



Frequently Asked Questions About Biochar Applied to Soil

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Introduction to Biochar

Q1. What is biochar?

- ✓ A1. A solid, carbon-rich material with agricultural, environmental, and industrial applications. In agriculture, biochar is applied to soil to improve soil quality and crop productivity while sequestering carbon.

Q2. How is it made?

- ✓ A2. There are several methods for producing biochar including pyrolysis in various kiln designs, gasification, hydrothermal carbonization, flash carbonization and torrefaction. In all these methods feedstock organic material undergoes some level of thermochemical decomposition or conversion that stabilizes carbon.
 - *Pyrolysis* is the thermochemical decomposition of organic material by heating at temperatures from 300 °C to over 750 °C, in the absence of oxygen.
 - *Gasification* is the thermochemical conversion of organic material by heating at temperatures similar to pyrolysis in the presence of a small amount of oxygen or steam.
 - *Hydrothermal carbonization* is the thermochemical conversion of organic material in heated (180-250°C) and pressurized (2-6 MPa) water.
 - *Flash carbonization* is the thermochemical conversion of packed organic material under flash fire and pressure (1-2 MPa).
 - *Torrefaction* is the thermochemical conversion of organic material by heating at temperatures from 200°C to 300°C in the absence of oxygen.

Q3. What is biochar made from?

- ✓ A3. Any organic material, but sustainably sourced materials that would otherwise be considered waste, or low-value materials should be used to optimize value and capture environmental benefits.

Q4. What is a feedstock?

- ✓ A4. The starting organic material that will be pyrolyzed to make biochar. Feedstocks include almost any organic waste such as woodchips, corn stover residue, rice hulls, sugarcane bagasse, manure, switchgrass, coconut husks, biosolids, food waste, etc. The best feedstock is a waste product found close to the production facility because of lower transportation costs and reduced environmental impact.

Q5. How much biochar would be produced by processing 1 ton of biomass?

A5. This answer depends on the pyrolysis method, temperature used, and the type of biomass. Lower temperature pyrolysis typically yields more biochar per unit of feedstock than higher pyrolysis temperatures. Slow pyrolysis (residence time minutes to hours) typically yields more biochar than fast pyrolysis (residence time seconds to minutes). Figure 1 in [Spokas et al. 2010](#) shows the relationship between biochar yield and pyrolysis temperature for a given biochar type.

Biomass Feedstock	Pyrolysis method	Temperature	Biochar yield	Yield estimate from 1 ton feedstock	Reference
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Palm fiber	Slow pyrolysis	300°C	54.83% (% feedstock dry wt.)	1,096.6 lb.	Selvarajoo et al. 2020
Palm fiber	Slow pyrolysis	900°C	26.67% (% feedstock dry wt.)	533.4 lb.	Selvarajoo et al. 2020
Kentucky Bluegrass seed screening	Gasification	650-750°C	~32%	640 lb.	Phillips et al. 2018
Macadamia nutshell	Fast pyrolysis	400-500°C	29.7% (% feedstock dry wt.)	594 lb.	Hasan et al. 2022
Macadamia nutshell	Slow pyrolysis	400-500°C	41.3% (% feedstock dry wt.)	826 lb.	Hasan et al. 2022
Biosolids	Slow pyrolysis	500-600°C	45-36%	900-720 lb.	Kundu et al. 2021
Wood	Hydrothermal carbonization	200°C	66%	1,320 lb.	Funke et al. 2010

Q6. Are there coproducts of biochar production?

- ✓ A6. Biochar and bioenergy production can be coupled since pyrolysis of organic matter generates three coproducts: biochar, syngas, and bio-oil. As the feedstock heats up, gases are released, mainly CO, H₂, CO₂ and CH₄, known as synthesis gas or syngas, which can be collected and combusted to release heat and energy. Examples of direct use of syngas would be to power an internal combustion engine like natural gas or combustion of syngas during biochar production to provide the heat for pyrolysis. Additionally, vapors released from organic compounds in feedstock material during pyrolysis cool and condense to produce bio-oil. Bio-oil may be compared to petroleum; however, it is energetically inferior due to higher water and oxygen content, and lower heating value. Due to this, bio-oil requires additional processing steps to be used in diesel engines or as transportation fuel. Without additional processing bio-oil can replace fuel in boilers, non-diesel engines, turbines, and furnaces. The fraction of water in bio-oil may be extracted to produce wood vinegar which is used as a pesticide and plant growth stimulant in organic agriculture. Wood vinegar contains many different chemicals and usually acetic acid and phenols are the most abundant. The yield of each biochar, bio-oil, and syngas during production depends on the pyrolysis conditions (e.g., highest heating temperature, residence time) and feedstock. For example, slow pyrolysis favors biochar and syngas formation, while fast pyrolysis favors bio-oil production. Another process similar to pyrolysis but introduces

some oxygen is gasification, which produces syngas and biochar ([Vuppaladadiyam et al. 2023](#) , [Fuchs et al. 2014](#), [Panwar et al. 2021](#)).

