DOES BIOCHAR IMPROVE DISTURBED, SANDY SOILS?

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Abstract

We studied whether adding biochar to sandy, carbon-poor soil impacts plant growth. Biochar is an organic compound composed mainly of black carbon and made by pyrolysis of organic matter. Biochar is of interest as a possible soil amendment to alleviate stresses on agricultural production due to its high water and nutrient retention capabilities, high cation exchange capacity, high porosity that increases mycorrhizal growth, and ability to sequester carbon dioxide.

We examined the growth of three different plant types, *Avena sativa* (common oat), *Vigna radiata* (mung bean), and *Raphanus sativus* (cherry belle radish), in greenhouse and garden plot experiments. In the greenhouse we used five different treatments of soil from a demolition site: soil alone and soil mixed with 2%, 5%, 10%, and 20% biochar by mass. All biochar was washed to remove ash and inoculated with compost tea before mixing. Four replicates of each species were planted in individual pots of each of the five soil types for a total of 60 plants. Plants were grown for 5 weeks and watered every other day. At the end of the growth period, *A. sativa* and *V. radiata* plants were cut off at the soil surface and entire *R. sativus* plants were removed from soil, then dried in a plant press before weighing. All 60 replicates produced plants, with no statistically significant differences in oat and mung bean above ground biomass or radish whole mass for any treatment.

In the garden experiment at a grassed-over former building site, we planted 10 seeds of each plant in each of 5 plots: soil only, 3% compost by mass, 3% biochar by mass, and 3% and 5% biochar inoculated with compost tea. Oats had 100% germination in all plots, while radishes yielded 8, 7, 5, 9, and 7 plants respectively. For mung bean the control and compost plots yielded only 2 and 4 plants while the biochar treatments yielded 7, 3, and 9 plants. Whereas all soil treatments grew plants under controlled greenhouse conditions, the garden experiment, which is ongoing, suggests that under more natural conditions biochar may influence germination and survival.

Introduction

With increasing pressures to supply food for the world's growing population, agricultural sustainability must be at the forefront of scientific investigations (Braun et al. 2004). Depletion of soil nutrients in crop land adds to these growing ecological and economic pressures, as does the increasing use of fossil fuels and consequent rise in levels of atmospheric carbon dioxide which pose a large problem in terms of global climate change (Metz 2005).

One material being investigated for the alleviation of these stresses on agriculture is biochar. Biochar is a solid, black, carbon byproduct of the pyrolysis of organic material. It is very stable at atmospheric conditions and can be used as a soil amendment (Lehmann et al. 2006). The addition of biochar to a soil provides many ecosystem services for the surrounding area. These include CO_2 sequestration, reductions in nutrient leaching, increased water holding capacity, and increased mycorrhizal activity (Barnes et al. 2011). Biochar can also increase the cation exchange capacity of soil, allowing for the mobility of cations that are useful plant nutrients (Lehmann et al. 2003). This, in addition to biochar's high porosity and surface area, allow for enhanced nutrient uptake capabilities for plants (Vaughn et al. 2015). Because biochar increases both the nutrient retention and the water holding capacity of soil, there is a decreased need for fertilization and watering.

A number of prior studies have investigated the effects of biochar amendment on plant growth. Many of these have shown an increase in plant biomass with the addition of biochar (Brennan et al. 2014). Some findings have shown that there are various other organic soil amendments, such as compost, that have comparable effects on agricultural production (Agegnehu et al. 2016). However, because biochar is composed of black carbon, it decomposes much more slowly than other organic soil amendments and therefore retains its beneficial chemical and physical characteristics for significantly longer periods of time (Lehmann et al. 2006; Kloss et al. 2014). Furthermore, the production of biochar has other potential applications with regards to sustainability. The off-gasses, such as methane, produced during pyrolysis can be collected and used as biofuel.

Improving agricultural productivity in any one area requires a great amount of specificity. Factors to be considered include crop selection, soil composition and fertility, regional climate, amount of soil microbial activity, and a plethora of other increasingly specific factors (Gruhn et al. 2000). Because the effects of biochar have been shown to vary both between plant types (Vaughn et al. 2014) and growing conditions (Singh et al. 2010), local research must be done before one can fully endorse the use of biochar in any given application.

