Organic Coating of Biochar by Compost-Incubation

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ABSTRACT

I conducted a common garden experiment by growing golden nugget tomatoes at the Oxford Tract Greenhouses at the University of California, Berkeley in Berkeley, CA. I tested the viability of incubating biochar and compost in the presence of a molasses solution to facilitate organic coating formation on biochar. From my results, I concluded that co-incubation at moderate biochar/compost levels leads to organic coating formation. Further, biochar elemental composition changes from co-incubation. Correlation between compost percentage in my treatments reached statistical significance ($P<0.05$) for the carbon to oxygen elemental ratio, potassium, and oxygen content. Although biological data reached statistical significance for tomato shoot height and number of leaves, the practical significance was limited, possibly to the limitations of my experimental design.

KEYWORDS

pot trial, sem, eds, molasses, tomato, common garden experiment, co-composting

INTRODUCTION

Food access is important, biochar can help. For many people however, getting access to food is not always guaranteed. In 2008, more than 49 million, or about 16% of Americans, faced food insecurity (Holben 2010). Further, there is the food desert problem, where inequalities in access to healthy foods disproportionately impact low-income neighborhoods (Gordon et al. 2011). In some areas, the discrepancy in healthy food access between high- and low-income neighborhoods is as high as 156% (Walker et al. 2010).

There are multiple approaches to combating the issue, ranging from policy-making, social and economic programs, food banks, and more. For my research project however, I chose to look at urban agriculture, as I thought it separated itself from other approaches to food issues because it enables a lot of self-agency within communities. Communities can decide what crops to grow based on what is culturally and nutritionally relevant to them, as well as the scale of implementation, ranging from centralized community gardens to individual homes. If affected neighborhoods were able to supplement fresh fruit and vegetables with urban agriculture, it would reduce their dependence on supermarket and improve food access. For highly perishable foods like vegetables, urban agriculture can account for an important share of their production as locally grown crops may be helpful in minimizing the spoilage of crops between harvest and consumption (Zezza and Tasciotti 2010). With this potential rise in urban agriculture, soil fertility is very important.

Biochar application is a potential method for increasing soil fertility. Biochar has been found to aid in crop yields on as long as four-year timeframes (Major et al. 2010). Although the mechanism for biochar facilitated crop yield improvement remains unclear, one proposed explanation is an organic coating on biochar (Hagemann et al. 2017). This organic coating is particularly prominent on co-composted biochar, which is produced when biochar is mixed with regular organic matter as microbial activity decomposes the organic matter into compost as well as develops an organic coating on the biochar (Khan et al. 2016). Although co-composted biochar seems promising in this regard, it also presents its own logistic challenges because co-composting requires a composting chamber, which can be bulky and costly, as well as being quite odorous as the raw materials decompose into compost. One potential alternative to co-composting is incubated-compost, in which biochar and compost are incubated together before being applied to soil (Khan et al. 2016).

Because it would be helpful in understanding optimal biochar application practices, my central research question is “can incubated-compost biochar serve as a viable alternative to co-composted biochar?” My first subquestion is “does incubated-compost lead to organic coating formation on biochar?” My second subquestion is “how does elemental composition of biochar change when incubated around different compost percentages?” My third subquestion is “how does plant growth vary at different treatment levels with respect to the number of leaves grown and overall plant yield?” To test these questions, I ran a pot trial by setting up pots with different proportions of compost and biochar at the Oxford Tract Greenhouses at the University of California, Berkeley in Berkeley, CA. I measured how the physical and chemical properties of the biochar changed through co-incubation and how plant growth varied between treatment groups.

METHODS

Study system description

I conducted my study as a common garden experiment at the Oxford Tract greenhouses at the University of California, Berkeley in Berkeley, CA. To determine the impact of compost on biochar, I grew tomatoes in soil mixtures consisting of different proportions of biochar to compost. I analyzed the elemental composition of biochar samples from the mixtures and recorded plant growth metrics.

Biochar creation and sourcing

Biochar is made by subjecting organic matter, such as nut shells and woody debris, to a process called pyrolysis. Pyrolysis is the thermal decomposition of biomass through heating at elevated temperatures (i.e. 250 degrees Celsius or more) in an inert environment (i.e. very little oxygen). This process results in a stable form of charcoal that can be used as a soil amendment. I obtained the biochar used in my study from All Power Labs (APL), located in Berkeley, CA. APL produced the biochar using a feedstock, or raw material subjected to pyrolysis, of walnut shells.

The technicians at APL heated the walnut shell mixture to a temperature of 800-900 degrees Celsius .