Q7. Is biochar different from charcoal?

- ✓ A7. While chemically similar, the starting organic material and end uses differ. Charcoal is usually made from wood and intended for use in heating and cooking. Biochar is made from any organic waste material and has targeted agricultural and environmental applications.

Q8. Why has biochar adoption been slow?

- ✓ A8. Adoption has been slow for many reasons including:
 1. Lack of education and awareness of biochar's benefits
 2. Lack of decision support tools
 3. Currently limited regional and local production facilities
 4. Uncertainty of site-specific impacts
 5. Lack of information on application and management recommendations
 6. Cost and availability
 7. Inconsistent production and characterization
 8. Variable economic outcomes

However, while barriers to adoption still exist, active research, extension, policies, and financial assistance programs are being developed to increase adoption.

Q9. Is biochar a 'silver-bullet' solution?

- ✓ A9. Biochar, like all technologies, is not a silver bullet to existing agriculture and environmental challenges. It is another tool in the toolbox that should be utilized in combination with other sustainable management practices.

Q10. What is the half-life of biochar?

- ✓ A10. Estimations of biochar stability in soil vary from decades to millennia and depend on environmental factors, biochar type and production conditions. An increase in the number of fused aromatic structures in biochar occurs as pyrolysis time and temperature increase and with lower feedstock ash content. The relative amounts of carbon to hydrogen or oxygen are used as predictors of biochar stability. Specifically, the ratio of hydrogen to organic carbon ($H:C_{org}$) content or oxygen to organic carbon ($O:C_{org}$) are used to estimate biochar carbon persistence. Stable biochar will have a lower $H:C_{org}$ value ≤ 0.4 and lower $O:C_{org}$ value ≤ 0.2 . Figure 3b in [Lehmann et al. 2021](#) depicts this relationship nicely.

H:C _{org}	Mean % Carbon remaining in soil after 100 years
0.4	80.5%
0.5	73.1%
0.6	65.6%
0.7	58.2%

Data taken from [Budai et al. 2013](#)

Biochar Field Application

Q1. How much do I apply?

- ✓ A1. It depends! Application rates to fields are site-specific and should be made after a production constraint or resource concern has been identified. Soils vary in their deficiencies and needs, and application rates are determined on a field-by-field basis to address a specific issue. Field application rates of between 1–10 tons per acre have shown consistent positive impacts in numerous studies ([Schmidt et al., 2021](#)). A good starting point for field applications is 1 ton per acre (4 cubic yards per acre) as the lowest effective rate to improve soil organism habitat and 3 tons per acre (12 cubic yards per acre) to improve soil organic matter levels. For container production or tree planting holes, 5-25% by volume maintains good plant performance ([Allaire et al., 2017](#)). Work is on-going to develop a national biochar decision support tool to help end users determine the most appropriate biochar type and application rate for a particular soil type.

Q2. How and where do I apply it?

- ✓ A2. There are many different methods to apply biochar, and this depends largely on the crop it is being applied to and the problem you are trying to solve (resource concern). Incorporation of biochar into the soil is important because it is a very light material that can easily get dispersed through wind and water erosion. For field crops, deep banding or broadcast application using a manure spreader to fields followed by incorporation are effective. In pasture/perennial grass systems, biochar can be incorporated using a no-till drill or dispersed through a liquid slurry. Deep incorporation into the planting row at the pre-plant stage of perennial crops has been shown to be effective. Combining biochar with compost, manure or other organic materials with higher moisture content can aid broadcast application and reduce the risk of off-site movement. In container production, biochar can be substituted as part of horticultural media.

Q3. Should I mix biochar with an organic or mineral fertilizer before applying it?

- ✓ A3. Yes, the literature supports that biochar should be mixed with a nutrient rich material before application. Biochar is between 50-90% carbon with very little nitrogen (~0.1%) so it is a relatively inert material, which serves as the backbone or carrier of nutrients and shelter for

microorganisms. If not pre-blended the risk of nutrient tie-up is higher and fewer benefits have been observed. Mixing biochar with manure, compost or other amendments may also improve the efficacy of those amendments.

Q4. If I soak biochar in water soluble fertilizer, will it retain the nutrients?