In our study, we seek to determine whether biochar will increase aboveground biomass in sandy, disturbed soils from two urban demolition sites. These soils are essentially entisols (Table 1). Many other studies have been conducted in ferralsols (Agegnehu et al. 2016, Lehmann et al. 2003) or oxisols (Melgar et al. 1992). Our study, performed using glacially derived sandy soils from a temperate climate, exemplifies the studies that must be conducted to fully understand the most efficient application of biochar.

Figure 1. Greenhouse Experiment Setup

Greenhouse experiment plants after three weeks of growth

Table 1. Analyses of Soils

Attribute	Soil in Greenhouse Experiment	Soil in Garden Experiment
Phosphorus (P)	87 ppm	125 ppm
Potassium (K)	30 ppm	68 ppm
Magnesium (Mg)	89 ppm	188 ppm
Calcium (Ca)	622 ppm	1315 ppm
CEC	3.929 meq/100 g	8.316 meq/100 g
Soil Type	Mineral, Sand	Mineral, Loamy sand
Soil pH	7.2	6.9
Lime Index	0	0
Organic Matter	0.80%	3.7%

Soil characterized by the Michigan State University Soil Test Team in the Department of Crop and Soil Sciences

Figure 2. Garden Experiment Setup

Five test plots with oats and mung beans, after harvest of radishes.

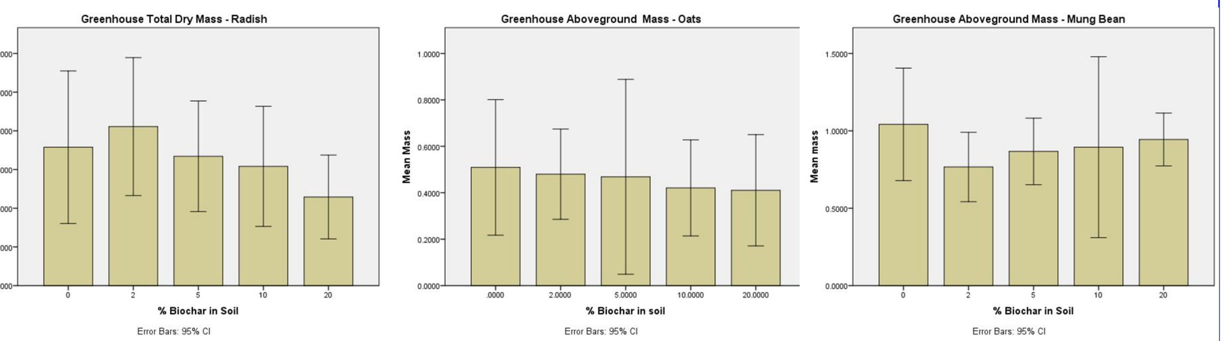
Table 2. Plant Survival in Garden Experiment

	Oat	Radish	Mung Bean
Control (soil only)	10	8	2
Compost	10	7	4
3% Biochar only	12*	5	7
3% Biochar + Compost Tea	13*	9	3
10% Biochar + Compost Tea	9	7	9

*Presence of more than 10 shoots above ground indicates either planting errors or multiple shoots from a single root system

Figure 3: Greenhouse data

Biochar shows no significant differences for any of the three plant species



Methods: Greenhouse Experiment

We collected soil at a building demolition site in Holland, Michigan, gathering material from the surface to a depth of ~10 cm. Soil was spread out indoors to air dry for at least 48 hours and screened with a 7.75 mm sieve to remove large stones and organic debris.

We purchased commercially available Mother Earth Premium Biochar (Sunlight Supply, Inc, Vancouver, WA) made from forest waste feedstock and passed it through a 2 mm sieve to remove larger fragments. The biochar was then rinsed several times with water to remove ash. The biochar was air dried, then mixed with compost tea made at the Hope College Physical Plant. Compost tea, water, and biochar were mixed in a ratio of 3:6:4 respectively. This mixture was aerated for 20 hours to inoculate the biochar. Soil was analyzed by the Michigan State University Soil Test Team in the Department of Crop and Soil Sciences. These results can be seen in Table 1.

The greenhouse experiment used five different soil treatments. These were soil alone as a control, and mixtures of soil and inoculated biochar with 2, 5, 10, and 20 percent biochar by mass. High-density polyethylene pipe, 4 inches in diameter, was used to make sixty 74.9 cm tall pots (Figure 1). A 15.2 cm square of aluminum door screen was attached to the bottom of each tube with a 10.2 cm hose clamp. These were filled with 30.5 cm of 1 cm pea gravel. The remaining 44.5 cm was filled with soil or soil/biochar mixtures. Plant species used were *Avena sativa* (common oat), *Vigna radiata* (mung bean), and *Raphanus sativus* (cherry belle radish), chosen from an OECD (2006) list of plants historically used in growth experiments. Pots were arranged in a completely randomized design and not moved for the entirety of the growth experiment.

