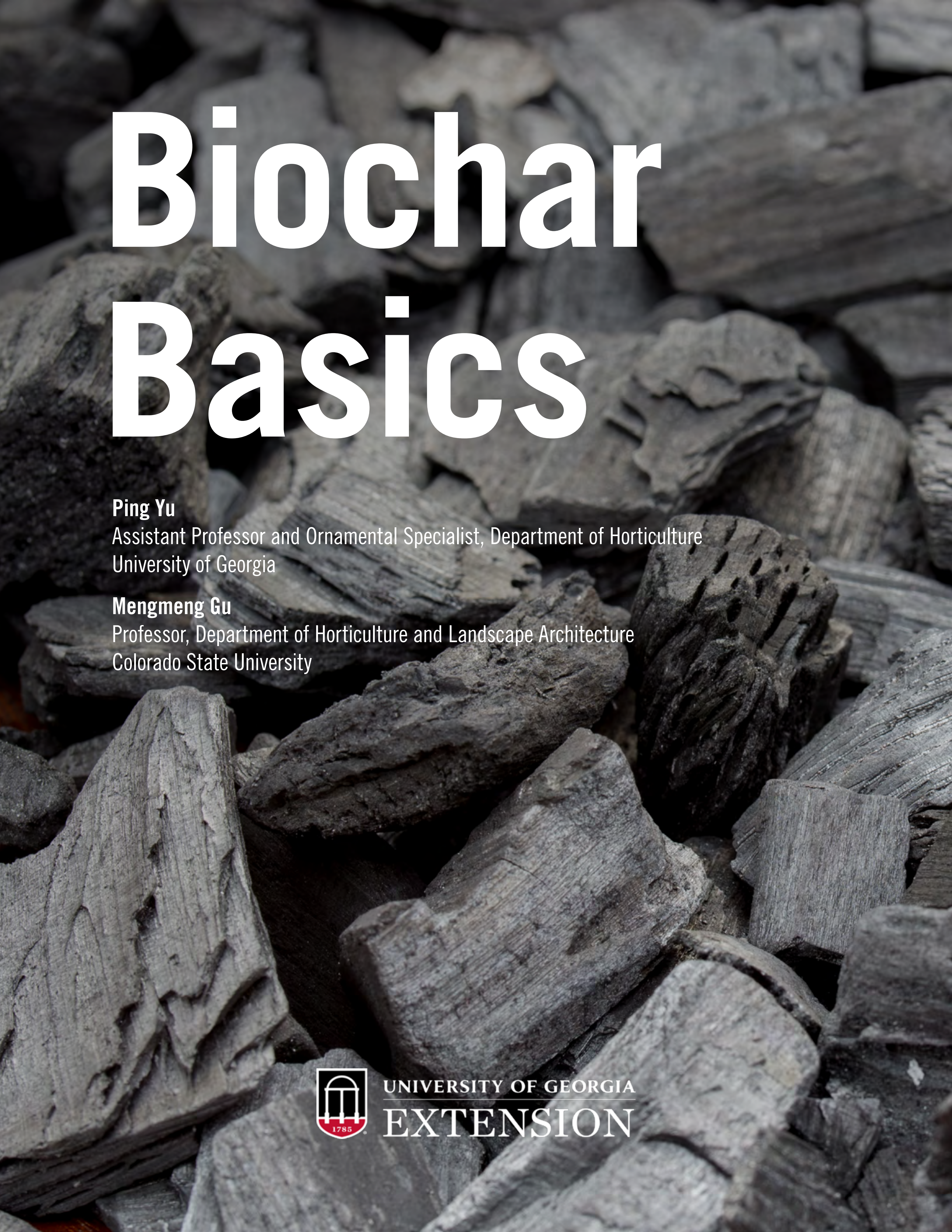

Biochar Basics

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Part 1: An Introduction to Biochar as a Container Substrate Component

Biochar has been proposed to be beneficial to the environment and plants. However, many people do not know what biochar is, what can biochar do, or how biochar can be used. In Part 1 of this publication, we provide introductory information on biochar used to partially replace peat moss as a container substrate component. Parts 2 and 3 focus on what biochar can do and discuss the effects of biochar on container-grown plant growth and disease. In Part 4, we cover the physical and chemical properties of biochar, and provide guidelines for growers to better use biochar.

What is Biochar?

The International Biochar Initiative defines *biochar* as a solid material obtained from the carbonization of biomass, which may be added to soil to improve soil functions and reduce emissions from biomass that would otherwise naturally degrade to a greenhouse gas. Other researchers define biochar as a multifunctional material related to carbon sequestration, greenhouse gas reduction, soil contaminant immobilization, soil fertilization, and water filtration (Lehmann, 2007).

To simplify things, we'll adopt the most popular definition: biochar is a black, carbon-enriched solid with a porous structure, mainly used in agriculture and environmental industries (Figure 1.1). Biochar is normally made from the thermal decomposition of biomass materials at high temperatures (570–2200 °F) in a low-oxygen or no-oxygen environment (this process is also known as *pyrolysis*). Biochar can be produced from pyrolysis of different materials such as pine bark, sugarcane bagasse, rice hull, and straw (Hina et al., 2010).