- ✓ A4. Yes, you can soak biochar in water soluble fertilizer, and it will retain the nutrients. How much of the nutrients the biochar retains will depend on specific surface area and surface charges. Therefore, for this application it is best to choose a biochar with high levels of both. Biochar produced at $\leq 500^{\circ}\text{C}$ tends to have more negative surface charges (higher cation exchange capacity) and would be suitable for adsorbing cationic (positively charged) fertilizer such as NH_4^+ . Biochar produced at temperatures $\geq 700^{\circ}\text{C}$ will have more positive surface charges (higher anion exchange capacity) and may be better suited for adsorption of anionic (negatively charged) fertilizer such as NO_3^- ([Banik et al., 2018](#)). Be sure to research the charge of ions in the fertilizer that you intend to soak the biochar in and the surface charges on the biochar to ensure that they are opposite.

Q5. How much does biochar cost?

- ✓ A5. Cost varies depending on feedstock, any pre- or post- treatments made to the biochar, transportation, and other factors. Transportation costs typically account for most of the cost so sourcing a local, sustainably produced biochar is best economically and environmentally. In recent years the per ton price of biochar has ranged from approximately \$350-1,500. As the scale of production has increased, however, cost has decreased. Markets continue to grow and evolve.

Q6. What machinery can I use to crush biochar?

- ✓ A6. You can use a soil grinder/shredder, leaf shredder, feed grinder, rock/lump crusher, drive over the biochar with a small tractor, cement mixer, and various mills to name a few.

Q7. What is the ideal particle size of biochar?

- ✓ A7. The ideal particle size depends on your soil texture and what the end goal is with applying biochar. Smaller biochar particle sizes such as powders, granules, and kernels provide larger surface area for sorption of water and nutrients and may enhance liming effects, however, may increase bulk density and decrease saturated conductivity (K_{sat}) of clay soil. The interaction of the biochar and soil may change the soil's pore size distribution which in turn changes water dynamics and aeration. In general, smaller biochar particle sizes added to coarser soil textures will increase water holding capacity and decrease soil pore sizes while larger biochar particle sizes added to finer soil textures will increase K_{sat} and increase soil pore sizes. For example, mesquite wood biochar particle sizes 0.25-2mm increased field capacity and plant available water in sand when applied at rate of 2% wt. (~20 tons per acre) while the smaller biochar

particle size tested (< 0.251) had little effect ([Liu et al., 2017](#)). Mesquite wood biochar crushed to 0.85mm applied at 10% wt. (~100 tons per acre) decreased K_{sat} by 92% in a sandy soil and increased K_{sat} by 328% in a clay-rich soil ([Barnes et al., 2014](#)). Coarse powder (<4.75mm) woody biochar amendment at rates of 0.5% and 2% wt. increased plant available water for sand and loam soil, and only 2% increased plant available water for clay ([Zhang et al., 2021](#)).

Q8. Is incorporating biochar into the soil generally recommended?

- ✓ A8. Yes, incorporation into soil can reduce the amount of biochar lost to wind and water erosion and puts the biochar closer to plant roots where it may provide the most benefit.

Q9. How do I use biochar with my tree and shrub plants?

- ✓ A9. If newly planting trees or shrubs, biochar can be added to the bottom of the hole dug at the planting site. Mix the biochar into the soil in the hole, then plant the tree or shrub. For established trees or shrubs, biochar can be added directly to the base of the plant (top-dressed) or injected into the root zone (micronized biochar suspended in water). Since biochar particles are light and susceptible to being blown away with wind, adding a layer of compost or mulch over the biochar is helpful to keep it in place if topdressing.

Q10. Is there a response when biochar is applied to better quality soil?

- ✓ A10. Biochar applied to highly fertile soil will likely not provide marked soil response but will still increase soil organic carbon. Additionally, adding high nutrient content biochar like those derived from manure feedstocks will provide soil nutrients offsetting the need for inorganic fertilizer. If applying biochar to better quality soil, ensure the biochar will not negatively alter soil pH. Check the liming equivalence and avoid biochar with pH < 7 as there is a chance it could contain harmful organic acids that linger due to incomplete pyrolysis ([Guo et al., 2020](#)).

Q11. Is there such a thing as liquid biochar?

- ✓ A11. This refers to micronized or pulverized biochar (<0.02mm particle size). This biochar can be suspended in water and applied through fertigation or mixed into manure slurry and injected.

Biochar & Compost

Q1. What is the role of biochar compared to compost?

- ✓ A1. Compost and biochar are both carbon-rich soil amendments that may increase soil water and nutrient holding capacity. However, key differences are in the production process, the stability of their carbon, nutrient contributions, pH, and sorption capacity.