Three seeds were planted in each pot to increase the likelihood of having one seed germinate. Each pot was given 750 mL of water initially, then 100 mL 4 hours after the initial watering. If, after the initial 750 mL of water the soil compressed more than 2.5 in, more soil was added to fill the pot, seeds were resown, and another 100 mL of water was added. Each pot was given 100 mL of water every other day for the remainder of the growth study. Once radish and mung bean seedlings had grown a set of true leaves and oat seedlings had begun to grow a second leaf, seedlings were thinned, leaving only the most viable plant (the tallest plant unless the tallest plant appeared unhealthy in any way).

After 5 weeks of growth, we cut *A. sativa* and *M. radiata* plants at soil level to harvest the aboveground plant matter. *R. sativus* plants were completely removed from the soil and weighed for fresh mass. All plants were then dried in a plant press and weighed. Data were analyzed for statistically significant differences between the aboveground biomass of different treatments in addition to the fresh weights for radish plants using SPSS univariate ANOVA.

Methods: Garden Experiment

An experimental site was prepared at Hope College's Community Garden (a vacant lot where a house formerly stood) by tilling soil 6 inches deep in five 20"x24" plots (Figure 2). Soil was analyzed by the Michigan State University Soil Test Team in the Department of Crop and Soil Sciences (Table 1).

Biochar was prepared as described for the greenhouse experiments, except that one treatment used rinsed biochar without inoculation. The garden experiment used five different soil treatments. These were soil alone as a control, soil with compost, soil with 3% biochar by mass, soil with 3% biochar inoculated in compost tea, and soil with 10% biochar inoculated in compost tea. Plants species used were again *Avena sativa* (common oat), *Vigna radiata* (mung bean), and *Raphanus sativus* (cherry belle radish). Each of the five plots were planted with 10 seeds of each of the three types of plants in rows in an east-west alignment. The plots were watered at the same time as the rest of the garden. The timing was sometimes irregular and based on local precipitation.

After 4 weeks of growth, *R. sativus* plants were completely removed from the soil, dried in a plant press, and weighed. *A. sativa* and *M. radiata* plants were cut at soil level and the aboveground plant matter was harvested at 6.5 weeks, dried, and weighed. We examined above-ground biomass for oats, which produce multiple shoots from the underground portion of the stem, so we compared total biomass from each plot rather than measuring masses of individual plants, normalized to 10 plants per plot. The lack of individual data precluded ANOVA analysis of the five plots for oats.

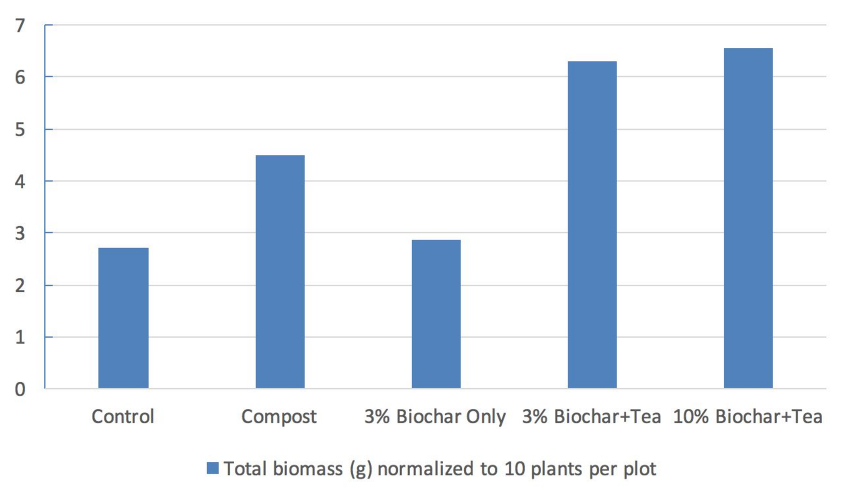
Results

The incorporation of biochar into disturbed, sandy soils gave varying results in our experiments. In the greenhouse experiment, no statistically significant differences were discovered between any treatments (Figure 3). After thinning, all plants survived the entire duration of the growth experiment.

