PACIFIC BIOCHAR

# Biochar + Compost

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Biochar can improve the compost process, and in turn the biochar is improved as well. Amending early stage compost with biochar can result in reduced nutrient loss, reduced greenhouse gas emissions, and other benefits. During composting, biochar is improved with benefits such as added complexity to biochar surfaces resulting in increased functionality and nutrient loading. (1)

Charcoal (biochar) is well known as a filter for gases and liquids. When biochar is added to compost, this filtration characteristic is directly related to measured results of lowered leaching and volatilization of plant nutrients, particularly nitrogen. Increased aeration, improved microbial habitat, and other mechanisms come into play as well, though with varying importance depending on the context. Using biochar and compost together is a powerful tool to reduce odors and emissions, reduce leaching of nutrients into waterways and groundwater, and conserve nutrients in the compost in forms that can help promote soil health and plant vigor. Commonly observed by the authors is that where compost has been amended with biochar, the nitrogen trends significantly towards nitrate rather than ammonia/ammonium. (1, 2, 8, 10)

Greenhouse gas emissions from composting are inescapable, biochar presents a tool to help mitigate the issue, and with additional benefits. Of particular interest are the emissions of nitrous oxides, methane, and ammonia, all of which can be reduced with prudent use of biochar as demonstrated by studies referenced below. In some cases where biochar is used in composting nitrogen loss has been found to be cut in half and greenhouse gas emissions reduced by a similar factor. In the experience of the authors, when biochar is added to compost, the immediate and prolonged reduction in ammonia smell can be profound (7, 9, 11)

During the compost process biochar surfaces become weathered, building up an organic coating. The organic coating formed during composting has been shown to further enhance surface functionality, cation exchange capacity, and biochar's capacity to bind anions such as nitrate and phosphate.(3, 4) In the experience of the authors, this can be visibly observed as a reduced reflectiveness of the biochar, as it's originally shiny surface develops an organic coating.

In the compost environment microorganisms transform raw organic materials into stable soil aggregates. Biochar provides superb habitat for these microorganisms. The diversity of pores and functional surfaces in biochar particles form a structure on which microorganisms can easily proliferate and diversify. Biochar's unique physicochemical characteristics provide access to air, water, nutrients, protection from predation, and a favorable environment for metabolic reactions. Studies demonstrate that biochar-amended compost increases microbial activity and diversity, improves nutrient cycling, and achieves higher levels of humification. (5, 6)

Compost amended with biochar is regularly reported to mature faster. This maturity is often observed in the field as more quickly reaching a sweet smell and pleasant hand feel. For some compost producers, this factor can be incredibly important, reducing the processing costs that accumulate with time. In lab analysis of finished compost, it is common to find maturity indices such as lower respiration rates, higher concentration of humic substances, and lower ratio of ammonia to nitrate in biochar amended compost when compared to unamended material. (1, 5, 6) In the experiments and observations of the authors, additions of biochar at 4% to 10% by volume are generally sufficient to achieve these results.

Aged biochar, as opposed to raw biochar, consistently shows better characteristics for aiding in plant growth in field trials. The ageing of biochar can happen relatively fast in a compost environment when compared to ageing in soil. In applying biochar amended compost, studies show immediate (first season) and dramatic increases in plant growth response beyond what the comparative compost provides without biochar. (1, 2, 3, 4)

Compost benefits from additions of biochar, biochar benefits from the compost process, plant growth response can be improved, soil health can be improved, and all of these benefits can be both economically and ecologically valuable.

**Reference section, with personal content notes added:**


1. Fischer, Daniel, and Bruno Glaser. “Synergisms between Compost and Biochar for Sustainable Soil Amelioration.” Management of Organic Waste, 2012, doi:10.5772/31200.
    a. Biochar and compost both contribute to the pool of stable soil carbon held in soil organic matter.
    b. Compost contains a majority of labile carbon available for microbial respiration with a small portion of stable carbon contained in humus complexes and the bodies of microorganisms.
    c. Biochar contains a small portion of labile carbon with the majority being present as poly-aromatic condensed carbon compounds with a high degree of recalcitrance.
    d. Biochar made from woody feedstocks at high temperatures contain more stable carbon and less labile carbon when compared to biochar produced at low temperatures and from feedstocks such as manure.
    e. Biochar made from materials like manure contains a higher mineral content and contributes additional fertilizer value while supplying labile carbon available for microbial respiration.

f. Biochar reduces leaching and volatilization of nutrients, specifically nitrogen species, during composting thereby increasing the nutrient value of biochar amended compost and reducing greenhouse gas emissions.
g. Biochar improves aeration, water retention and infiltration, reduces bulk density, and provides habitat for supporting increased populations of microorganisms.
h. Symbiotic relationships between biochar and free living nitrogen fixing bacteria and arbuscular mycorrhizal fungi have been observed along with increased root nodulation in legumes following biochar application.

