THE ELASTICITY OF BIOCHAR ACROSS THE FARM: NUTRIENT CAPTURE, COMPOST FEEDSTOCK, AND SOIL AMENDMENT

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ABSTRACT

When biomass is thermochemically altered in a low oxygen environment over a wide range of temperatures, the solid, carbon rich material that results is biochar. Biochar is an appealing material as a farm management tool because its potential use is varied, owing, in part, to its unique physicochemical properties. To better understand the potential on-farm use of biochar and its effect on nitrogen capture, we selected two regionally produced biochars (80 and 88 % C), and collaborated with a local compost producer to design two experiments: 1) each biochar was blended with manure bedding mix at a rate of 40.79 lb C, placed in 150.5 gallon stock tanks, allowed to rest for three weeks and analyzed for moisture, total C and N, NO_3-N, and NH_4-N, included in the experiment was an unblended manure bedding mix, which acted as the control, and 2) after the stock tank process was replicated three times, the total material for each treatment (biochar 1 and 2 and the manure/bedding mix control) was combined with additional manure/bedding mix (300 gallons) in a 450 gallon aerated composting vessel, composted for four weeks, and analyzed for moisture, total C and N, NO_3-N, and NH_4-N. Because composts are often used as soil amendments in vegetable production, we designed an additional field experiment that included six treatments (biochar 1, biochar 2, compost biochar 1, compost biochar 2, compost control, and control). Treatments were amended to meet an application rate of 8921.79 lb C acre^{-1} (dry) and then planted to broccoli. Following one growing season, broccoli plants and soil samples were collected and analyzed for yield biomass and bulk density, respectively. Nutrient and yield results suggest that biochar had very little effect on nutrient capture, though following amendment and incorporation, effects on soil physical properties, like bulk density, were observed.

INTRODUCTION

Woody waste material, which includes forestry residuals, hog fuel and construction debris, can be thermochemically altered in an oxygen deprived environment in a process known as pyrolysis. Under ideal conditions (temperatures above 482° F) and in modern systems, three products can result from biomass pyrolysis: an oil, a gas, and a solid. The gas and liquid products are often captured and utilized as fuel sources, among other uses, while the solid, commonly known as biochar, can be used utilized as a tool in environmental management (e.g., soil amendment or bioremediation). In part, what makes biochar so flexible in use, is its physicochemical properties: it has a high surface area and a varied porous structure, and, it is generally low in bulk density and made primarily of stable carbon (C). When biochar is used as an additive (e.g., soil amendment) these physicochemical properties impart certain generalizable functions. For example, biochar influences chemical properties like those involved in the sorption and desorption of organic and inorganic compounds, and it can alter physical properties like bulk density, permeability, and porosity.

Much research has focused on the use of biochar and its ability to adsorb organic and inorganic compounds. In organic mediums that include liquid, gaseous, and solid phases like those of manures, composts, and soils, biochar is frequently incorporated to retain elements like nitrogen (N). This approach, though not strictly limited to N, is frequently described as nutrient capture or retention, and the mechanisms responsible for this function are varied. Evidence from several discrete studies suggest that biochar can be used effectively to reduce nutrient loss in these same mediums (i.e., cow manure, composts, and soils). These effects, however, depend upon the properties of the biochar.

Therefore, the objective of this research is to evaluate the potential nutrient capture of two regionally produced biochars via on-farm use as an additive in manure/bedding mixes, a feedstock for a downstream compost product, and as an amendment in local vegetable production.

METHODS

Stock tank experiment

Biochar was purchased from two commercial manufacturers, Oregon Biochar Solutions (White City, OR) (Bior) and Olympic Biochar Solutions (Port Orchard, WA) (Bioly), and produced from pine and Douglas fir forestry residuals at 1600 °F and from Douglas fir, hemlock, alder and pine hog fuel and construction debris at 2004 °F, respectively. Additional biochar characteristics are listed in Table 1.