However, some garden data were determined to be significant. Table 2 shows the survival of plants in the garden experiment. One factor that limited the statistical power to demonstrate significant differences was low survivorship of some treatments. For example, only two mung bean plants in the control treatment survived the entire growth period.

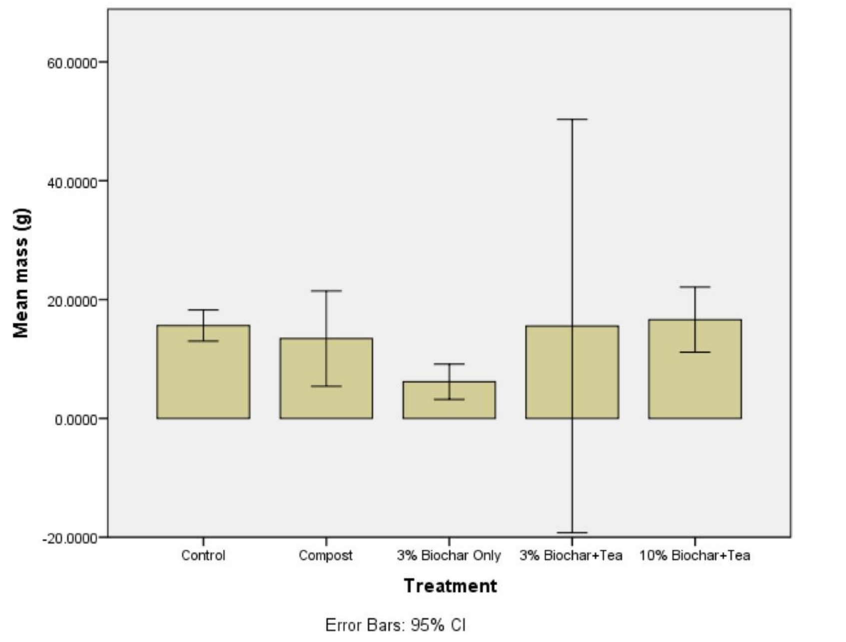
Both the 3% biochar + compost tea and the 10% biochar + compost tea treatments for oats had more than double the biomass of the control treatment, suggesting that biochar may improve growth for this crop in sandy, low-organic content soils like those in our test garden (Figure 4). Most of the oat seeds germinated and persisted in the garden, regardless of soil treatment. The only statistically significant differences in other treatments was that mung bean planted in 10% biochar had significantly more biomass than 3% biochar alone, as shown in Figure 5. Results for the statistical analyses of the radish plants are shown in Figure 6.

Figure 4. Oat Total Aboveground Biomass



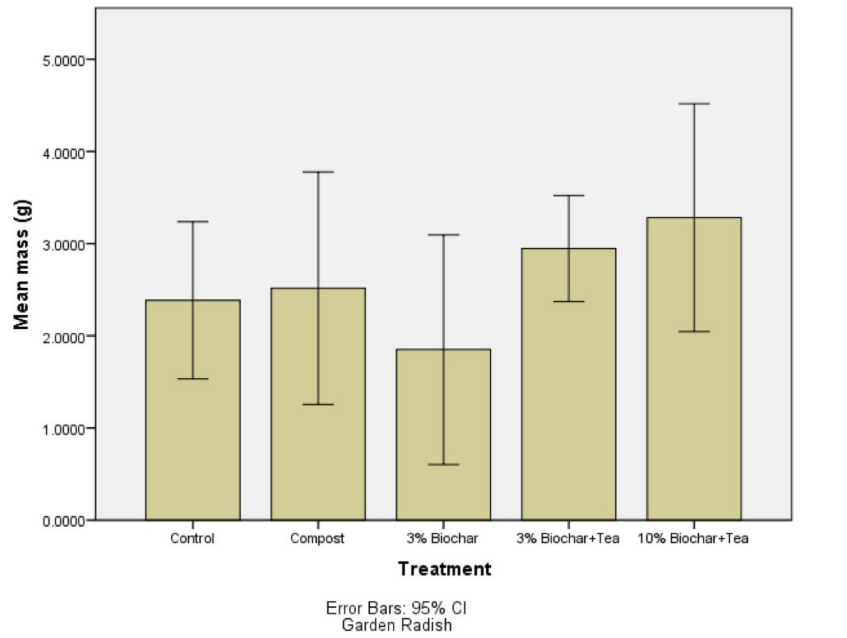
This figure compares the total aboveground biomass of oat plants in the garden experiment. Both the 3% Biochar+Tea and 10% Biochar+Tea treatments had more than double the amount of biomass of the control treatment.