2. Kammann, Claudia I., et al. “Plant Growth Improvement Mediated by Nitrate Capture in Co-Composted Biochar.” Scientific Reports, vol. 5, no. 1, 2015, doi:10.1038/srep11080.
    a. Biochar has been shown to produce a range of plant growth responses both enhancing and reducing aboveground biomass primarily as a result of nutrient loading occuring before or after soil application.
    b. It has been shown that applying “raw” biochar directly to soil prior to planting can produce a negative plant growth response due to nutrient loading of biochar surfaces occuring in the soil and thus reducing the availability of plant nutrients.
    c. In contrast, nutrient loading prior to soil application (i.e. co-composting biochar with organic waste) demonstrated a dramatic increase in aboveground biomass.
    d. In this study quinoa was used to assess plant growth response to soil applications of biochar using woody biochar produced at 700 $^{o}$C.
    e. Co-composting biochar resulted in an aboveground biomass yield increase of 305% while applying “raw” biochar resulted in a yield decrease to 60% of the control demonstrating the enhanced benefits of biochar nutrient loading prior to soil application.

3. Joseph, Stephen, et al. “Microstructural and Associated Chemical Changes during the Composting of a High Temperature Biochar: Mechanisms for Nitrate, Phosphate and Other Nutrient Retention and Release.” Science of The Total Environment, vol. 618, 2018, pp. 1210–1223., doi:10.1016/j.scitotenv.2017.09.200.
    a. Co-composting biochar alters functional surfaces by complexing with organomineral compounds including humic substances, carbon nanoparticles, and inorganic minerals, clays, and metals present during the composting process.
    b. During co-composting bichar surfaces develop additional functionality demonstrated by changes in the C-O moieties resulting primarily from interactions with organic and inorganic compounds and soluble nutrients with little evidence of direct oxidation of biochar surfaces.
    c. Co-composting facilitates entrainment of nutrient-rich water within micropores, enabling charged compounds to be held tightly with water by capillary action and osmotic forces within small inner pores within the biochar matrix.

d. Nitrate and phosphate retention is enhanced by the organomineral complexing that occurs during co-composting, increasing pore diversity and functional surfaces capable of adsorbing and retaining anions in solution.
e. Release of nutrients loaded on biochar surfaces during co-composting to plants occurs across a concentration gradient in the soil (high concentration within biochar particles move toward low concentrations around plant roots) and within the biochar matrix subject to pore clogging, electrostatic and H-bonding forces.

4. Hagemann, Nikolas, et al. "Organic Coating on Biochar Explains Its Nutrient Retention and Stimulation of Soil Fertility." Nature Communications, vol. 8, no. 1, 2017, doi:10.1038/s41467-017-01123-0.
    a. Surface oxidation plays a minor role in enhancing biochar functionality when compared with the organic coating resulting from co-composting.
    b. Organic coating alters biochar surfaces non-homogeneously with hotspots around outer surfaces and inner pores.
    c. Co-composting altered the elemental composition of the organic coating on biochar surfaces reducing the abundance of CHO and increasing CHON bearing compound classes while an extraction of the organic coating and subsequent analysis revealed enrichment of nitrate, organic carbon, carbonate, Ca, and K when compared with non-composted pristine biochar.
    d. NMR spectroscopy revealed that the differences in organic carbon speciation observed in co-composted biochar versus pristine biochar cannot be explained by transformation of the existing biochar carbon alone and must result from the introduction of new carbon species from the composting process
    e. Co-composting does not substantially affect biochar bulk carbon speciation and therefore carbon stability is unaffected by the composting process.
    f. The organic coating may actually help preserve aromatic carbon structures from oxidative degradation leading to increased longevity in soils.
    g. Biochar nanoparticles created during co-composting associate with compost organic matter to form and shape the porous organic coating
    h. The organic coating increases overall porosity while also contributing to pore clogging by a build-up of humic-like organic compounds on the inner surfaces of pores, restricting water mobility and contributing to water adsorption and soluble nutrient retention.

5. Sanchez-Monedero, M.a., et al. "Role of Biochar as an Additive in Organic Waste Composting." Bioresource Technology, vol. 247, 2018, pp. 1155–1164., doi:10.1016/j.biortech.2017.09.193.
    a. Biochar improves multiple aspects of the composting process including stimulating microbial activity, increased aeration, nutrient retention, and water conservation

   b. A number of biochar properties can enhance compost by increasing porosity, reducing bulk density, improving water holding capacity, and preventing nutrient loss by adsorption onto biochar surfaces.
   c. Biochar has been shown to increase temperatures of the thermophilic phase of the composting process and accelerate compost maturity due to the stimulation of compost microbiology.
   d. Application rates in composting systems have varied from 3-50% biochar (dry-weight) with optimal conditions achieved at 10% and significant benefits realized at application rates as low as 3-5%.
   e. The composting process alters properties of biochar by modifying surface functionality, increasing reactive oxygen-containing groups, cation exchange capacity, and microporosity.
   f. Biochar provides improved habitat for microorganisms, specifically bacteria, actinomycetes, and fungi by providing moisture, nutrients, and a favorable environment for metabolic reactions.
   g. The varied porosity, macro and micropores, of biochar particles provide a physical structure available for colonization and utilization by soil biology.
   h. Biochar's charged pore surfaces can facilitate metabolic functions performed by soil organisms and can protect extracellular enzymes from denaturing effects.

