Assessing the influence of biochar preparation methods on soil health in diverse managed ecosystems

United States Department of Agriculture, National Institute of Food and Agriculture, Agriculture and Food Research Initiative (AFRI) , project number 2022-67019-36960

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Project description

The project, "*Assessing the influence of biochar preparation methods on soil health in diverse managed ecosystems*" was awarded to Virginia Polytechnic Institute and State University (Virginia Tech) in 2022 by the United States Department of Agriculture, National Institute of Food and Agriculture, Agriculture and Food Research Initiative (AFRI), project number 2022-67019-36960.

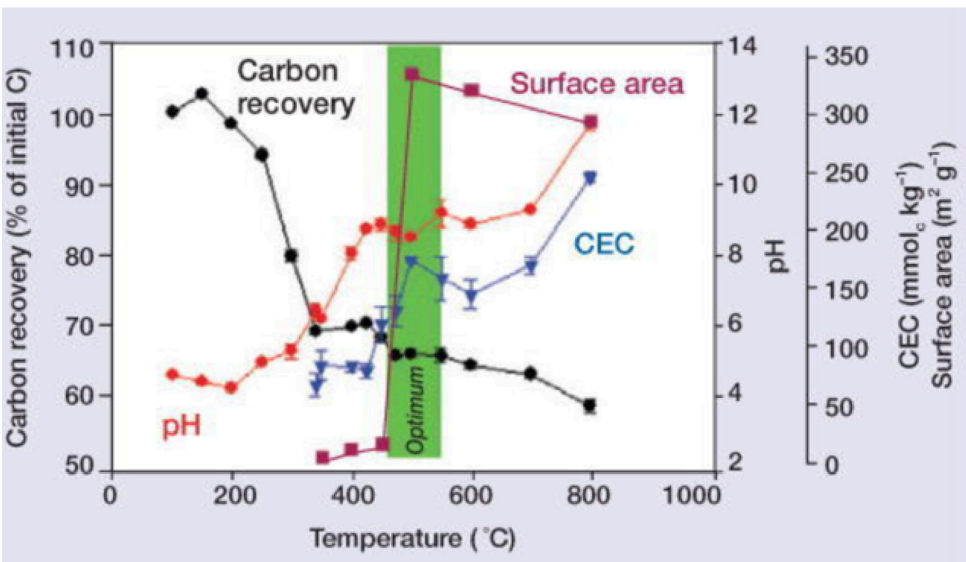
The objective of the research project is to evaluate methods for producing and activating biochar as a soil amendment for improving soil health in diverse managed ecosystems. Biochar applications improve soil health in a variety of ecosystems, primarily through modifying soil microstructure in ways that enhance aggregation and hydraulic properties. Using a combination of field experiments, advanced imaging techniques, and modeling, the project examined the mechanisms by which biochar influences soil structural and hydraulic properties. and, thereby, the mobility of nutrients, carbon sequestration, and microbial communities in controlled field studies across a range of managed agricultural systems (pasture, row-crop, forest) and soil types (fine and coarse texture soils across 6 orders). The project included biochar experiments to encompass a range of temporal perspectives on the benefits of biochar to growers and the long-term implications for how biochar potentially influences multiple indicators of soil health.

What is Biochar?

Biochar is made from a variety of feedstocks via pyrolysis: an irreversible thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen.

The biochar used in this project was produced by Seneca Farms Biochar[1] at two different temperatures on "either side" of the "sweet spot" shown in the green bar in Figure 1. This graph is typical of the production of biochars from most feedstocks in that there is a marked increase in the carbon infrastructure's surface area around 400 to 500°C in concert with substantial changes in other properties.

Figure 1. The "Sweet Spot" for Optimum Biochar Production Temperatures



Source: Lehmann, J. (2007), Bio-energy in the black. Frontiers in Ecology and the Environment, 5: 381-387. https://doi.org/10.1890/1540-9295(2007)5[381:BITB]2.0.CO;2

[1] https://sfbiochar.com/

A Detailed Look at the Biochar Used in this Project

This report will use the USBI fact sheet[3] "INTERPRETING BIOCHAR LAB REPORTS" for explanations about the individual characteristics shown in the breakdown of the analysis of the biochars used in this project (Table 1). The analyses were provided by the biochar manufacturer and were performed by Control Labs, Inc.[2] in Watsonville, CA in accordance with the IBI (International Biochar Initiative) Standards at the time (2023).