Figure 1.1. Biochar made from (A) fast pyrolysis at a temperature of 1022 °F from mixed hardwood; (B) sugarcane bagasse at 572 °F and (C) 842 °F; (D, F) pine wood chips (temperature not known); and (E) slow pyrolysis of sugarcane bagasse at a temperature of 662 °F.

Who Started Biochar Production?

Bioenergy companies are major biochar producers as they produce bio-oil or syngas through pyrolysis; biochar is the by-product of these processes. The growing interest in biochar research and use date back to the 2001 energy crisis when a significant number of bioenergy companies launched their facilities for the thriving bioenergy market. Fuel prices increased again during 2022–23 and have presented more opportunities for biochar development.

How is Biochar Produced?

The biochar (pyrolysis) production system normally consists of three basic parts: the heating system (Figure 1.2A, Figure 1.3A), conditioning control systems (Figure 1.2B, Figure 1.3B), and a biomass receptor/biochar collector (Figure 1.2C, Figure 1.3C). In larger biochar production systems, a cooling system is also included (Figure 1.3D). Industrial pyrolysis systems vary in size from what's shown in Figures 1.2 and 1.3, but major components are similar. After biochar is produced, it is collected, cooled, and stored. Biochar can be stored in open fields (industrial scale) or indoors. Biochar is often stored in barrels or plastic bags indoors (Figure 1.4), which will not cause dust or safety issues and make transportation easier.

Feedstock for biochar production may differ in origin and pretreatments. Feedstocks can be subjected to pretreatments, such as washing the raw material with distilled water, dilute alkali, acid, or tannery slurry. For the same reason, the end-product biochar can vary from feedstock to feedstock. Biochar also can be further treated

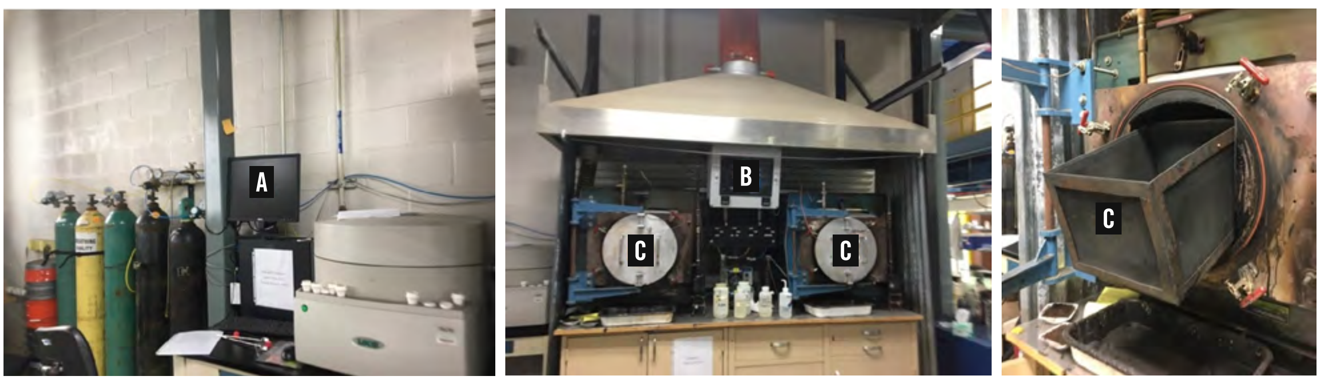

Figure 1.2. Biochar production system (USDA-ARS, New Orleans, LA) consisting of three main parts: (A) heating, (B) conditioning control, and (C) biomass receptor and biochar collector.

Figure 1.3. Biochar production system (Texas A&M University, College Station, TX) consisting of four main parts: (A) heating, (B) conditioning control, (C) biomass receptor and biochar collector, and (D) cooling system.

Figure 1.4. Biochar often is stored in (A) barrels or (B, C) plastic bags.

Figure 1.5. Biochar subjected to posttreatments: (A) pelletized biochar; (B) biochar from pine wood chips before posttreatment; and (C) after posttreatment (grinding).

with posttreatments such as pelletizing, grinding, or blending with other materials such as peat moss, perlite, fertilizer, wood flour, polylactic acid, starch, or soybean-based bioplastics for different purposes (Figure 1.5).

Many agricultural by-products such as green waste, wood straw, bark, sugarcane bagasse, rice hull, wood, and wheat straw can be used as feedstock for biochar production. The huge agriculture industry in Georgia could potentially provide large amounts of agricultural by-products as biochar feedstocks, such as forestry industry wastes, cotton gin trash, dairy and equine manure, pecan shells, corncobs, and crop residuals.

Why Use Biochar to Replace Peat Moss?

Peat Moss Environmental Concerns

The overharvesting of peat moss has interfered with peatlands' ecological functions, causing many ecological concerns. Peatlands serve as a large natural carbon sink to mitigate climate change, but harvesting peat moss could reduce the capacity of this carbon sink and hinder peatlands' potential to mitigate climate change. Peatlands also provide rare habitats for wild animals.