Production process

Biochar is produced from the pyrolysis of organic waste materials and can produce energy when bio-oil or syngas are harvested during pyrolysis. Compost is produced from the controlled, aerobic biological decomposition of biodegradable materials such as crop residues, food waste, manure, yard waste, etc. (US Composting Council).

Carbon stability

Most biochar carbon is stable and is not easily broken down by microbes, thus less CO₂ is released compared to less stable carbon in non-pyrolyzed materials. Instead of being broken down quickly, biochar carbon is stabilized or sequestered in the soil for decades to thousands of years. Compost contains more easily broken-down (labile) carbon molecules that feed soil microbes, thus releasing more CO₂. Labile carbon in compost may only persist in soil for a year or two.

Nutrient contributions

Both biochar and compost may contain appreciable amounts of a variety of plant nutrients, however compost may contain 0.5-2.5% nitrogen (% dry weight) while biochar usually contains only ~0.1% nitrogen (this value is higher for biochars derived from manure ~1-2%).

pH

Biochar's pH range is very wide (~5.52-11.10) and depends on feedstock material and pyrolysis conditions. Compost's pH range is comparatively narrow (~5.5-8) and depends on composted materials and production conditions. High pH biochars can replace lime to neutralize acidic soils.

Sorption capacity

Biochar and compost both have highly charged surfaces that improve soil ion exchange capacity and sorption properties; however, biochar typically has a higher surface area for sorption thus higher sorption capacity ([Siedt et al., 2021](#)).

Q2. What is co-composting?

- ✓ A2. Co-composting refers to mixing biochar into intended compost material prior to the composting process.

Saves time and fuel

The presence of biochar during the composting process improves pile aeration which can increase microbial activity, thereby increasing the temperature of the pile and hastening the composting process. Increased aeration, microbial activity, and decreased time to maturity has led to savings on fuel and time as composters do not need to turn piles as often ([USBI Biochar in Compost](#)).

Improves nutrient retention

Increased microbial activity associated with co-composting biochar can also enhance microbial nitrification leading to a final product with higher plant available nitrogen (NO₃⁻) content ([Sánchez-García et al. 2015](#)). The high ion adsorption capacity of biochar enables NO₃⁻ capture

and retention which decreases nitrate loss during the composting process and enhances compost nutrient value. Application of co-composted biowaste compost and oak biochar (9:1) was shown to be as effective as mineral fertilizer for increasing yield of grape and leek with comparatively lower environmental impact ([Oldfield et al. 2018](#)). Biochar addition to the composting process can also improve retention of other water-soluble nutrients such as PO_4^{3-} , K^+ , and Ca^{2+} ([Zhang et al. 2016](#)).

Reduces greenhouse gas emissions

Many studies have found that co-composting biochar reduces compost N_2O emissions through N_2O , NH_4^+ , and NO_3^- adsorption, and increased pile aeration. Increased pile aeration reduces anaerobic N_2O formation, increases expression of N_2O -reductase in the microbial community, and facilitates electron transfer to enhance reduction of N_2O to N_2 ([Sanchez-Monedero et al. 2018](#)). Co-composting with biochar also reduces compost NH_3 emissions by adsorption and enhanced nitrification ($\text{NH}_3 \rightarrow \text{NO}_3^-$) mechanisms. Many studies also report CH_4 emission reductions by co-composting biochar associated with better pile aeration and microbial community shifts favoring methanotrophs ([Sanchez-Monedero et al. 2018](#)). It should be noted that due to enhanced microbial activity, co-composting biochar sometimes results in greater CO_2 emissions compared to compost alone. For example, [Steiner et al. 2010](#) found that 20% biochar addition to poultry litter compost resulted in 14% increase in composting CO_2 emissions. This environmental impact is potentially offset by the reduction in more potent greenhouse gasses CH_4 (56x more potent) and N_2O (280x more potent) ([Global Warming Potentials IPCC Second Assessment Report](#)).