The manure/bedding mix was collected from animal pens, mixed on a concrete pad, and scooped into each of three 150-gallon stock tanks. Bioly and Bior were incorporated into each of two filled stock tanks at a rate of 40.79 lb C (dry), while the third filled stock tank, without biochar addition, was treated as the control. The three tanks were placed in a dry covered storage area and allowed to rest - exposed to ambient air temperatures - for three weeks. Then, three sub- samples from each of three stock tanks were collected, homogenized, and composited into an individual sample for each treatment. Samples were sealed in plastic bags and frozen, and later analyzed for moisture, total C and N, and inorganic N, on a dry and as-is basis. The remaining material was used as feedstock for the composting experiment and the entire process was repeated two additional times.

Table 1. Chemical and physical properties of the biochar products included in the study.

Biochar	% total C[†]	% total N	C/N	% ash	Surface area ($ft^2\ lb^{-1}$)	Particle size range (in)
Olympic biochar	80.7	0.97	83.2	6.5	1.758×10^6	<0.019 - 0.315
Oregon biochar	88.0	0.78	112.8	3.7	2.226×10^6	0.039 - 0.157

[†]Total C and N, C/N, and ash are on a dry weight basis

Compost experiment

To evaluate the effects of biochar incorporation on the composting process, each of three stock tank materials (i.e., manure/bedding control, and two biochar blended manure/bedding mixes) was turned out onto a clean concrete pad, blended with 300 gallons of additional fresh manure/bedding material, and this new material (450 gallons in total) was homogenized and scooped into a 450-gallon, square plywood composting reactor. The composting vessels were capped with 75 lb of wood chips and outfitted with temperature probes positioned midway between the top and bottom of the reactor (data not shown). Reactors were placed in a dry covered area and the materials were composted for four weeks, sampled, and then analyzed for moisture, total C and N, and inorganic N on a dry and as-is basis. This process was repeated an additional two times, and each of the three materials from all three repetitions were combined into separate piles and stored until use in the field experiment.

Field experiment

Six treatments were arranged in a randomized complete block design, with four repetitions, across two, 100-foot, vegetable beds. The six treatments included: a control, Bior alone, Bioly alone, composted Bior (BiorC), composted Bioly (BiolyC) and a control compost (CC). Treatments were applied, by hand, to 32 ft^2 research plots to meet an application rate of 8921.79 lb C $acre^{-1}$ (dry); amendment rates are listed in table 2. Following application, amended plots were tilled to a depth of six inches, and evaluated for bulk density following one growing season.

Broccoli ‘green magic’ starts were grown from seed, in a greenhouse, for four weeks, and then transplanted into each of two beds, in two rows at 15 and 18 inch, in-row and between row spacing, respectively. Broccoli plants were fertilized with a 12-0-0 feather meal product at 104 lbs N $acre^{-1}$ and irrigated by drip irrigation. Once main shoots reached a marketable size, they were collected, counted, and weighed.

Table 2. Quantity of material applied to meet targeted carbon rate.

Treatment	Material applied (tons $acre^{-1}$)
Control compost	31.2
Oregon biochar	11.2
Olympic biochar	17.3
Composted Oregon biochar	29.3
Composted Olympic biochar	30.8

RESULTS AND DISCUSSION

Stock tank experiment

Overall, and in comparisons between treatments, no statistical differences were observed for any of the properties evaluated. Following biochar incorporation, we expected to see variation in inorganic N, but concentrations of NH_4-N and NO_3-N were below detectable levels (data not shown). This is likely due to the high levels of moisture in the material (Table 3), which may have impeded mineralization. Interestingly, we observed an increasing trend for total C and N treatment means (Bioor > Bioly > Control) which followed the concentration of added C (i.e., in the form of biochar).

Table 3. Treatment mean values for selected properties following stock tank incubation.

Treatment	% moisture	% total C††	% total N
Oregon biochar	74.46	52.9	1.23
Olympic biochar	75.16	44.5	1.20
Control	74.67	36.6	1.02

††Total C and N are on dry weight basis.

Compost experiment

The C and N content for the three composted materials was largely in line with expectations (Figure 1). C/N ratios for biochar amended materials (BiolyC and BiorC) were significantly greater than the control, reflecting the additional C in the form of biochar (Figure 1b), and total and organic N concentrations illustrated small, but significant differences between treatments (i.e., Control > BiorC > BiolyC) (Figure 1c,d). Given the low nutrient content of the biochars, the differences in total and organic N content likely reflect nutrient dilution, caused by the additional biochar material which was amended at different volumes (e.g., 15 and 9% (v/v), Bior and Bioly, respectively) to meet an equal amount of dry C. This is further supported, in part, by the levels of NH_4-N and NO_3-N which were below detectable limits and thus, had very little impact on total N concentrations.