The production and use of peat moss remain relatively stable. From 2015 to 2019, around 165 million tons of peat moss were produced worldwide. In the United States, an average of about 0.47 million tons of peat moss is produced every year. In Canada, around 27,615 acres of peatlands have been or are currently used for horticultural peat moss production. Among the total acreage, 65% is under production, 17% has been restored or reclaimed, 14% still needs to be restored, and 3% has been converted to other land uses. The horticultural peat moss used in the United States is mainly peat imported from Canada (1.1 million tons in 2019), the biggest sphagnum peat producer in North America.

Researchers believe that worldwide peat moss production will decrease in the coming years. The volume of global peatlands has been decreasing at a rate of 0.05% annually because of harvesting and land development. The good news is that several major peat moss-producing European countries have announced restriction plans. For instance, Ireland's peat production is expected to decrease over the coming years because of its transition to alternative fuel sources. In 2019, the country announced it planned to stop all peat harvesting by 2028, 2 years ahead of the previously announced schedule. Finland announced its goal of becoming carbon-neutral by 2035, and peat production will be phased out in favor of other forms of noncarbon energy.

In addition to the potential environmental concerns associated with peat moss, the cost is another major concern. The price of peat moss is constantly increasing, from $0.62 per cubic foot in 1986 to $4.87 per cubic foot in 2018.

Biochar and Peat Moss Comparison

In greenhouse production, major container substrate components include peat moss, vermiculite, and perlite, with peat moss being the key component (Figure 1.6). Peat moss has long been used as a major container substrate component because of its desirable properties such as low pH, bulk density, high cation exchange capacity, appropriate aeration, and good water holding capacity (Nelson, 2012). However, questions have been raised about peat moss among environmentalists and researchers because of its potential environmental and economic concerns.

Researchers and growers have an increased interest in finding environmentally friendly, cost-effective peat moss alternatives. Biochar, a by-product of pyrolysis, is considered a good peat moss alternative for the horticultural industry. Biochar presents the potential to address environmental and economic concerns associated with peat moss. Because of the diverse nature of biochar, this substrate can have certain limitations. In Table 1.1 we compare peat moss and biochar. Mixed-hardwood biochar mixed with peat moss-based commercial substrate at 50% and 70% are two of the most successful biochar-based mixes, based on our research (Figure 1.7).

Figure 1.6. Major container substrate components used in greenhouse production include (left to right): perlite, vermiculite, and peat moss.

Figure 1.7. Mixes based on mixed-hardwood biochar at 50% (left) and 70% (center) by volume, and peat moss-based commercial substrate (right).

Table 1.1. Comparison Between Peat Moss and Biochar.

Characteristic	Peat moss	Biochar
Source	Bog plants: moss, sedge, etc.	Any biomass: sugarcane, bark, municipal wastes, etc.
Formation	Plant material not fully decayed	Chemical thermal reaction
Condition	Waterlogged, acidic, anaerobic	Oxygen-free, high temperature
Rate of regeneration	0.5–1 mm/year (naturally)	Comparable to generation of biomass
Renewable	Yes	Yes
Regrowth	Yes, 30%–40%	Yes, 100%
Main application	Fuel, soil amendments, potting mix	Fuel, soil amendments, potting mix, pollutant filtration
Price per cubic foot	~$4.87	~$2.22
Commercialization	Yes	Limited
Harvesting condition	Depth > 2 m	n/a
Reclaim rate	10–20 years (harvested wisely)	n/a
Restoration rate	1.5–10 cm/year	n/a

Environmental Benefits

Biochar as a container substrate is environmentally and economically friendly. Compared to peat moss, biochar is renewable and faster to regenerate. The raw materials for biochar production can be agricultural wastes such as green waste, rice hulls, straw, wood, bark, or organic waste such as city and kitchen wastes. Those raw materials can be renewed and regenerated within a short period of time, making biochar a renewable and sustainable material. Peat moss needs at least 10 years to renew after being harvested; in addition, existing peatlands took thousands of years to be established.

Economic Benefits

Since biochar can be generated from various feedstocks, it can be manufactured locally to reduce shipping and handling costs. The average price of biochar is $2.22 per cubic foot, less than half of peat moss ($4.87 per cubic foot). If biochar can be produced on a large scale from local suppliers, the price could be as low as $0.99 per cubic foot. In 2017 in the United States, the total amount of substrate used in the specialty crop industry (including bedding plants, hanging baskets, flowers, nursery plants, etc.) was 5.4 million cubic feet, with 91% being peat. If 70% of peat moss could be replaced by biochar (as studies have successfully proven), 3.44 million cubic feet of peat moss on the market could be replaced by biochar, generating $7.64 million in value annually.

With the interest in biochar rising, the number of biochar producers has grown accordingly. In 2015, there were approximately 150 biochar supply companies, with most of them being small garden and specialty retailers. The number of biochar companies has increased to 326 and is still growing.

Limitations

Like peat moss and other peat moss alternatives, biochar also has limitations. Biochar may contain potentially toxic substances, growers have a limited awareness of using biochar as a container substrate, the biochar supply–demand loop remains immature, and there is not yet sufficient production of biochar to make it available to all growers who do want to use it.

