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Biochar: A Potential Substrate Amendment in Container Production

Biochar is a charcoal-like material produced from wood and other agricultural wastes exposed to high temperatures and no/low oxygen (Figs. 1 & 2). The process results in a stable material with available nutrients (such as nitrogen, sulfur, manganese, and potassium) and a high cation exchange capacity. With greenhouse/nursery producers interested in using locally available waste materials in container substrates, biochar may be a beneficial substrate component. However, similar to compost, the feedstock and processing method used have a large impact on the resulting biochar properties. And studies are lacking on crop performance in response to biochar. In this article we will begin by describing the processes in biochar production and their influence on chemical and physical properties. Second we will share results from an experiment using three different biochars as a

Figure 1. Examples of some feedstocks used for formation of agricultural biochar.

substrate amendment in container basil production.

Several feedstocks are used in production of agricultural biochar (Table 1) including various wood and agricultural waste products. There are three main methods of biochar production: pyrolysis, gasification and hydrothermal carbonization. In pyrolysis (thermal decomposition), the feedstock is heated at temperatures of 750-1100 °F in the absence of oxygen. In gasification the feedstock is heated to 1300-2200 °F in the presence of low quantities of oxygen. Biochar produced through gasification contains lower carbon content (and greater nutrient availability) than pyrolysis. Finally, the Hydrothermal process involves heating a feedstock at a lower temperature (400-575 °F) and high pressure under water, and the resulting biochar is known as hydrochar. Hydrochar is more acidic in nature and has greater cation exchange capacity (CEC) than biochar produced through pyrolysis and gasification. Biochar's physical and chemical characteristics like moisture holding capacity, porosity, surface area, pH, nutrient availability, and CEC are highly associated with feedstock and manufacturing conditions (heating temperature, pressure, and timing) (Table 2). In addition, treating feedstocks with water or some kind of acid prior to decomposition can also alter physical and chemical properties of biochar.

Biochar has greater bulk density (weight per unit volume) than common substrate components, so its incorporation with growing media would be very helpful in increasing substrate weight, helpful in outdoor production when wind can topple containers. Depending on the specific biochar, it can improve the air porosity, as well as moisture and nutrient holding capacity. Biochar incorporation also increases percentage of micropores in substrates thereby increasing container water holding capacity and nutrient retention. Air porosity can be enhanced by increasing the number of macropores.

Figure 2. A wood chip biochar with larger particle size.

Citrus wood	Wheat straw	Rice husk	Pine chip
Conifer wood	Corn straw	Coconut husk fiber	Pine cone
Mixed hardwood	Cotton sticks	Crab shells	Pruning waste
Mixed softwood	Bamboo sticks	Eucalyptus chip	Sewage sludge
Pine wood	Forest waste	Oak chip	Sugarcane bagasse
Spruce wood	Green waste	Olive mill waste	Grasses
Orchard pruning	Miscanthus	Cow manure	Pig manure
Shrimp hull	Corn cob	Bone dreg	Waste paper
Sawdust	Palm kernel shell	Peanut shell	Soybean stover

Table 1. Examples of some feedstocks used for formation of agricultural biochar.

Table 2. Characteristics of example biochars used in container production.

Biochar	Production temp. (°F)	pH	Bioavailable nutrients
Coconut husk fiber	850	8.2	N, C, P, K, Ca, Mg
Crab shell	390-480	8.8	N, C, P, K, Ca, Mg
Eucalyptus wood chip	1000	8.8	N, C, P, K, Ca, Mg, S
Green waste	1000	8.8	N, C
Holm oak	1200	9.3	N, P, K, Ca, Mg
Mixed softwood	1650	10.9	P
Oak chip	400-500	5.1	N, C, P, K, Ca, Mg
Olive mill waste	900	9.7	N, C, P, K, Ca, Mg, S
Pine chip	400-500	6.4	N, C, P, K, Ca, Mg
Pine cone	400-500	5.1	N, C, P, K, Ca, Mg
Pine wood	850	5.6	N, C, K, Mg
Poplar	2000-2200	9.7	N, P, K, Mg
Pruning wastes	550	7.5	N, C
Rice husk	900	10.2	N, C
Rice husk	500	6.3	N, C, P, K, Ca, Mg
Sewage sludge	850	7.9	N
Southern yellow pine	750	6.0	P, K, Mg,
Spruce wood	2000-2200	11.1	N, P, K, Mg
Switchgrass	1800	10.8	N, C, P, K
Wheat straw	1100	10.0	N, C