Similar to the stock tank experiment, moisture levels were consistently high in all materials (75%) and no treatment significantly increased or decreased moisture content (data not shown).

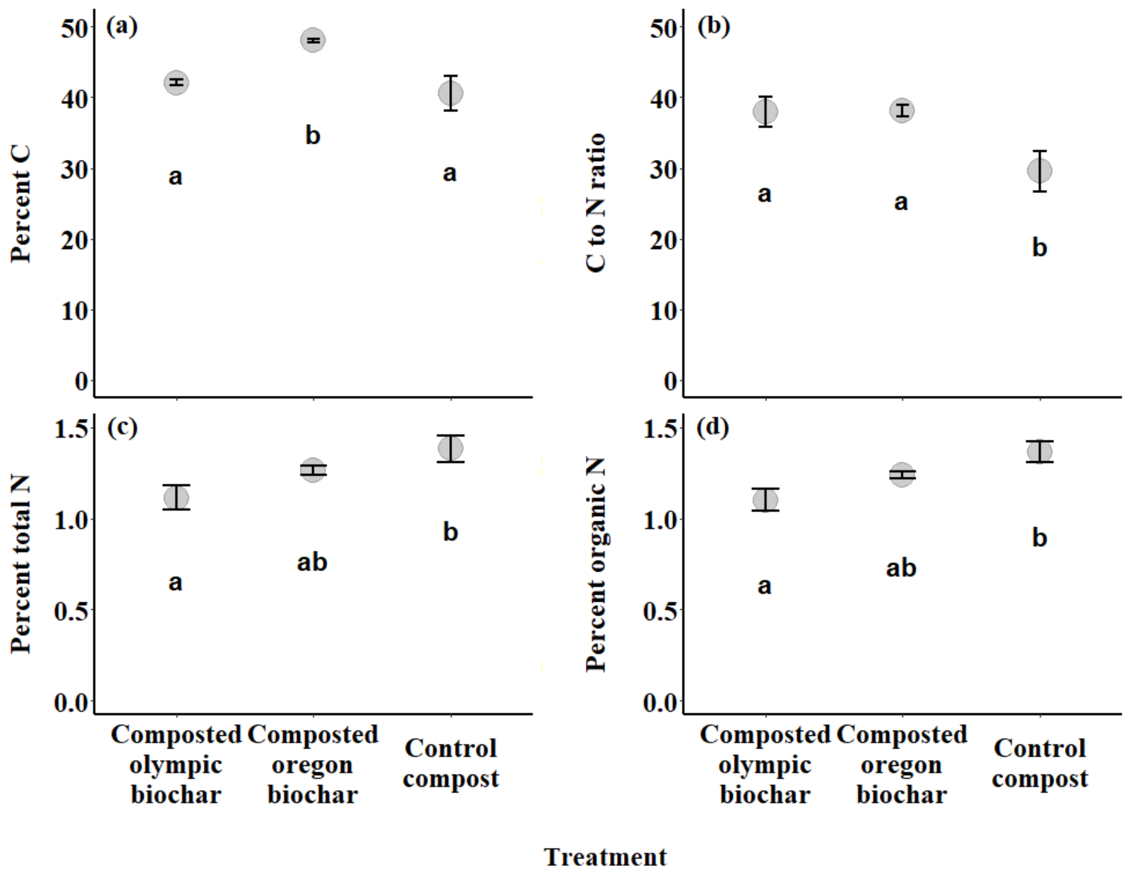

Figure 1. Treatment means for percent C (a), C to N ratio (b), percent total N (c), and percent organic N (d) following four weeks of composting. Letters in (a), (b), (c), and (d) indicate results of Tukey's HSD test ($p < .05$). Chemical properties are presented on a dry weight basis.