Biochar may contain potentially toxic compounds such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and dioxin, depending on the feedstocks and producing conditions. Heavy metals including copper, zinc, lead, chromium, manganese, and nickel could cause severe damage to plants. PAHs are hydrocarbons—

organic compounds containing only carbon and hydrogen—that are composed of multiple aromatic rings. A high PAH concentration could harm plant growth.

Biochar made from toxic feedstocks may contain toxic compounds, which include heavy metals, PAHs, or chlorine. For instance, biochar made from heavy metal-contaminated willow leaves and branches still contained a large portion of the heavy metals from the feedstock. Biochar made from pine wood and switchgrass at certain temperatures could contain PAHs. Similarly, biochar made from feedstocks like straws, grasses, halogenated plastics, and food waste containing sodium chloride could contain dioxin.

Although biochar contains PAHs and/or dioxin, the amounts usually were not a significant problem because they were normally below the threshold values recommended by the International Biochar Initiative and European Biochar Certificate, which are 6–20 mg/kg and < 9 ng/kg, respectively (Wiedner et al., 2013). Companies should select feedstocks with no or low heavy metal contaminants for biochar production.

Biochar can create fine dust, which may lead to safety issues if not addressed correctly. Because of the high temperatures used in the biochar-producing process, biochar tends to have very fine, ash-like biochar particles in the final product. When using biochar, the black dust could be blown into the air and inhaled by workers. Simple safety practices such as wearing a mask and goggles could be helpful. If safety cautions are not addressed, workers' safety could be at risk.

Lack of awareness of using biochar as a container substrate presents another limitation in biochar application because people remain unaware of its benefits and thus are reluctant to use it. Both suppliers and end-users may benefit from knowing about the potential of using biochar as a container substrate. Currently, biochar suppliers are not sufficiently aware of the research on this product as a container substrate, and most horticultural growers are unaware of biochar as a container substrate. Even for those who are knowledgeable, the lack of availability may cause some logistical issues.

Lack of availability, even with the growing number of biochar suppliers, presents a challenge because there still are few producers of biochar compared to that of peat moss. The demand for container substrate is around 5.4 million cubic feet per year, with 91% being peat moss. There are only around 300 biochar companies worldwide, and not all the biochar produced is suitable for container substrates. Growers who are not aware of biochar as a container substrate tend to stick to peat moss, which keeps the demand low for biochar as a container substrate. Many companies are not able to produce biochar that is of sufficent quality for use as a container substrate. Even when some growers want to use biochar as a container substrate, most of the time they can't find the biochar they want on the market.

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The permalink for this UGA Extension publication is extension.uga.edu/publications/detail.html?number=C1292-01

Circular 1292-01 **January 2024**

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Part 2: Biochar's Effects on Plant Growth

Is Biochar Good or Bad for Plant Growth?

This is not an easy question to answer. Mixing biochar into soilless substrates may have negative, zero, or positive effects on plant growth.

Biochar made from green waste mixed with peat at 50% by volume has been shown to increase prayer plants' (*Maranta leuconeura*) total biomass and leaf surface. Adding 10% by volume of sewage sludge biochar with peat-based substrates can increase lettuce biomass by 184%–270%. Mixing pruning-waste biochar with peat-based substrates at 50% or 75% by volume can also increase lettuce biomass. Mixing 20% or 35% (weight per weight) of coir biochar with 0.5% or 0.7% humic acid into a composted green-waste medium showed increased biomass of rattlesnake plants (*Goeppertia insignis*) compared to those without biochar and humic acid amendments (Zhang et al., 2014).

Mixed hardwood biochar (50% by volume) and sugarcane bagasse biochar at 50% or 70% with a bark-based substrate increased basil plants' average root diameter (Yu et al., 2019). Mixed hardwood biochar at 20%–80% by volume increased photosynthesis, shoot fresh weight, and shoot dry weight of chocolate mint, peppermint, Kentucky Colonel mint, spearmint, and orange mint plants. Also, pinewood biochar mixed with pine bark increased chrysanthemum shoot fresh and dry weights.

Pinewood biochar (at 20%–80% by volume) mixed with a peat-moss-based substrate had no effects on Easter lily or poinsettia plant growth compared to those in a 100% peat moss-based substrate (Guo et al., 2019). Tomato crop green-waste biochar did not affect tomato plant growth, fruit number, or fruit yield when applied in sawdust-based soilless substrates.

Biochar may also have adverse effects on plant growth. For example, we tested one type of biochar with high salinity; plants grown in these biochar mixes wilted within 30 min. When plants do not have enough water to dissolve the extra salts, they die.

Biochar ***percentage*** also plays a significant role in the effects on plant growth. Generally speaking, low biochar percentages may increase plant growth, while high biochar percentages decrease plant growth. For instance, biochar at 40% and 60% (by volume) mixed with bark could increase the growth index of tomato plants, but when the biochar rate was increased to 80% and 100% (by volume), the growth index of tomato plants significantly decreased. Also, biochar at 30% (by volume) did not affect the dry weight of leaves or growth of whole aerial parts of geraniums (*Pelargonium*). However, when the percentage increased to 70% (by volume), geranium plant growth and flowering traits were significantly decreased (Altland & Locke, 2017).

What Determines the Effects of Biochar on Plant Growth?

There are four main factors in determining the effect of biochar on plant growth: biochar type, rates, plant species, and other substrate components.