Compost material	Biochar Type	Biochar rate	Effect	Reference
Poultry manure (78%), barley straw (22%)	Oak slow pyrolysis 650°C	3%	<ul style="list-style-type: none"> Increased NO_3^- in biochar-compost ~439% Shortened compost time to maturity by 28 days 	Sánchez-García et al. 2015
Olive mill waste 46%, sheep manure 54%	Oak slow pyrolysis 650°C	4%	<ul style="list-style-type: none"> Increased NO_3^- in biochar-compost ~134% Decreased total N loss 16% 	López-Cano et al. 2016
Pig manure and wheat straw (70:30 by wet)	Wheat straw 500-600°C	10%	<ul style="list-style-type: none"> Shortened compost time to maturity 	Zhang et al. 2016

weight of pig manure)			<p>(mature in 42 days)</p> <ul style="list-style-type: none"> • Increased NO_3^- in biochar-compost ~34% • Increased concentration of PO_4^{3-} (10%), K^+ (~37%), and Ca^{2+} (~23%) in biochar-compost 	
Sewage sludge and wheat straw (4:1)	Wheat straw	12%	<ul style="list-style-type: none"> • Reduced compost CH_4 emission ~93% • Reduced NO_2 emission ~95% • Reduced NH_3 emission ~59% 	Awasthi et al. 2017
Hen layer manure and sawdust (3:1)	Cornstalk biochar 450-500°C	10%	<ul style="list-style-type: none"> • Reduced compost NH_3 emission 24.8% • Reduced CH_4 emission 26.1% • Increased NO_3^- in biochar-compost 23.8% • Compost reached thermophilic phase faster 	Chen et al. 2017
Poultry litter	Pine chip 400°C	20%	<ul style="list-style-type: none"> • Reduced NH_3 emission 64% • Reduced H_2S emission 71% • Compost reached a higher max 	Steiner et al. 2010

			temperature faster	
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*NO₃⁻ data for Sánchez-García et al, López-Cano et al, and Zhang et al were extracted from graphs in the publication using [plotdigitizer](#).

Q3. How much biochar do I mix with compost?

- ✓ A3. This answer depends on when in the composting process you are adding the biochar, what material is in your compost, and what type of biochar you plan to add.

If you plan on adding the biochar during the composting process, a.k.a. co-composting biochar, the commonly recommended addition rate would be ~10% biochar although lower (3-5%) and higher (20%) rates have also produced beneficial effects to composting ([Sanchez-Monedero et al. 2018](#)). It should be noted that adding too much biochar during co-composting could over-aerate the pile and reduce moisture to levels uncondusive to microbial activity. Most studies on co-composting biochar use woody or crop residue biochar pyrolyzed at 400-700°C because this biochar has high porosity, specific surface area, cation exchange capacity, and water holding capacity which are desirable traits for co-composting ([Antonangelo et al., 2021](#)). Be sure that the biochar does not increase the pH of the compost beyond the optimal pH range for composting (5.5-8).

If you plan on adding the biochar to mature compost, the optimal ratio of compost: biochar has not been studied, but [Agegnehu et al. 2014](#) observed increased plant growth and water and nutrient availability using a ratio of 2:1.

Q4. Can I use biochar in compost tea?

- ✓ A4. Yes! There are many methods you can use to incorporate biochar into compost tea. You will need to do some research to figure out the best method for you.

Things to note:

- To charge biochar in compost tea you will need compost, a sugar source, water, biochar and aeration. The sugar source can be granulated sugar, syrup, molasses, corn syrup, etc. To aerate the biochar: compost tea solution you may use a system such as water stones, aquarium pumps, or simply stir vigorously every 30 min-1 hour.
- The ambient temperature of the area where you are brewing the biochar: compost tea solution will affect the level of microbial activity in the solution. At temperatures < 25°C the process may take much longer as microbial activity will be slower. In warm temperatures ≥ 25°C the process may take 12 hours – 3 days.
- Some biochar may be too alkaline for fungal microbes to grow and reproduce in the biochar: compost solution, so it is good to know the approximate pH and liming equivalence of your biochar. If the biochar solution is too alkaline (pH > 7), you could add some acid (like vinegar) to neutralize the biochar in water before adding the compost.

Some YouTube videos:

- [Compost Tea & Biochar - Here's How!](#)
- [Activating biochar with worm castings tea from scratch..](#)
- [Compost Tea & Biochar Hydroponics](#)

Biochar changes to soil

Q1. Will biochar change the pH of my soil?

- ✓ A1. It is possible depending on the pH and particle size of the biochar, pH and buffering capacity of your soil, and biochar application rate. The generalizations are that higher pyrolysis temperature (>400°C) biochar typically has higher pH and may be more likely to raise pH of acidic soil while lower pyrolysis temperature (<400°C) biochar may be acidic and could lower pH of calcareous, alkaline soil. However, studies regarding the effect of acidic biochars on soil are less common. Higher amendment rates will lead to greater pH change. Typically, higher clay content soils have higher buffering capacity so pH may be less affected by biochar application. Biochar particle size also plays a role, biochar with smaller particle size will have larger surface area available to interact with and neutralize acid or base ions in soil. If you are using biochar as a liming alternative, it is often most effective to apply in powdered form.