Field experiment

There were no clear trends in soil bulk density values following amendment. In comparisons with the control, only the Bior and BiolyC treatments significantly decreased soil bulk density (Figure 2). Other researchers have observed linear relationships between soil bulk density and amendment rate (i.e., soil bulk density decreases as amendment rate increases), but

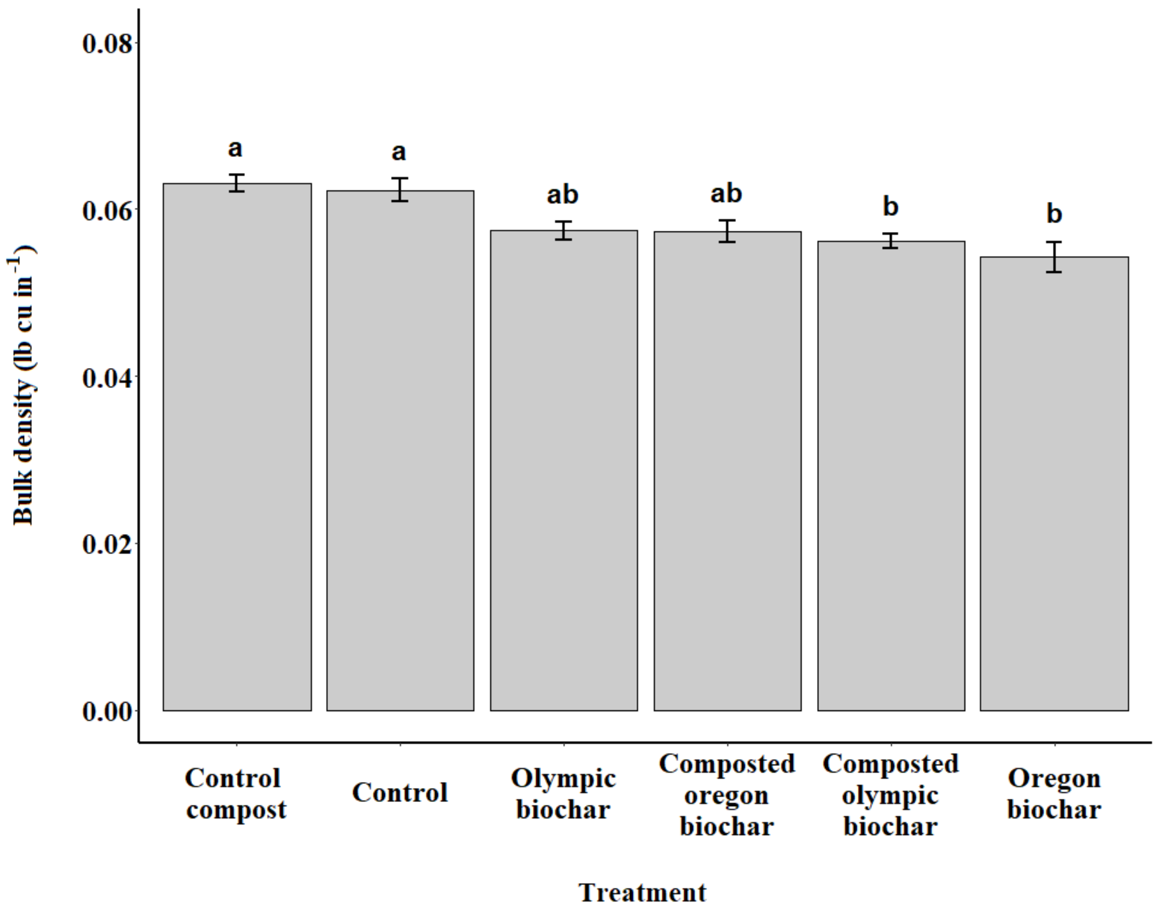

Figure 2. Soil bulk densities following treatment and one growing season. Letters above a bar indicate results of Tukey's HSD test ($p<0.05$).

in our study we observed nearly the opposite. The CC treatment, amended at the highest material rate, had no effect on soil bulk density when compared to the control, while the Bior treatment, amended at the lowest material rate, had the greatest effect on soil bulk density. The amount of labile C in each treatment may have something to do with this observation, but the inconsistent results, including bulk density values for BiolyC and BiorC treatments, make clear interpretation difficult.