Compost creation and sourcing

I obtained the compost used in my study from the Oxford Tract field. This compost came from crop-scraps that were left over from experiments at the Oxford Tract field. The crop scraps were collected into a pile on the field and had a tarp placed over it as it decomposed.

Organic coating preparation

To facilitate organic coating formation on the biochar by the microbes in the compost, I made a molasses solution to provide sugar for microbial consumption (Hagemann et al. 2017). While there are different recommendations for the optimal concentration of molasses solutions for fermentation, most studies recommend concentrations around 20% molasses (w/w) (Doelle and Doelle 1990, El-Gendy et al. 2013). I made a 17% molasses (w/w) solution. I used “Grandma’s” brand molasses, which is sourced from sugar cane. I dissolved the molasses in water and mixed it thoroughly. I then mixed the molasses solution with the biochar to create a molasses-biochar slurry. I then used this molasses-biochar slurry to create different mixtures of sugary-biochar and compost in pots. These mixtures contained various combinations of biochar and compost, consisting of either component as 0, 17, 33, 50, 77, 83 and 100 percent of the total mass of the mixture. I then arranged these pots into a randomized 8x3 grid. The positions of each pot is shown below (Table 1). After I finished preparing all the pots for the various treatment levels in my experiment, I allowed the pots to sit in the greenhouse for 7 days.

Table 1: **Treatment level compositions.** Each cell represents a pot in the study, where the first and second percentage numbers denote the biochar and compost weight percentages, respectively. I have written in "compost" and "biochar" in the first cell as an example.

0% compost, 100% biochar	50%, 50%	50%, 50%
0%, 100%	33%, 67%	83%, 17%
33%, 67%	83%, 17%	67%, 33%
17%, 83%	17%, 83%	100%, 0%
100%, 0%	0%, 100%	100%, 0%
17%, 83%	83%, 17%	33%, 67%
67%, 33%	50%, 50%	67%, 33%
0%, 0%	0%, 0%	0%, 0%

SEM sample preparation

At the end of the 7 day incubation period, I collected 2 to 3 pieces of biochar from each pot and placed the pieces into separate sealable plastic bags for each treatment level. Before being analyzed by a scanning electron microscope (SEM), non-conductive samples needed to be prepared with a conductive coating to provide a path to ground for the electrons in the primary electron beam (PEB) of the SEM (UC Riverside n.d.). I applied a gold coating to each biochar sample using a Denton Vacuum Desk V Sample Preparation System. Although previous literature has criticized using gold as a coating material due to it adding unwanted peaks in the X-ray spectrum, the AZtec software by Oxford Instruments I used allowed me to specify that I had used a gold coating so that the software could ignore the gold signal coming from the coating on the sample.

Scanning electron microscope (SEM)

Imaging

In my experiment, I used the Zeiss Evo LS 10 scanning electron microscope to both image and characterize the elemental composition of my biochar samples. For imaging a sample, the SEM operates using the phenomena of backscattered electrons (BSE) and secondary electrons (SE). Firstly, the primary electron beam (PEB) fires a stream of electrons at the sample, which gives off BSE and SE (University of Louisville 2017)**.**

For BSE, the negatively charged electrons in the PEB are attracted to the positively charged protons in the nuclei of the sample. If the angle of approach of the electrons in the PEB are just right, the electrons can circle around the nucleus and make it to a detector. Depending on the angle of deflection of the BSE as they hit the detector, an image of the sample can be drawn (Iowa State University n.d.).

After the PEB hits the sample, SE can be ejected from the valence shell of the material in the sample. Depending on the time it takes for these SE to reach the detector, topographical image can be gathered about the sample (University of Louisville 2017)**.**

Elemental Analysis

I determined the elemental composition of each biochar sample using energy dispersive spectroscopy (EDS)**.** EDS works on the principle that high energy electrons excite valence shell electrons in the sample. In dropping from their excited state, the electrons release energy in the form of characteristic x-rays. I used a detector to draw the x-ray spectrum given off by the sample. From the spectral peaks coming off the sample, I determined the elemental composition. This is based on the fact that the wavelength of each spectral peak is directly related to which elements are present because the difference in the energy of the core and the shell is unique for each element (UC Riverside n.d.). Although EDS cannot measure absolute concentrations, I was still able to measure the weight percentage of each element in the sample by comparing relative peak heights in a given spectra (Kutchko and Kim 2006).