Biochar type and **rate of application** influence plant growth differently. We tested sugarcane bagasse biochar and mixed hardwood biochar on tomato and basil plant growth (Figures 2.1 and 2.2). Tomato and basil plants grown in sugarcane bagasse biochar or mixed hardwood biochar substrates had similar growth compared to those grown in commercial mixes. When we tested the same types of biochar with different rates on pepper and petunia (Figures 2.3 and 2.4), we found that pepper plants in 50% and 70% mixed hardwood biochar had similar growth compared to these in commercial substrates. On the other hand, petunias grown in the 50% sugarcane bagasse biochar had improved growth compared to those in 100% (Figure 2.4).

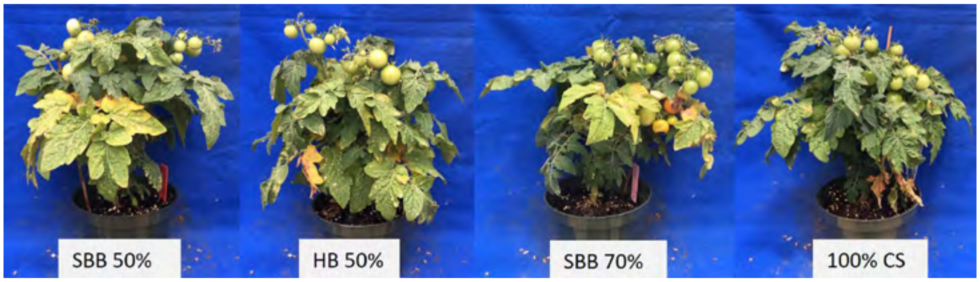

Figure 2.1. Tomato plants are grown under different percentages of sugarcane bagasse biochar (SBB) and 50% hardwood biochar (HB) mixed with a peat-moss-based commercial substrate (CS).

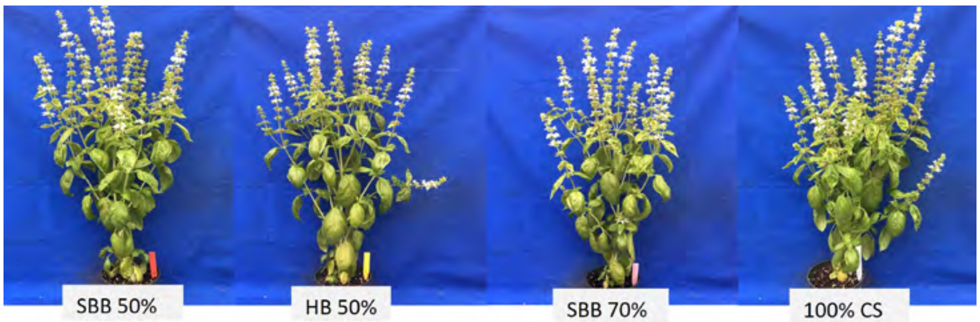

Figure 2.2. Basil plants are grown under different percentages of sugarcane bagasse biochar (SBB) and 50% hardwood biochar (HB) mixed with a peat-moss-based commercial substrate (CS).

Figure 2.3. Pepper plants are grown under different percentages of mixed-hardwood biochar (HB) mixed with a peat-moss-based commercial substrate (CS).

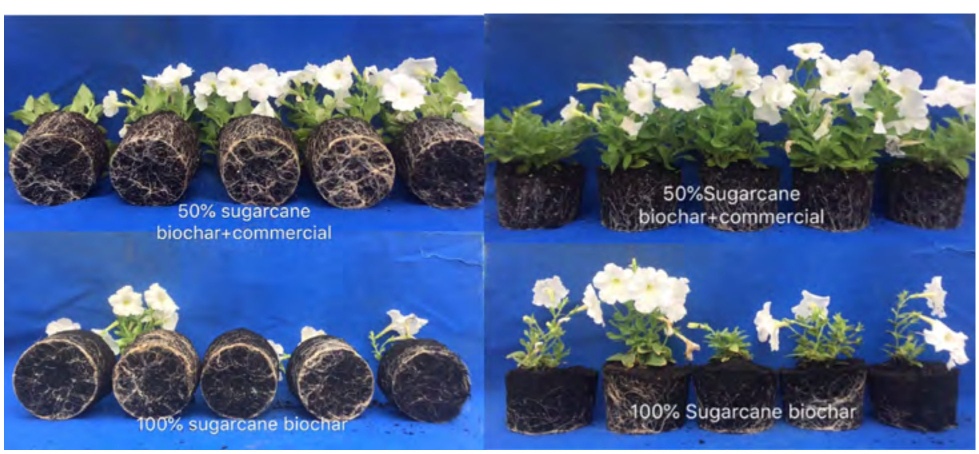

Figure 2.4. Petunia plants are grown in different percentages of sugarcane bagasse biochar mixed with a bark-based commercial substrate.