Following amendment and one growing season mean broccoli yields ranged from 6672 to 9079 lb acre^{-1}. In comparisons with the control, however, no significant differences in yield were observed between treatments (Figure 3). This is likely a result of the high C/N ratios in the materials (Figure 1b). Even so, as the C/N of the material decreased (composted materials < biochars), yields increased (composted materials > biochars). This effect may have been more pronounced if we had not included a supplement N application which could have masked different N mineralization rates between treatments. Additional plant nutrients supplied by the compost and co-composted biochar amendments may have also contributed to the trend in broccoli yields.

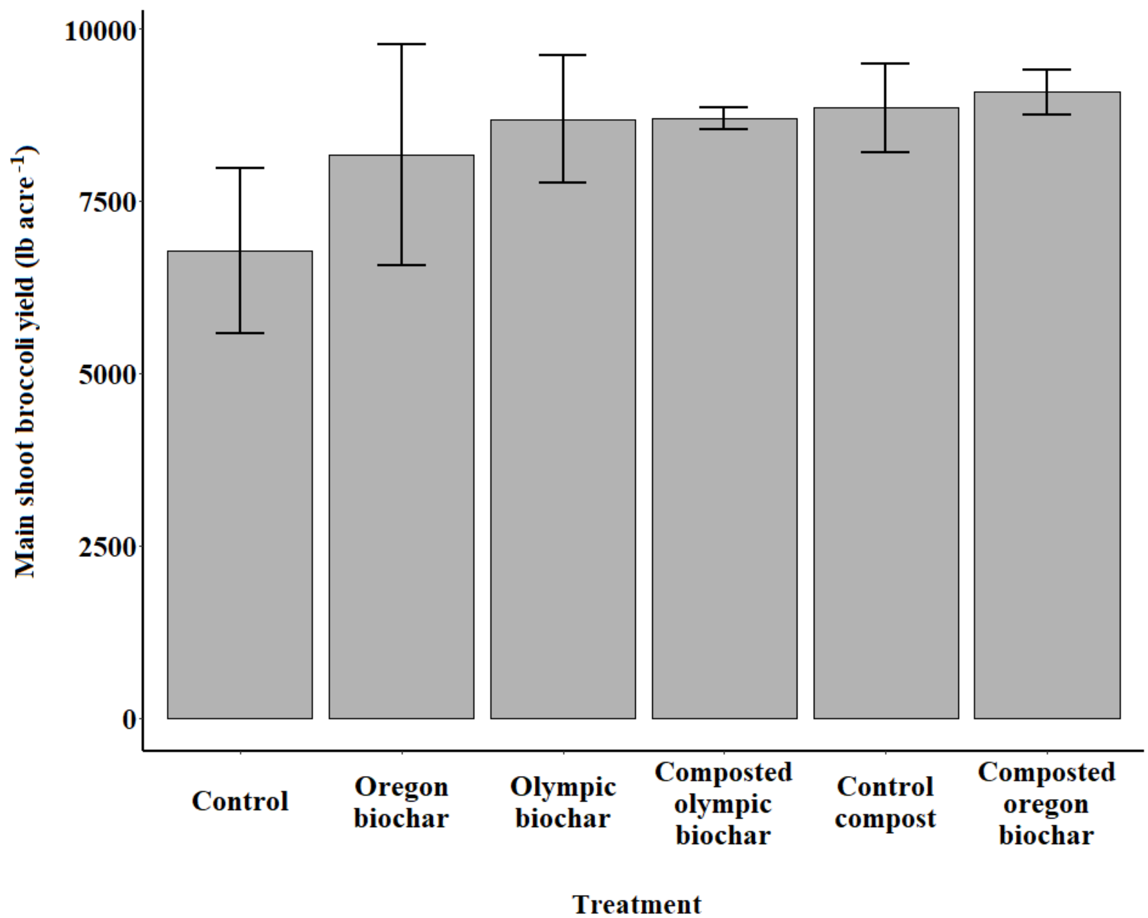

Figure 2. Broccoli main shoot yields for each treatment following amendment and one growing season.

At the rates utilized in this study, and when blended with manure/bedding mixes and composted, these two biochars had little effect on nutrient capture, and thus, no effect on broccoli yield. Amending soils with biochar and co-composted biochar materials, however, did reduce bulk density, but the physicochemical properties of the material likely had an impact on the magnitude of that effect. As many other researchers have observed, for biochar to be an effective environmental and farm tool, users must take into consideration, the physicochemical properties, application rate, and intended use of the biochar material.