Although, the pH of biochar depends upon the type of feedstock and production conditions (particularly heating temperature) most biochars are neutral to basic in nature - which is important to be aware of as it will raise pH of the substrate. The biochar materials have a negative charge on their surface which helps in buffering the pH substrates and significantly improves the substrate's cation exchange capacity (CEC) which reduces leaching of positively charged nutrients (ex: NH_4^+, Ca^{2+}, Mg^{2+}, K^+).

In addition, depending upon type of feedstock, biochar improves nutrient status of substrate by adding N, P, K, C and some micronutrients. It also serves as a slow release source for N, P, and K. Biochar can promote microbial activity due to increased pH, improved nutrient and moisture retention, supply of carbon, and micropores which serve as as a place for microbes to live. Some studies have found cases where biochar was effective in suppressing airborne and soilborne pathogens like *Rhizoctonia*, *Fusarium*, *Phytophthora*, and *Botrytis*.

Considering the multidimensional properties of biochar, it could be an excellent substrate-amendment in greenhouse production to potential improve crop production and reduce leaching while using locally available waste materials. Use of biochar in container production is gaining popularity, but there is need to establish best-management-practice (BMPs) for its application in soilless production.

Research-based recommendations and information about biochar application methods, rate, application timings, nutrient dynamics and kinetics in field and container grown ornamental crops are limited. These research gaps are a major barrier to biochar use in greenhouse and nursery production on large scale.

Cornell Experiment with container grown basil

The effects of biochar amendment on basil 'Caesar' with three types of biochar were studied. The biochars included an organic certified commercial biochar (Black Owl Premium Organic Biochar), and locally produced mixed hardwood biochar and willow chip biochar (Fig. 3). Basil seedlings were transplanted into 6-inch containers with a soilless potting mix (75% peatmoss and 25% perlite, v/v) which was amendmend with control (receiving no biochar), 5%, 10% and 20% of biochar, by volume. Due to large particle size, mixed hardwood biochar and the commercial biochar were ground and sieved through a 2 mm mesh sieve before incorporation into the soilless mix. Depending on the biochar source/quantity differing rates of limestone were added to achieve a substrate pH of 5.5. The plants were grown for 30 days in a greenhouse at 77 ˚F day and 64 ˚F night temperature. Plants were watered daily as needed with Jack's 21-5-20 All Purpose water soluble fertilizer at 150 ppm N. Plants were evaluated for fresh weight (yield) and height.

For basil plants, both their fresh weight (Fig. 4) and height were significantly increased by biochar amendment however the degree of increase and the optimum application volume varied by biochar type. For the Commercial biochar (Black Owl Premium) an incorporation rate of 5% gave an increase in fresh weight of 30% and higher application rates showed decreaed benefits. For the mixed hardwoods biochar an incorporation rate of 10% gave the greatest fresh weight increase (of 60%) and while reduced benefits for noted at 20%. For the willow biochar a 10% application rate also gave the greatest benefits (a 63% increase in FW vs. control).

For plant height, a 20% increase in plant height was noted for the commercial biochar (at 20% application rate) and for the hardwood biochar (at 10% application rate). The willow biochar exhibited a 10% increase in height (at 10% application rate). Visually we observed increased branching with biochar application which may have been largely responsible for the yield (fresh weight increases) (Fig. 5). We were surprised by the experiment findings as we had assumed that our base substrate and liquid feed program would be sufficient for good basil growth.

Figure 3. A willow chip biochar that was produced in a specialized kiln was used in the Cornell study.