Plant growth experimental design

To determine the impact of varying biochar to compost ratios on plant growth, I grew tomatoes in a common garden experiment. Using the ratios previously mentioned (Table 1), I prepared each ratio in three replicate pots (Ren et al. 2012). With the exception of the controls, the I arranged the pots into a randomized 8x3 slot grid. At this time, I also added Sungro Horticulture's Sunshine Mix #4 soil, which consists of 70% peat moss and 30% perlite, to each of the pots. Each pot was seeded with three golden nugget heirloom tomato (*Lycopersicon* lycopersicum) seeds in a triangular pattern to account for potentially unviable seeds. These seeds were packaged for 2019 by the Lake Valley Seed Corporation. The greenhouse staff at the Oxford Tract watered the plants daily with tap water. They used natural light during the daytime to provide light for my plants. If it was cloudy on a given day, the greenhouse staff provided light to my plants using fluorescent lighting.

Plant growth

Height

I measured plant height using a graduated ruler, 26 days after seeding (T. W. Sammis et al. 1988). I defined plant height for my study as the distance from the soil surface to the apical bud along the shoot of each plant. Because the plant shoot is not perfectly straight, I stretched out each shoot to straighten it before measuring.

Number of leaves

I measured the number of leaves on each of my plants 26 days after seeding. Because external factors like temperature differences has been shown to result in variations in the number of leaves grown by tomato plants, I also chose to count the number of leaves on my tomato plants (Calvert 1957). I used the diagram of tomato plant morphology shown below to count the number of leaves on each of my plants (Figure 1) (Bonnie Plants n.d.).

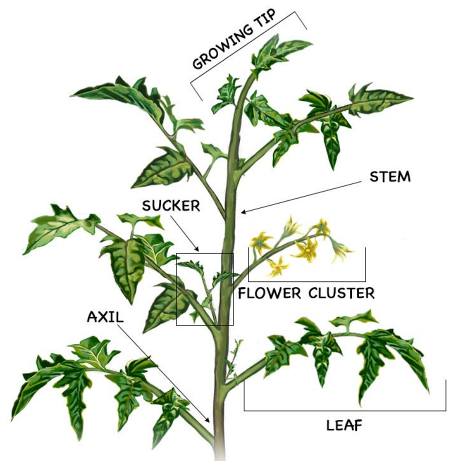

Figure 1: **Tomato plant diagram.** (Bonnie Plants n.d.)

Data analysis

After collecting all of my data for the elemental composition of my biochar samples, plant height, and number of leaves, I took the average values for each of the treatment groups. Using these averages, I ran simple linear regressions for each of the outcome variables using R version 3.5.1 and the R Commander package version 2.5-1.

RESULTS

SEM imaging

Through imaging by the SEM, I observed partial coating of the biochar samples from the treatment groups containing 23% and 50% biochar (figure 2). I have included an image produced by a previous study researching organic coating formation on biochar for comparison (figure 3).