Biochar	Amendment rate	Soil	pH change	Reference
Woody feedstock pyrolyzed 450°C and 600°C	2% w/w	“Acidified (pH 4) brown soil” CEC 13.38 ± 0.16	+3 units (approx.)	Geng et al. 2022
Switchgrass pyrolyzed at 250°C	2% w/w	Fine sandy loam (pH 7.4)	-0.2 units	Ippolito et al. 2012
Switchgrass pyrolyzed at 250°C	2% w/w	Loam (pH 8.3)	-0.2 units	Ippolito et al. 2012
Eucalyptus wood pyrolyzed at 550°C	5 tons/hectare	Sandy loam pH (5.96)	+0.3 units (approx.)	Shetty et al. 2020
Kentucky bluegrass seed screenings pyrolyzed at 650-750°C	8 tons/acre	Silty loam pH (3.95)	+0.43 units	Phillips et al. 2018

Q2. Biochar retains water, but helps with drainage in clay soil, how?

- ✓ A2. Biochar particles have high porosity, with many meso- and micropore spaces that allow it to retain water even as larger pores dry out. Biochar added at high amendment rates may improve drainage in clay soil depending on the particle size of the biochar added. Clay soils naturally have low drainage because clay particles are very small and pack tightly together, making it difficult for water to pass through. Amending clay soils with larger biochar particles disrupts the tight packing of clay particles and may enlarge soil pore spaces, making it easier for water to move. Thus, even though biochar may retain water within its own meso- and micropore spaces, larger particle size biochar can improve drainage in tightly packed, fine-textured soil.

Biochar Carbon Credits

Q1. How much in carbon credits could I get from 1 ton of biochar?

- ✓ A1. These numbers have not been established yet but are estimated to be between 1.9 -2.7 tons of CO₂ per ton biochar produced. Whether that entire amount gets transferred to a biochar purchaser remains to be seen. Currently biochar CO₂ removal credits are \$90-600/ton (“Nasdaq Carbon Removal Marketplace and Technologies” 2022) [Biochar Carbon Credit Market Analysis](#).

Biochar and pollutant remediation

Q1. How can biochar aid in the degradation of organic pollutants?

- ✓ A1. Biochar may immobilize organic pollutants in soil and water through sorption mechanisms including hydrophobic interaction, pore filling, partitioning, electron donor and acceptor interaction, and electrostatic interaction ([Abbas et al., 2018](#)). While immobilized, pollutants are considered inert. Matching biochar properties to the properties of the organic pollutant to be adsorbed will lead to high adsorption efficiency. See Table 2 in [Abbas et al., 2018](#) for examples of various biochar sorption capacities for various organic pollutants. Potential desorption of organic pollutants from biochar in the environment is not well studied, but is estimated to take years to millennia ([Cornelissen et al., 2005](#); [Jonker et al., 2005](#)).

Hydrophobic interaction

Hydrophobic biochar such as those produced at high pyrolysis temperature may attract and adsorb hydrophobic organic pollutants because hydrophobic substances are attracted to one another to minimize surface exposure to water. Studies have shown that hydrophobic attraction can even overcome electrostatic repulsions between biochar and organic pollutants in water ([Chen et al., 2011](#)).

Partitioning

Partitioning of organic pollutants refers to the incorporation (absorption) of organic pollutants into the biochar organic matrix. Characteristics of the biochar organic matrix (partition matrix) are dependent on the pyrolysis temperature. The partition matrix in biochar pyrolyzed at temperatures < 400°C consists mainly of remaining organic matter that is non-pyrogenic, or volatile and is aliphatic meaning it consists of open carbon chains that are easily accessible by

organic contaminants. Partitioning may account for most organic contaminant removal by biochar pyrolyzed at temperatures < 400°C in the presence of high contaminant concentration. At temperatures > 400°C, most of the aliphatic partition phase is eliminated and replaced by stable, aromatic carbon rings that are not easily accessible by organic contaminants. Thus, for biochar pyrolyzed at temperatures > 400°C, partitioning accounts for little organic contaminant removal while larger surface area and porosity account for most ([Chen et al., 2008](#)). While both polar and nonpolar organic contaminants may be partitioned, polar contaminants are slightly more effectively partitioned ([Chun et al., 2004](#)).