Table 1. Biochars' Physical Properties

Temp	Bulk Density lb/cu ft	Organic Carbon % of dry mass	Carbonates %CaCO3	Hydrogen/ Carbon molar ratio	Electrical Conductivi ty dS/m	Volatile Matter % dry wt.
350C	10.3	77.8	5.5	0.3	1.073	12
600C	12.1	92.4	3.4	0.13	0.344	9

Bulk density

Bulk density is a required value to allow conversion between volume-based units (such as cubic meters or yards) and weight based units (e.g., Kg or tons.) The mass of biochar per unit is substantially lower than the bulk density of soil. When applied to soils, biochar typically reduces soil bulk density.

The higher temperature biochar increased the bulk density due to more volatiles being evaporated.

Organic carbon (Corg) and carbonates (as CaCO3)

Total carbon analysis measures both organic carbon and inorganic carbonates, the latter of which is contained in the ash fraction (typically in the form of carbonates). This report separates total carbon into organic carbon (Corg) and carbonates (as CaCO3). For all feedstocks Corg generally increases with increasing production temperature. The carbon sequestration potential of biochar is directly related to Corg, and this analysis is required under all existing carbon removal methodologies for biochar and for use as a soil amendment under USDA incentive payment programs for biochar such as USDA Natural Resources Conservation Service (NRCS) Conservation Practice Standard (CPS) 336. Manure and grass biochars tend to be lower in Corg than wood-derived biochars.

2 Biochar Testing - Watsonville, CA - Control Laboratories

3 https://biochar-us.org/sites/default/files/learning/files/USBI_Fact_Sheet_DFB_BiocharLabReports.pdf

These samples illustrate this relationship between organic carbon and production temperatures by the higher temperature biochar's significantly greater (19%) amount of organic carbon and a lower H:Corg ratio (by 57%).

H:C ratio and fixed carbon

The ratio of hydrogen (H) to carbon (C) atoms, abbreviated as H:Corg (sometimes reported as H:C or H/C) ratio, is an indicator for biochar stability. Lower H:C ratios generally correspond to stronger bonds between carbon atoms, reducing susceptibility to microbial and chemical decomposition, therefore indicating a greater long-term carbon sequestration potential. Many biochar standards and carbon removal methodologies require an H:C ratio less than 0.7.

The higher temperature biochar, with its lower H:Corg ratio, will have more stable Carbon, resulting in longer lasting carbon than the lower temperature material.

Electrical conductivity

Electrical conductivity (EC) measures soluble salt content in biochar. A low EC indicates that biochar is low in soluble salts and vice versa. The impact of biochar salts on salinity is typically short-lived in applications where water percolates through media. That is the case in stormwater treatment, nursery and seedling production, and most farming except in drier regions. Intentionally rinsing biochar with fresh water can be used to reduce biochar EC. High amounts of salt can cause plant toxicity, especially in seedlings, transplants, and nursery crops. However, high EC may indicate that the biochar has high levels of plant nutrients, so higher EC biochar may be a good choice for established crops.

The Electrical Conductivity of the two samples changed significantly with the increased temperature.

Volatile matter

Volatile matter is composed of compounds that volatilize from the biochar in the absence of oxygen at 950 °C. Volatile matter may contain gases like carbon monoxide and methane; organic hydrocarbons, acids, and tars; and some inorganic compounds. Volatile matter can be an important food source for microbes, which can improve soil fertility.

As *would be expected, the volatile matter decreased with higher temperature.*

Table 2. Biochars' pH, Liming, Ash, and Surface Area Properties

Temp	pH	Liming %CaCO3	Total Ash % of dry mass	Surface Area Correlation m2/g dry
350C	9.89	6.7	14	492
600C	8.33	6.2	3.3	373

pH and liming

Biochars generally have alkaline pH (above pH 7), but acidic and neutral pH biochars can also be produced under certain production conditions. As the ash fraction of the biochar increases, salts, oxides, hydroxides, silicates, and carbonates also increase, which contributes to biochar alkalinity.

Biochar pH does not directly describe the potential of biochar to change the pH of soils. Soils have pH buffering capacity that allows soils to resist pH changes. Liming equivalent estimates biochar's ability to impact the pH of soil, soilless media, and other media blends.