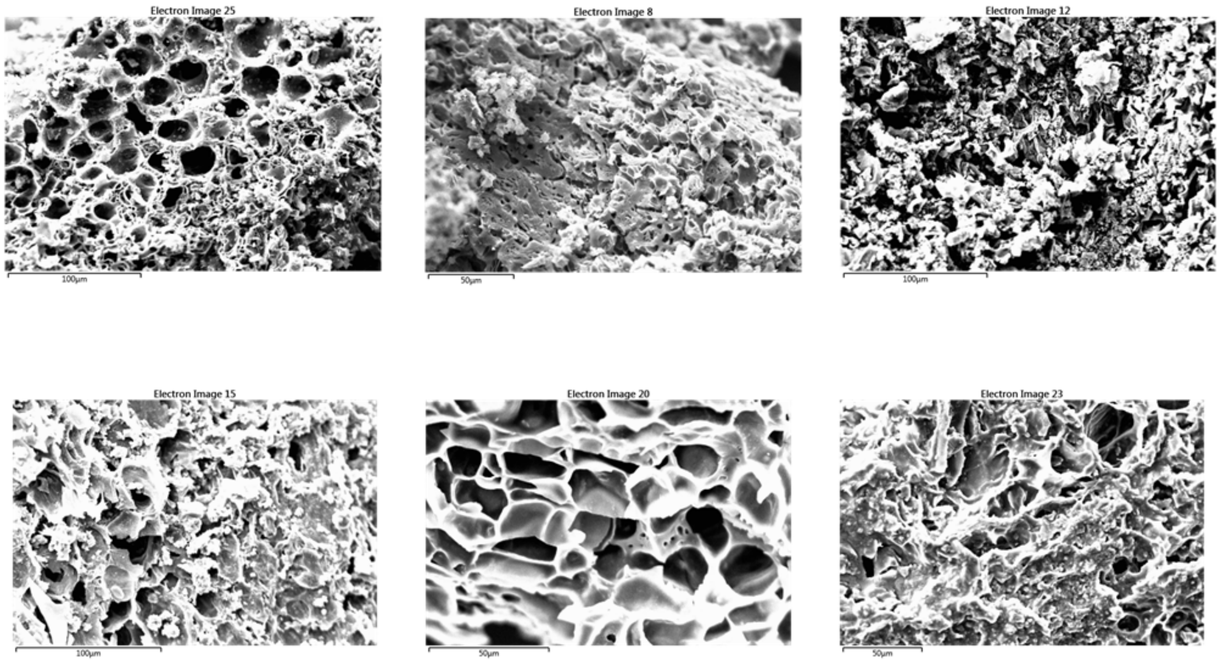

Figure 2. Selected images of biochar samples from my study. Pictured here are biochar samples collected after one week of incubation in compost. From left to right, top to bottom, the images are from treatment groups with compost percentages of: 17, 23, 50, 67, 83, and 100, respectively.

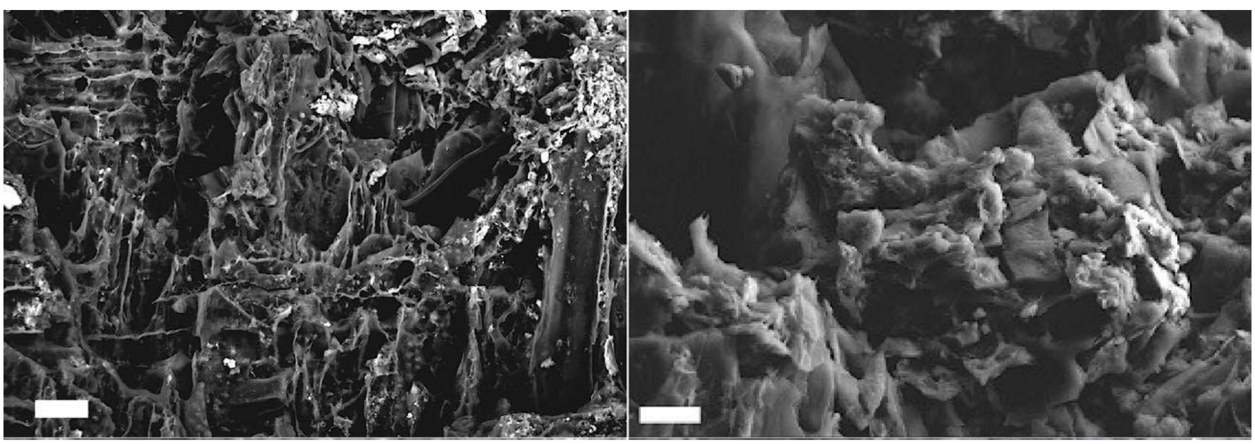

Figure 3. Images of biochar from previous study. Pictured here are unaltered biochar (left) and biochar surface partially covered with an organic coating (right) (scale bar 10 microns). Source: (Hagemann et al. 2017)

Elemental analysis by EDS

After I performed a linear regression for each element with the treatment compost percentage, I found that potassium (K), oxygen (O), and the ratio between carbon and oxygen (C:O) were statistically significant. I produced the following regression equations (1), (2), and (3):

(1): K (Wt %) = (-0.06825 ± 0.02374)*Compost (%) - (6.89 ± 1.25) with R^2 = 0.6739, F(1, 4) =8.265 , p = 0.04525.

(2): O (Wt %) = (-0.18045 ± 0.06)*Compost (%) - (23.72 ± 3.39) with R^2 = 0.6636, F(1, 4) =7.892 , p = 0.04835.

(3): C:O (Wt %) = (0.08542 ± 0.03)*Compost (%) - (4.28 ± 1.57) with R^2 = 0.673 , F(1, 4) =8.234 , p = 0.04549.

For the rest of the elements tested, I found that the p-values failed to reach statistical significance. I have summarized these p-values and other relevant statistical information below (Table 2).

Table 2. Summary of tests for correlation. "r" values were obtained using Pearson's product-moment correlation.