Plant species play a significant role in biochar's effects on plant growth. Similar biochar types may have variable effects on different plant species. For example, the mixture of Japanese oak biochar, peat, and vermiculite can improve zinnia shoot growth but has no effect on marigold or scarlet sage. Citrus wood biochar (1%, 3%, or 5% by weight) mixed with commercial soilless substrates (a mixture of 70% coconut fiber and 30% tuff by volume) increased the flower and fruit yield of pepper but had no effects on tomato plants (Graber et al., 2014),

Other substrate components in the biochar mix also could affect plant growth. Mixing biochar with bark did not affect the growth index of chrysanthemums, but mixing the same biochar with Sunshine #1 Mix increased the growth index of chrysanthemums. Gomphrena plants grown in pinewood biochar mixed with peat-based substrates had higher fresh dry weight than those grown in pinewood biochar mixed with bark substrates (Gu et al., 2013). Lettuce grown in deinking sludge biochar mixed with peat (50% each by volume) had higher total biomass, shoot, and root weight than those in deinking sludge biochar mixed with coir (50% each by volume; Méndez et al., 2015).

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Circular 1292-02 **January 2024**

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Part 3: Biochar's Effects on Plant Disease

Disease Basics

Have you ever checked your plants and found brown, yellow, or white soft-tissue spots either on the roots, stems, or foliage? Those nongreen spots may indicate plant disease. Plant diseases can be broadly classified according to the nature of their primary causal agents, either infectious or noninfectious. Infectious plant diseases are caused by pathogenic organisms such as a fungus, bacterium, virus, or nematode. Infectious plant diseases can spread from plant to plant and may infect all types of plant tissues. Noninfectious plant disorders are not caused by living agents but by environmental conditions, such as nutritional deficiencies, salt injury, sun scorch, or ice damage. Noninfectious plant disease cannot spread from plant to plant (Shurtleff et al., n.d.).

How do pathogens infect plants and how do diseases develop? A pathogen is a type of microorganism that enters plants and interferes with plant growth. For a disease to occur, we need an environment that favors pathogen growth, a susceptible host plant, and a virulent pathogen (Graber et al., 2014)—these three factors represent the disease triangle.

In any given soil sample, there are two types of microorganisms: pathogenic microorganisms ("bad guys") and beneficial microorganisms ("good guys"). These microorganisms maintain a balanced relationship under normal conditions. Once the environment favors the "bad guys," they can outgrow the "good guys." When the environment is favorable for the pathogen and the pathogen is virulent, then plant disease may start to develop if the plant is susceptible to the pathogen.

Biochar and Plant Disease

As we mentioned before, every element in the disease triangle needs to be present for disease to occur. Therefore, any interference in the disease triangle could affect disease development. How does biochar play a role in a plant-disease system? Before the pathogen infects plants, biochar can improve plant growth by increasing water and nutrient uptake; a healthier plant may be more resistant to attack. On the other hand, after a pathogen infects a plant, biochar could absorb the toxins, enzymes, and other compounds produced by the pathogen.

Certain types of biochar could contain chemical compounds which are bad for pathogen growth. When incorporating this biochar into a substrate, the growth environment may become toxic to pathogens so they cannot grow well enough to attack plants. For instance, water extracts from eucalyptus biochar were found to inhibit *Pythium* growth in a lab setting. This finding indicates that substrates containing certain chemical extracts may impede plant infection by inhibiting the growth of *Pythium* (Bonanomi et al., 2015). Many types of biochar can improve plant growth, making the host plant stronger to fight against pathogens, thus reducing disease occurrence.

Some studies have shown that incorporating biochar into growing media can suppress plant disease. For instance, amending a substrate with 30% softwood bark biochar produced at 475 °C reduced disease development. In addition, mixing in 3% of pine biochar produced between 550–600 °C reduced pepper blight caused by *Phytophthora capcisi* (Gravel et al., 2013). Reports indicate that biochar influences other plant diseases, such as asparagus root rot, tomato bacterial wilt, red oak and red maple seedling stem canker, and strawberry gray mold caused by different pathogens. Table 3.1 summarizes biochar's effect on plant-disease systems.

Table 3.1. Biochar's Effects on Soilborne Plant Disease Development.

Plants	Diseases	Pathogens	Biochar raw material	Biochar temperature in °C	Biochar rate†	Influence on plant disease incidence or severity
Tomatoes	Bacterial wilt	*Ralstonia solanacearum*	Municipal biowaste	N/A	20% (v/v)	Reduces
Red oak and red maple	Stem rot	*Phytophthora cinnamomi* and *P. cactorum*	Pine	550–600	5%, 10%, 20% (v/v)	Reduces
Cucumbers	Root rot	*Rhizoctonia solani*	Eucalyptus wood and greenhouse wastes	350, 600	0%–3% (w/w)	Reduces
Lettuce	Root rot	*Rhizoctonia solani*	Holm oak wood	650	1%, 3% (w/w)	Reduces
Peppers	Root rot	*Rhizoctonia solani*	Maple wood bark	700	1%, 3%, 5% (w/w)	Reduces
Beans	Root rot	*Rhizoctonia solani*	Eucalyptus wood and greenhouse wastes	350, 600	0%–3%	Mixed
Asparagus	Fusarium root rot	*Fusarium oxysporum* f. sp. *asparagi*	Coconut fiber (mixed with coffee compost)	N/A	10%, 30% (v/v)	Reduces

† v/v means volume per volume; w/w means weight per weight.