In these samples, the lower temperature char's higher pH is consistent with its higher ash content.

Total ash

The ash fraction of biochar contains mineral carbonates and oxides that can react in soil to increase pH, provide nutrients to plants, and bind metals and phosphorus. The ash fraction is composed of elements that do not volatilize (calcium, potassium, magnesium, silicon, phosphorus and trace metals) at typical biochar production temperatures.

The differences between the two production temperatures illustrates the ability to "design" chars to fit specific applications—in this case to increase liming potential.

Surface area

Surface area, typically reported in square meters per gram (m2/g), indicates the total area of the biochar surface. Biochar with high surface area typically has greater potential to absorb environmental toxins, metals, and nutrients, so the surface area of biochar is especially important when used in environmental remediation applications. The surface area of biochars used in soil are important to indicate the char's capacity to retain moisture and nutrients, as well as to bind pollutants.

In these samples, the lower temperature char actually had the higher surface area, providing another example of potential design parameters available for matching specific applications.

Table 3. Biochars' Elemental Properties (Heavy Metals and Micronutrients)

Temp	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Cobalt (Co)	Copper (Cu)
350C	ND	ND	11.4	4.5	41
600C	ND	ND	71.9	1.5	9.1
Temp	Lead (Pb)	Molybdenum (Mo)	Mercury (Hg)	Nickel (Ni)	Selenium (Se)
350C	1.5	1.1	ND	11.4	ND
600C	0.23	0.37	ND	29.2	ND
Temp	Boron (B)	Chlorine (Cl)	Sodium (Na)	Iron (Fe)	Manganese (Mn)
350C	36.9	1371	ND	4488	4433
600C	12.7	67.4	369	900	787

Note: All units expressed in PPM-parts per million; ND means none detected.

Many biochar standards require that it be analyzed for a broad suite of metals. The IBI and, in the USA, NRCS standards for biochar include a range of maximum allowable concentrations for metals based on a review of regulatory values; however, state and local regulations may be more stringent.   Many state departments of agriculture also maintain standards for heavy metal application rates via soil amendments, typically expressed as limits on total metals mass applied per acre.

Some metals (e.g., arsenic, chromium, mercury) are phytotoxic and/or pose human health hazards, while other metals are plant micronutrients (e.g., nickel, zinc, boron) and contribute to the growth and health of crops.

In the two samples for this project all the elements tested fell well below the limits at which they needed to be reported, and were below or within the maximum acceptable levels.

Table 4. Biochars' Nutrients

Temp	Total (K) mg/kg	Total (P) mg/kg	Total Nitrogen % of dry mass	Organic (Org-N) mg/kg	Nitrate (NO3-N) mg/kg	Ammonia (NH4-N) mg/kg
350C	11248	2869	0.58	5817	0.92	5.5
600C	3074	493	0.63	6304	5.9	26.6

Total potassium (K)

Biochar produced from certain feedstocks, such as manure, can contain substantial amounts of potassium (K). Potassium in biochar is readily available to plants and can meet a portion of crop potassium needs.

The lower temperature biochar had 3.7 times more potassium than the high temperature biochar, 0.11% vs 0.03%, however both were insignificant for plant health purposes.

Total phosphorus (P)

The P found in biochar is generally present as calcium and magnesium-phosphate complexes. In these forms, biochar can act like a slow-release fertilizer, and allow plants to uptake available P. Their availability depends on which phosphate compounds are present in biochar but also on inherent soil properties, such as the mineralogy of the soil and dynamic soil properties, like pH. Some studies have shown that applying biochar produced from manures or biosolids can meet a significant portion of crop P demand.

The lower temperature biochar had almost 6 times more phosphorus than the high temperature biochar, 0.03% vs 0.005%, however both were insignificant for plant health purposes.

Nitrogen

Nitrogen is useful for soil fertility management. Total nitrogen is the sum of organic nitrogen, ammonia, and nitrate. Even when raw biochar is applied at very high rates, it will not provide sufficient nitrogen for optimal plant growth. Biochar is extremely effective at retaining nitrogen in soil and making it more available for plant uptake over time, which can increase the nitrogen-use efficiency of applied fertilizers. If biochar is applied as a co-composted or nutrient-charged product, it can supplement other forms of nitrogen to meet crop demand. Pelletized and prilled biochar-enhanced fertilizers can contribute to crop nitrogen needs and improve fertilizer efficiency.