Element	df	F value	P value	r	Significant?
C:O	4	8.234	0.0455	0.8204	Yes
K	4	8.265	0.0453	-0.8209	Yes
O	4	7.892	0.0484	-0.8146	Yes
C	4	5.458	0.0797	0.7597	No
Al	4	n/a	0.5874	n/a	No
Ca	4	n/a	0.71	n/a	No
Cl	4	n/a	0.6962	n/a	No
Mg	4	n/a	0.1609	n/a	No
Si	4	n/a	0.6755	n/a	No

Plants

Height

After performing a linear regression on my plant data, I modeled plant height with the following equation: Plant height (cm) = (0.10 ± 0.03)*Compost (%) - (1.22 ± 1.88) with R^2 = 0.6818, F(1, 5) =10.71, p = 0.02212.

Number of leaves

After performing a linear regression on my plant data, I modeled plant leaves with the following equation: Number of leaves = (0.048 ± 0.015)*Compost (%) - (0.74 ± 0.91) with $R^2 = 0.6763$, $F(1, 5) = 10.45$, $p = 0.02315$.

DISCUSSION

Properties of the biochar samples

Visualization of organic coating

I found organic coating formation in the treatment groups containing intermediate proportions of compost (23% and 50% compost). This may be because fermentative processes are inhibited when molasses concentrations get too high (Doelle and Doelle 1990). Because I soaked my biochar in molasses solution, by keeping the biochar percentage down in these treatment levels, this prevented the inhibitory effects to fermentation. This is important because when it comes to organic coating formation, microbial activity could play an important role (Hagemann et al. 2017).

Elemental analysis of biochar samples

Carbon to oxygen ratio. I found that as compost percentage in my treatments increased, the C:O ratio on my biochar samples increased. This is the reverse trend to what has been found in co-composting, where the biochar O:C ratio increased (i.e. the C:O ratio decreased) (Hagemann et al. 2017). This suggests that there may be a difference in how carbon is sorbed onto biochar particles when conducting co-composting compared to co-incubation experiments.

Potassium. I found that as compost percentage in my treatments increased, the potassium content of my biochar samples decreased. This coincides with a previous study that found that co-incubated chicken litter had less potassium than that of plain chicken litter (Khan et al. 2016).

Carbon. After co-incubation with compost, changes in carbon content of my biochar samples failed to reach statistical significance (P=0.0797). Further, I found that the 95% confidence interval when taking the Pearson product-moment correlation coefficient spanned zero (-0.1353544, 0.9719824). This suggests that co-incubation with compost does not significantly affect carbon content on biochar. This is further corroborated by previous research that found that there was only a small (1.0%) increase in C content in co-incubated chicken litter compared to plain chicken litter (Khan et al. 2016). When comparing this to the effect of co-composting, the difference between carbon content in co-composted and macadamia nut shells was as much as 12.4%. This suggests that co-composting leads to higher carbon sorption onto biochar compared to co-incubation.

However, due to the small sample size of my study, and the relatively close p-value to significance, further research should be done with a larger sample size to see if the carbon data can reach statistical significance.

Plant growth

Although my data for plant height and number of leaves was statistically significant, I think it is practically insignificant in that the actual effect is quite small. For example, by increasing the compost percentage in the treatment by 10 percent, I would only expect a 1cm change in plant height.

The plants in the control pots of plain soil grew far better than the rest of the treatment groups in terms of both plant height and number of leaves. However, this may be because of limitations in my study design.

Limitations

Although my study design allowed me to test for changes in biochar material properties, there were two limitations to my study design. Firstly, my controls were not randomized. They were instead placed at the edge of the grid, which may have introduced bias into their growth patterns whether by the way they were watered, how much light they received, or etc. Secondly, while the experimental pots received about 100g of soil each, the control pots received about 250g of soil each, due to size limitations of the pots I used. The additional soil in the control pots may have contributed to the better growth I observed.

Future directions

In the future, I should address the limitations of my experimental design, such as by randomizing my control pots in with the rest of the experimental layout. Further, I should set up future experiments such that all the pots receive the same amount of soil, with the compost and biochar added as a soil amendment in their accordingly chosen ratios. Additionally, I should conduct future experiments with more treatment levels so that I can have a larger sample size to see if the carbon data can research statistical significance.

Other considerations include testing with different plants and different types of biochar. For the latter, biochar produced with different feedstocks and production temperatures can alter the properties of the biochar (Zhao et al. 2013).

Broader implications

The knowledge I have produced in this project will give insight into how co-incubation and/or co-composting can be used to help biochar work best as a soil amendment for improving soil fertility. This will have implications in urban agriculture if biochar can be used for this purpose. If food wastes can be used for either of these processes, this would provide a useful pathway instead of having food wastes end up in landfills.

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