We must remember that every biochar is different. Among the studies listed in Table 3.1, most of them used low biochar rates (0%–5%) and the highest rate was 30% by volume. Also, the field of biochar plant disease research is small. More greenhouse research needs to be done on this topic for the following reasons: (a) the humid and warm environment could favor a lot of pathogenic organisms; (b) monocultivation could make the plants more susceptible to pathogens; and (c) pathogens are resistant to fungicides, pesticides, and bactericides.

How Do We Measure Biochar's Influence on Disease?

Biochar influence on plant disease was measured according to the following parameters: (a) when the first symptom appears; (b) percentage of diseased plants; and (c) disease severity. Biochar alone may not be capable of stopping diseases, but it may delay the appearance of symptoms.

For instance, in previous trials, adding mixed hardwood biochar delayed the first symptom of poinsettia root rot by 5 days. Also, adding biochar may reduce *disease incidence* (the total number of diseased plants). Biochar may also reduce disease severity in infected plants. Poinsettias produced with biochar in the growing media may exhibit reduced disease symptoms, such as a reduction in the size of a necrotic spot.

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The permalink for this UGA Extension publication is extension.uga.edu/publications/detail.html?number=C1292-03

Circular 1292-03 **January 2024**

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Part 4: Biochar Properties and Making the Right Biochar Mix

Container substrates must fulfill several functions for plant growth: create a suitable environment for root growth, physically support the plant, hold nutrients and water, and enable gas exchange between the roots and the atmosphere. Suitable physical and chemical properties of container substrates facilitate these functions.

In this last section of the *Biochar Basics* series, we discuss biochar's physical and chemical properties and provide a guide for producers who may want to make their own biochar mixes.

Physical Properties

The physical properties of container substrates include air space (%), container capacity (%), total porosity (%), bulk density (g/cm^3), and water holding capacity. *Air space* measures the proportion of air-filled large pores (*macropores*) after drainage. Air space influences gas exchange and water holding capacity. *Container capacity* measures the maximum percentage volume of water a substrate can hold after drainage. *Total porosity* equals container capacity plus air space, and it measures the substrate volume that holds water and air. *Bulk density* measures how much one unit of the substrate weighs. *Water holding capacity* measures the container substrate's ability to physically hold water against gravity; its maximum value equals container capacity (Huang, 2018).

As mentioned in Part 1 of this publication, biochar can be derived from various feedstocks, processed under different pyrolysis temperatures, and subjected to various pre- or posttreatments, which can lead to dissimilar physical properties that affect a container substrate's physical properties. Adding biochar may affect air space, container capacity, total porosity, and bulk density with variable effects. For instance, substituting peat moss with 50% green waste biochar (by volume) did not affect total porosity and container capacity, but significantly decreased air space, which was still in the optimal range (15%–30%) for container substrates. Similarly, a peat-moss-based substrate's total porosity decreased with the increased addition of pelleted biochar (Dumroese et al., 2011). However, adding deinking sludge biochar increased the total porosity and air space of the container substrate. The impacts of biochar on a substrate's air space, container capacity, and total porosity have been reported to vary, with no specific trends emerging.

Unlike the varied effects of biochar on air space, container capacity, and total porosity, the impact of biochar on bulk density and water holding capacity has been more consistent. Biochar has higher bulk density than commonly used substrate components such as peat moss and vermiculite. Thus, replacing a certain percentage of peat moss and/or vermiculite with biochar can increase the overall bulk density of substrates. The addition of biochar can also increase the water holding capacity of a soilless substrate. For instance, a proper mixture of 25% pelleted biochar and 75% peat (by volume) was shown to hold more water than 100% peat substrates (Dumroese et al., 2011).

Chemical Properties

Container substrate chemical properties include electrical conductivity (EC) and pH. The EC is an index of soluble salt content and measures all the electrically charged ions dissolved in a solution. pH is a measure of the acidity or alkalinity of a substrate.

The chemical properties of biochar vary widely and the addition of biochar to a container substrate can have different effects on the chemical properties of the container substrate. The addition of biochar to peat-moss-based substrates has been shown to increase the overall EC of those substrates (Rahman et al., 2016; Tian et al., 2012). In general, biochar has been reported to increase the pH of soilless substrates because of its alkalinity. However, the pH of biochar ultimately depends on the feedstock and pyrolysis temperatures. Under certain conditions with certain feedstocks, biochar may be acidic. The pH of biochar made from pyrolysis of oak and switchgrass at 250 °C was 3.5, while the pH was 5.9 when made from switchgrass alone (Novak et al., 2009). Generally, the lower the temperature used in pyrolysis, the lower the pH in the resulting biochar.

The addition of biochar to a container substrate may affect nutrient availability as well. Some forms of biochar can serve as a source of phosphorus (P) and potassium (K), increasing P and K availability and potentially reducing the total amount of fertilizer needed for plant growth. Pretreatment of biochar feedstock bark with tannery slurry as an alkaline treatment also resulted in greater ammonium absorption capacity than in untreated feedstock (Hina et al., 2010). However, another study found that available nitrogen and K were decreased after the addition of green-waste biochar to peat substrates (50% volume per volume; Tian et al., 2012). Biochar in a pelletized form using soybean-based bioplastics also has been shown to be a source of nutrients in a soilless substrate.