Pore filling

Biochar with high porosity has a large specific surface area for adsorption of organic pollutants. Typically, higher pyrolysis temperatures will increase biochar porosity and specific surface area but will reduce surface functional groups that contribute to polarity, electron interaction, and electrostatic interaction. At pyrolysis temperatures < 700°C biochar will retain surface polarity and favor adsorption of polar organics, but at temperatures > 700°C biochar loses much of its surface polarity and adsorption becomes less selective ([Chen et al., 2008](#)). Smaller biochar particle sizes (~0.05mm) result in faster organic pollutant remediation as the pollutant has easier access to pore space to adhere to ([Zheng et al., 2010](#)).

Electron donor/acceptor interaction

Biochar has surface functional groups that may donate (phenolic, hydroxyl or ether groups) or accept (quinone or carbonyl groups) electrons that may lead to transformation or sorption of organic contaminants. Feedstock and pyrolysis conditions affect surface functional groups and therefore electron donor/acceptor behavior of biochar. [Klöpffel et al., 2014](#) found that in general total electron exchange capacity was highest in wood and grass biochar pyrolyzed at moderate temperatures 400-500°C; electron donating capacity was relatively higher for lower temperature biochar (< 400°C) and electron accepting capacity was relatively higher for high temperature ($\geq 400^\circ\text{C}$) biochar. Biochar electron donor and acceptor interactions have also been shown to enhance activity of chemical and biological redox agents that degrade organic pollutants ([Tian et al., 2020](#); [Huang et al., 2018](#); [Fang et al., 2015](#); [Yu et al., 2015](#)).

Electrostatic interaction

Biochar has charged surfaces which may attract and immobilize molecules of opposite charge. Biochar surfaces are often negatively charged, thus could attract and bind positively charged (cationic) organic pollutants ([Xu et al., 2011](#)). Biochar pyrolyzed at temperatures > 700°C or biochar feedstock treated with AlCl_3 prior to pyrolysis will have increased positive surface charges that may bind negatively charged (anionic) pollutants ([Banik et al., 2018](#)). In addition, polar surface functional groups may form hydrogen bonds with polar organic contaminants to immobilize them.

Q2. Can biochar help with Per- and Poly-fluoroalkyl substance (PFAS) mitigation?

- ✓ A2. This is an active area of research, but evidence suggests that both pyrolysis of PFAS contaminated feedstock and application of biochar to PFAS contaminated soil and water can reduce PFAS levels. Pyrolysis of PFAS contaminated biosolids at 650°C removed PFAS on average >97.4% and produced a biochar product containing no or low amounts of PFAS ([Thoma et al. 2022](#)). However, more research needs to be conducted on the emissions and breakdown products of PFAS thermal degradation since it is unclear whether target PFAS are transformed into non-target PFAS during pyrolysis. Biochar application to contaminated soil also reduces PFAS leaching. Waste timber biochar pyrolyzed at 900°C applied at 5% rate to soil with low total organic carbon (1.6%) reduced leaching of 22 PFAS species on average ~ 99% but was less effective for soil with high total organic carbon (34.2%) where 5% biochar application reduced PFAS leaching on average ~ 69%* ([Sørmo et al., 2021](#)). Biochar produced from PFAS contaminated biosolids exhibited the potential to reduce PFAS in contaminated water > 80% for long-chain PFAS and 19-27% for short-chain PFAS ([Kundu et al. 2021](#)).
* calculated from tables S3 and S4 [Sørmo et al., 2021](#)

Q3. Can biochar help in dioxin removal?

- ✓ A3. Dioxins are organic (carbon based) pollutants, thus the mechanisms (e.g. hydrophobic interaction, partitioning, pore filling, etc.) discussed in question 1 for degradation and immobilization of organic pollutants by biochar apply. Biochar has removed polychlorinated dibenzo-p-dioxins (PCDD) from soil. Corn stover and pine wood chip derived biochar applied to a sandy loam with total organic carbon content of 3.71% removed 52.3% and 40% of PCDD in the soil, respectively ([Chai et al., 2011](#)).

Q4. Can biochar remove heavy metal pollutants?

- ✓ A4. Yes, biochar can sorb and immobilize heavy metals from contaminated soil and water through electrostatic interactions, cation exchange, metal complexation with biochar surface functional groups, and through electron donation to reduce or precipitate the metal ([Tan et al. 2015](#)). Certain types of biochar may be more effective than others for remediation of specific metals. For example, manure-derived biochars are effective for remediation of lead possibly due to high levels of phosphorus which can form insoluble precipitates with lead ([Cao et al. 2009](#)). Meta-analysis conducted by [Chen et al. 2018](#) indicates that biochars produced at 450-500°C are most effective for reducing plant uptake of cadmium, lead, copper, and zinc possibly due to abundance of oxygen-containing surface functional groups which are removed at higher pyrolysis temperatures. Adsorption of heavy metals can also be influenced by pH where more alkaline pH may precipitate and immobilize heavy metals such as aluminum, in which case a biochar with liming properties and high pH would be most effective. See Table 1 of [Abbas et al. 2018](#) for a list of heavy metals removed by different types of biochar and the adsorption mechanism.