6. Jindo, Keiji, et al. "Chemical and Biochemical Characterisation of Biochar-Blended Composts Prepared from Poultry Manure." Bioresource Technology, vol. 110, 2012, pp. 396–404., doi:10.1016/j.biortech.2012.01.120.
   a. Effect of 2% (v/v) biochar addition to poultry manure composting resulted in a 10% increase in extractable carbon from humic and fulvic acids, a 30% decrease in water soluble carbon, and a 30-40% increase in enzyme activity despite decreased amounts of microbial biomass in biochar-amended composts.
   b. Biochar-amended compost hosted a higher diversity of fungi when compared to non-amended compost
   c. Biochar-amended compost reached higher temperatures during active composting and contained lower concentrations of labile carbon during the thermophilic phase and after maturation.
   d. The higher concentration of humic extractable carbon and higher ratio of HA/FA in biochar-amended compost show increased humification and compost stability at maturation.
   e. Changes observed in the organic matter degradation rate were minimal, however, the composition of organic matter in biochar-amended compost was altered such that indices of compost stability and maturation were significantly increased.

7. Yuan, Yinghong, et al. "Is Biochar-Manure Co-Compost a Better Solution for Soil Health Improvement and $N_2O$ Emissions Mitigation?" Soil Biology and Biochemistry, vol. 113, 2017, pp. 14–25., doi:10.1016/j.soilbio.2017.05.025.

a. Biochar-amended chicken manure compost showed reduced emissions of $CO_2$ and $N_2O$ during the composting process.
b. Biochar suppressed microbial nitrification as demonstrated by a reduction in the abundance of glucosaminidase enzyme activity and nirK gene expression.
c. Biochar addition to chicken manure stabilized carbon in the compost demonstrated by an increase in peroxidase activity.
d. Biochar can stabilize carbon, reduce $CO_2$ and $N_2O$ emissions, and alter microbial functional groups to reduce nitrogen losses in composting of high nitrogen materials like chicken manure

8. Hestrin, Rachel, et al. "Fire-Derived Organic Matter Retains Ammonia through Covalent Bond Formation." Nature Communications, vol. 10, no. 1, 2019, doi:10.1038/s41467-019-08401-z.
    a. Biochar acts as a sink for ammonia gas forming covalent bonds between ammonia N and biochar C
    b. The nitrogen retention capacity of biochar (180 mg N/g) resulted in a higher nitrogen content than any unprocessed plant material and many manures, making it a valuable nitrogen fertilizer.
    c. During biochar weathering, nitrogen retention capacity increased six-fold
    d. Ammonia N was retained primarily by chemisorption over physisorption where covalent interactions dominated over electrostatic interactions.
    e. The study reveals that ammonia retention mechanisms differ from ammonium retention in that ammonium N is adsorbed in stoichiometric balance with ammonium H while ammonia N is not, implying that ammonia is bound covalently while ammonium is bound electrostatically.

9. Li, Shuqing, et al. "Linking $N_2O$ Emission from Biochar-Amended Composting Process to the Abundance of Denitrify (*nirK* and *nosZ*) Bacteria Community." AMB Express, vol. 6, no. 1, 2016, doi:10.1186/s13568-016-0208-x.
    a. Biochar significantly reduces $N_2O$ emissions during manure composting by suppressing *nirK* gene expression.
    b. Biochar alters gene expression related to bacterial nitrification/denitrification leading to reduced emissions of $N_2O$ gas.

10. Hagemann, Nikolas, et al. "Nitrate Capture and Slow Release in Biochar Amended Compost and Soil." Plos One, vol. 12, no. 2, 2017, doi:10.1371/journal.pone.0171214.
    a. Biochar amendments in mixed manure composting showed slower release of nitrate, with up to 30% being released after the first hour compared with the control where all nitrate was extracted after one hour.
    b. Extractable nitrate from all samples (compost and soil) amended with biochar showed an increase up to double the total extractable nitrate over controls.
    c. Nitrate held in biochar may be underestimated in many studies because of the long time necessary to fully extract all nitrates.

11. Steiner, Christoph, et al. “Reducing Nitrogen Loss during Poultry Litter Composting Using Biochar.” Journal of Environment Quality, vol. 39, no. 4, 2010, p. 1236., doi:10.2134/jeq2009.0337.
    a. Biochar additions to poultry litter composting reduced emissions of ammonia gas by up to 64% and reduced N losses by up to 52% at the highest biochar application rate of 20% on a dry weight basis.
    b. Biochar was made from pine chips without further modification.