Make Your Own Biochar Mix

So how would you guarantee success when using biochar as a container substrate for plant production? When using biochar mixes, you must couple the right biochar with the right plant (based on the pH and EC tolerance). Choose a biochar with suitable properties (pH, EC, particle size, etc.) and be careful with the amount of biochar added. For example, if you were growing blueberries, hydrangeas, or azaleas, which require an acidic substrate, you wouldn't want to grow them in a substrate with a high percentage of alkaline biochar. By volume, 80% is the highest percentage of biochar successfully being used for container plants.

We compared the physical and chemical properties of the biochar we tested with some commonly used commercial mixes. The recommended chemical and physical properties for those container substrates are listed in Table 4.1. While biochar may have different properties, many can successfully be used as container substrates for plant growth by mixing with other components.

There are two main ways of creating your biochar mix:

Option 1: Mix with a commercial substrate. A simple way to make the target biochar work is to mix it with commercial mixes that contain components such as perlite and/or vermiculite, lime, a wetting agent, fertilizer charge, etc.

Option 2: Create your own mix. You can mix biochar with other components such as peat moss, perlite, pine bark, etc.

No matter which way you choose to create your biochar mix, particle size is important. If you choose Option 1 and your biochar is coarse-textured (with a relatively larger particle size), think about mixing it with a peat-moss-based commercial substrate to bring down the particle size of the final mix. If, however, your biochar is fine-textured (with a relatively smaller particle size), think about mixing it with a pine-bark-based commercial substrate to increase the particle size of the final mix. The same concept applies to Option 2. When the chosen biochar is relatively coarse-textured such as a mixed hardwood biochar, mixing it with other components with a fine texture, such as vermiculite and peat moss, would ensure appropriate particle size in the final mix.

Besides particle size, another important consideration is pH. A pH range of 5.4–6.5 is suitable for most greenhouse crops; acidic biochar used in greenhouses usually falls within the suitable pH range (5.4–5.9) for use as a container substrate. Alkaline biochar, however, can have a high pH which may make nutrients less available to plants and lead to adverse effects on plants. A way to solve this problem is to mix it with acidic components such as peat moss. Theoretically, alkaline biochar also can be mixed with acidic biochar if their particle sizes can compensate for each other, but further research is necessary to support this concept.

The EC of biochar can vary as well, but normally those used in greenhouse studies had a relatively low EC because they were made from ligneous feedstock such as wood, bark, sugarcane bagasse, etc. A lower EC may allow you to add more fertilizer before salt damage becomes an issue. Research has shown that you may be able to mix a low-EC biochar with nutrient-rich components. Based on our research, the percentage of nutrient-rich components should be low (less than 30% by volume) or else the high EC could cause plant phytotoxicity.

Table 4.1. Properties of Different Container Substrate Components.

Properties and mixes	Total porosity (%)	Container capacity (%)	Air space (%)	Bulk density (g/cm^3)	pH	Electrical conductivity (mS/cm)	Particle size (mm)
Recommend ranges	**50–85**	**45–65**	**10–30**	**0.19–0.7**	**5.4–6.5**	**< 0.75 (seedlings) < 1.5 (general crops)**	**—**
Pinewood biochar	83	48.6	34.2	0.17	5.4	—	0.59–2
Mixed hardwood biochar	85	60.3	24.4	0.15	10.8–11.8	0.11	67.3% > 2
Sugarcane bagasse biochar	74	66–85	3–9	0.09–0.11	5.9	0.08	0.17 (mean)
Peat moss	83	64	18.9	0.08	4.3–5	—	—
Perlite	92	59	34	0.05	7.3	0.01	—
Vermicompost	75	72	3	0.38	4.8	6.7	89.4% < 2
Chicken manure	64	60	4	0.62	7.5	32.9	89.4% < 2
Peat moss based commercial growing mix	74–78	58–71	3–20	0.09–0.1	—	—	65.2% < 2
Peat moss based commercial propagation mix	71–75	84	15	0.11	6.8	0.07	—
Pine bark based commercial mix	79–97	47–85	12–31	0.15	6.5–6.75	0.18	3–6

Is Biochar Worth Using?

Does it make dollar sense to use biochar as a container substrate for horticultural production? The 2023 prices of commercial peat-moss-based substrates and locally sourced biochar averaged \$4.87/ft^3 and \$2.22/ft^3, respectively. According to the biochar literature, 20% to 80% of peat moss in a substrate can be replaced with biochar (using 50% as the average) without any negative influence on plant growth or yield.

If you switch some peat moss to biochar, you may save money on media without sacrificing plant production. For example, if a grower uses 1,000 cubic feet of peat-moss-based substrate for container plant production each growing cycle, using biochar mixes at 50% could save approximately \$1325 each growing cycle [(\$4.87/ft^3 - \$2.22/ft^3) × 1,000 × 50% = \$1,325]—not to mention the potential savings through reduced use of fertilizer, fungicides, and/or pesticides.

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The permalink for this UGA Extension publication is extension.uga.edu/publications/detail.html?number=C1292-04

Circular 1292-04 **January 2024**

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