Effect of biochar addition on available heavy metal concentration in soil

Soil heavy metal	Biochar removal rate	Comparisons studied (n)
Cadmium	~52%	365

Lead	~46%	191
Copper	~29%	156
Zinc	~36%	180

*Data taken from Figure S2 of meta-analysis by [Chen et al. 2018](#) using Plotdigitizer.

Q5. What is the difference between biochar and activated carbon?

- ✓ A5. Biochar and activated carbon are both highly adsorptive materials used in pollutant remediation. Production of activated carbon is more specific than biochar as it requires high temperature (600-1200°C) and additional activation processes such as steam or chemical activation. Biochar production typically occurs at temperatures from (500- 800°C) and does not require additional activation processes. Production of biochar is cheaper and requires less energy than activated carbon.

Biochar Testing

Q1. Where/what lab can I send my biochar for testing/analysis?

- ✓ A1. See this International Biochar Initiative webpage for information on biochar testing laboratories: <https://biochar-international.org/testing-laboratories-for-ibi-biochar-certification/>

Q2. Does standard soil organic matter testing include the biochar fraction or does a different analytical method need to be used?

- ✓ A2. Soil organic matter (SOM) testing is often conducted by combustion of dry soil samples at temperatures ~400°C and subsequent measuring of either CO₂ release or sample weight loss as a proxy for organic matter content. Biochar may contain a portion of volatile organic carbon that can be combusted as part of this process, but much of the stable, pyrogenic fraction may not. Thus, standard soil organic matter testing may include part of, but not all the biochar fractions. A method for measuring biochar volatile, ash and fixed carbon content called proximate analysis ([Aller et al., 2017](#)) could provide a more complete measure of the biochar fraction in soil. Volatile and fixed carbon fractions measured by proximate analysis relate to soil/biochar organic carbon content (related to SOM) while the ash fraction provides approximate inorganic carbon content.

Misc.

Q1. Is anyone doing research on biochar as a seed treatment?

- ✓ A1. Biochar may be mixed with binders like talc, starch, guar gum, etc. to coat seeds. Some studies indicate that coating seeds with biochar improves germination, increases seedling weight and improves vigor ([Banu et al., 2022](#); [Zhang et al., 2022](#)), while others report no increase in germination and only slight increase in seedling growth for certain species ([Williams et al., 2016](#)). Like with many things, the results likely depend on the interaction of type of

biochar, binder, soil and plant. It has also been shown that biochar can serve as a carrier for seed coating with beneficial microbes for improved seedling growth ([Glowdowska et al., 2016](#)).

Q2. How much does a cubic yard of biochar weigh?

- ✓ A2. The dry weight of a cubic yard of biochar is ~135-540lbs. ([Brewer et al., 2015](#)). Biochar readily absorbs moisture from the air so the way a biochar is stored (protected from moisture or not) can affect its weight.

Q3. Are there bacterial inoculums present in biochar?

- ✓ A3. No, the biochar production process requires the material to be heated to temperatures that kill microbes. Sterile biochar may be inoculated with microbes by mixing with compost or beneficial microbial solutions.

Q4. Who qualifies for financial assistance to apply biochar?

- ✓ A4. USDA NRCS financial assistance programs are designed for use on working lands i.e., farms, rangeland, pasture, range, forest lands and associated agricultural lands. USDA NRCS [Environmental Quality Incentives Program \(EQIP\)](#) accepts applications for financial assistance to implement conservation practices that address state and county resource concerns. The official conservation practice standard that includes biochar is called [Soil Carbon Amendment 336](#), while the interim conservation practice standard is [Soil Carbon Amendment 808](#). Each state decides what conservation practices will be available for funding through the EQIP program, so you need to check whether your state offers Soil Carbon Amendment before applying for EQIP funds for that practice. You can search for your state's Field Office Technical Guide through the [NRCS Field Office Technical Guide](#) website. Navigate to Section 4, "Practice Standards and Supporting Documents" and scroll through the alphabetized list of practice standards that are available in the state, or click on the Document Search tab, then search 'biochar' or 'soil carbon amendment'. If Soil Carbon Amendment is not shown, that means NRCS will not fund EQIP applications proposing to implement it in that state for the current fiscal year. If you do see the Soil Carbon Amendment practice standard that means the state will consider EQIP applications proposing to implement it.

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