Figure 5. Garden Experiment Results for Mung Bean



Shown here are the average masses of mung bean plants in the garden experiment. Mung beans of the 10% biochar+tea treatment were significantly larger than the 3% biochar only plants.

Figure 6. Garden Experiment Results for Radish



Compared in this figure are the mean masses of radish grown in the garden experiment. No significant difference was found amongst treatments.

Discussion

All plants grew relatively well in the controlled environment of the greenhouse experiment. In contrast, the variability of the outdoor garden experiment yielded significant differences in plant growth. One difference between the greenhouse and garden results was in the germination of seeds. Plants in the greenhouse experiment received a constant flow of water and were protected from the elements. This allowed for consistent germination of seeds. Furthermore, the methodology of the greenhouse experiment included planting multiple seeds per pot and weeding out the weakest plants. This type of growth experiment cannot be directly compared with that of the garden experiment where only ten seeds were planted for each species in each test plot. The number of germinating seeds became a factor that impacted the statistical analyses of the garden data. Although the loss of many plants weakened the strength of these tests it also presents establishment success as another factor to consider when assessing the effectiveness of biochar as a soil amendment. Loss of plants from non-germination or death of seedlings happened within the first three weeks following planting (June 23). All seedlings beyond that time persisted until July 22 (when radishes were harvested) or August 9 (when oats and mung beans were harvested). Biochar may therefore influence the early stages of plant growth, possibly through biochar making more nutrients available, or because of its ability to increase the soil's water retention. The varied number of successful plants in the garden experiment hinders biomass comparisons among individual plants since the plants that survived in plots with low numbers of plants, such as the mung beans in the control plot, grew with less competition for light, water, and nutrients. This could possibly skew results by allowing those few individuals to attain greater average biomass than was possible in more crowded plots. While these uncertainties cloud the results when assessing biochar's effect on radish and mung bean growth, our experiment shows that biochar charged with nutrients from compost tea caused a marked increase in aboveground biomass in oats.

Another result to note is that, while only statistically significant in mung beans, the average mass of plants grown in biochar alone was lower than other treatments in nearly all cases. This is consistent with the previous findings of Liang et al. (2014), who have shown that biochar can have nitrogen absorbing capabilities when used without the proper fertilizing agents, thus limiting nutrient availability to plants. Saturation with compost tea may have eliminated this nutrient disparity and led to the observed increases in biomass in the inoculated biochar treatments.

Overall, in growth experiments, it must be determined what the limiting factor in a plant's productivity is. This limiting factor may be water or nutrient supply, it could be a lack of sufficient soil microbial relationships, or it could be insufficient charge or pH of soil. Any of these factors can limit the growth of a plant. A full understanding of the impact of biochar will require us to identify the factor that must be altered in order to improve plant growth. In the case of our two comparative studies, the limiting factor in the garden was likely water supply relative to the greenhouse experiment. Within the garden experiment, the limiting factor was likely nutrient availability, which was altered by the presence or absence of compost tea that provided biochar with extra nutrients (Chan et al. 2007) and by the density of plants competing for nutrients in each plot.

Conclusions

- Greenhouse experiments showed no significant difference in plant growth between a control of soil alone and mixtures ranging from 2 to 20% inoculated biochar
- Oats grown in a garden plot had high rates of germination and survival in soil, compost, and biochar treatments, but plots containing biochar inoculated with compost tea produced more than double the biomass of the control plot
- Radish and mung beans in garden plots had variable rates of germination and survival, but did not clearly demonstrate significant differences among most soil treatments
- Uninoculated biochar may inhibit plant growth, at least initially, by taking up nutrients that would otherwise be available to plants

Acknowledgments

We thank T. Bultman, D. Dougherty, R. Stehouwer, and K. VanEerden of Hope College for technical assistance. Black River Public Schools graciously provided access to soil samples. Also, we gratefully acknowledge the donors to the Holleman Geology and Environmental Science Student Research Fund at Hope College, the Hope College Campus Sustainability Committee, and the Dean of Natural Sciences at Hope College for financial support of this project.

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