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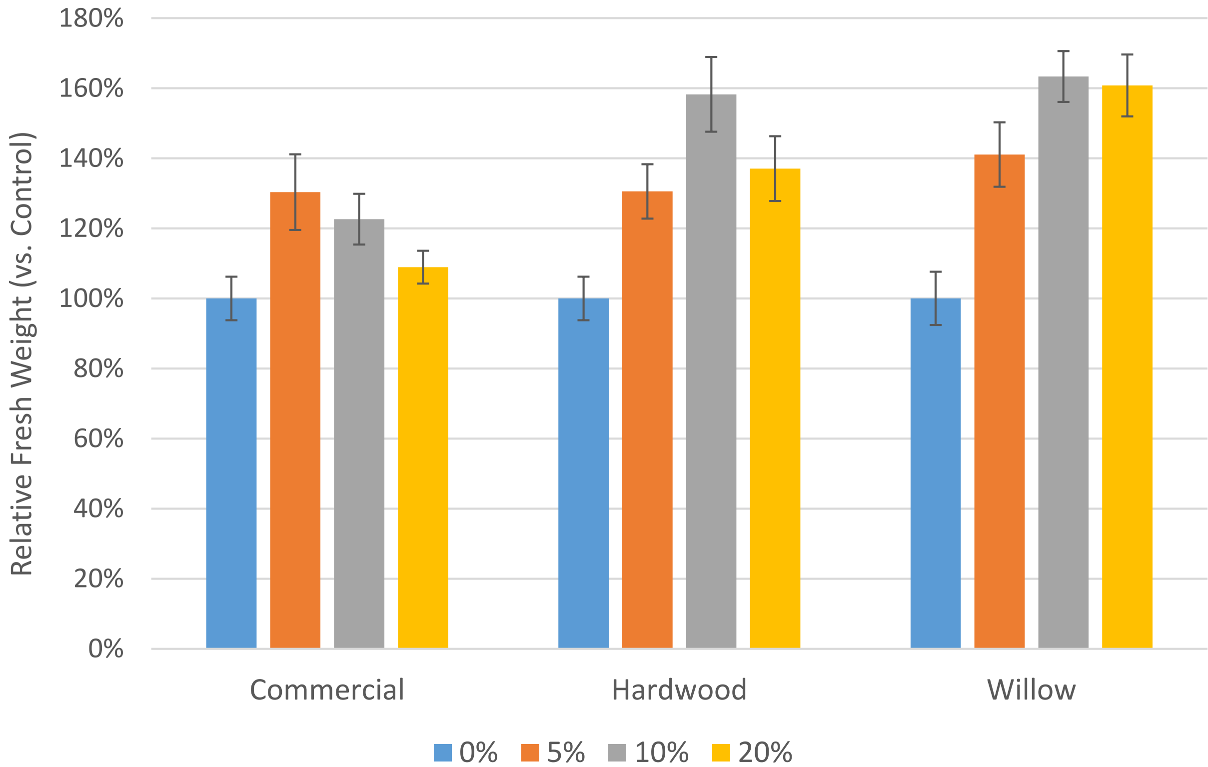

Figure 4. Relative fresh weight of basil 'Casear' in response to three types of biochar incorporated into a peat:perlite substrate at 0, 5, 10, or 20% by volume. The fresh weight of control (0%) biochar was plants was 50 grams per plant.

We hypothesize that the increases in growth may have been to increased nutrients supplied from the biochar itself or increased cation exchange capacity (and thus nutrient retention) from the biochar. Overall our results demonstrate that a relatively small amount of biochar (5 to 10% by volume) could lead to plant growth/yield benefits. Results varied based on the specific biochar product. At higher application rates (20%) we observerved declines in yield benefit. We are not sure of the cause but it may be due to excessive supply of fertilizer and non-fertilizer salts or changes to the substrate water holding capacity.

For growers interested in trying biochar as a substrate amendment it is important to note that biochar properties vary substantially from product to product and the results will also depend on one's growing conditions. Growers should always always obtain information from the biochar supplier on its properties including feedstock source, heating temperature, pH, CEC, nutrient analysis (including mineral nutrients as well as unwanted ions such as sodium, chloride, and aluminum), and recommend application rate. Small scale trials (beginning with a small percentage of biochar by volume) must always be conducted before considering more widespread adoption. This is to ensure that the specific biochar used is beneficial (or at least not harmful) under your conditions but also because it's use may require adjusting nutrition and irrigation practices.

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Commercial Biochar (Black Owl Premium)

Mixed Hardwood Biochar (locally produced)

Willow Chip Biochar (locally produced)

Figure 5. Basil ‘Caesar’ grown with 3 different biochars at (L to R) 0, 5, 10, and 20% incorporation rates by volume. Photos courtesy of Jingjing Yin, Cornell University, Ithaca, NY.

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