In these samples, the higher temperature biochar showed increased nitrogen across all forms, but at insignificant levels for plant health.

Summary

The objective to produce biochars at low and high temperatures to illustrate the different effects on soil chemistry, soil biota reaction, soil health generally, and plant response was successful. This is a notable success in that commercial biochar production is generally done at a specific temperature for specifically available feedstocks in order to produce a consistent product. Custom biochars are most commonly produced at a bench or pilot scale where critical parameters can be controlled easily. Given the large number of characteristics considered important, it's apparent how challenging it is to produce a tightly specified biochar, especially given the variability of potential organic feedstocks.

The characteristics presented in an analysis are defined by Standards currently recommended by the International Biochar Initiative, and embodied formally in the European Biochar Standards. While currently voluntary, the IBI standard is used by many other national biochar initiatives, including the US Biochar Initiative which, in turn, is considered "official" by the US Department of Agriculture's various soil health initiatives.

The analysis of the two biochars used in this project illustrate the differences in their physical and chemical characteristics, however, this report is focused solely on the biochars.

In practice, specifying biochar with a narrow range of all but a few of the characteristics is challenging for commercial processors and is being constantly influenced by research using different feedstocks, and different additives and process parameters. Some characteristics can be controlled more effectively than others—carbon content via processing temperature for instance—and some by post processing, like particle size distribution and nutrient or pH levels. Most of the elemental characteristics are dependent on the feedstock and processing parameters and are relatively stable once the operating system is optimized and stable.

References

1. Seneca Farms Biochar. 2025. https://sfbiochar.com/
2. Biochar Testing - Watsonville, CA - Control Laboratories

Appendix

1. USBI Interpreting Biochar Lab Reports Fact Sheet (Trippe, K., Aller, D., Gray, M., Delaney, M., Smith, B., Baschieri, R., Miles, T., Slezak, K., and Cawood, L..) https://biochar-us.org/sites/default/files/learning/files/USBI_Fact_Sheet_DFB_BiocharLabReports.pdf
2. Control Laboratories. 2023. International BioChar Initiative (IBI) Laboratory Tests for Certification Program. Hi-Temp.
3. Control Laboratories. 2023. International BioChar Initiative (IBI) Laboratory Tests for Certification Program. Lo-Temp.

US BIOCHAR INITIATIVE

biochar-us.org

INTERPRETING BIOCHAR LAB REPORTS

Learn about

- Biochar properties
- Interpreting a test report
- Tests recommended for different applications
- How to collect samples

Biochars are variable in their physical and chemical properties. These properties are generally determined by feedstock type and production temperature. For example, biochar feedstocks vary in their particle size (increasing along the top arrow), while feedstock and temperature can influence ash content (increasing with bottom arrow). Biochar properties influence how biochar interacts with soil or other media, which influences performance. A lab report assesses these properties. A sample report is shown inside.

Biochar's physical and chemical properties control its effectiveness in different applications. Properties are determined by:

- **feedstock**
- **production conditions**
- **pre- or post- processing**

Biochars differ greatly in their properties so laboratory analytical data provides a way to predict biochar's effectiveness.

Physical properties

1 Moisture content

Moisture content is the amount of water in the sample at the time of analysis. If the report indicates that the moisture content is 30%, then 100 lbs of biochar would contain 30 lbs of water. Moisture content is important to reduce dust. All other biochar analytical data are reported on a dry basis (content per unit dry mass).

2 Bulk density

Bulk density is a required value for converting between volume-based units such as cubic yards and weight-based units such as tons. The mass of biochar per unit is substantially lower than the bulk density of soil. When applied to soils, biochar typically reduces soil bulk density.

3 Surface area

Surface area, typically reported in square meters per gram (m^2/g), indicates the total area of the biochar surface. Biochar with high surface area typically has greater potential to absorb environmental toxins, metals, and nutrients, so the surface area of biochar is especially important when used in environmental remediation applications.

4 Particle size distribution

Particle size distribution indicates the mass percentage of a biochar sample that falls within specific size classes. When used as a soil amendment, particle size distribution influences biochar:soil interactions including impact on soil pH, leaching potential, and soil water dynamics. Particle size distribution is also a critical parameter for filtration applications and when used in granulated products.

Chemical properties related to carbon

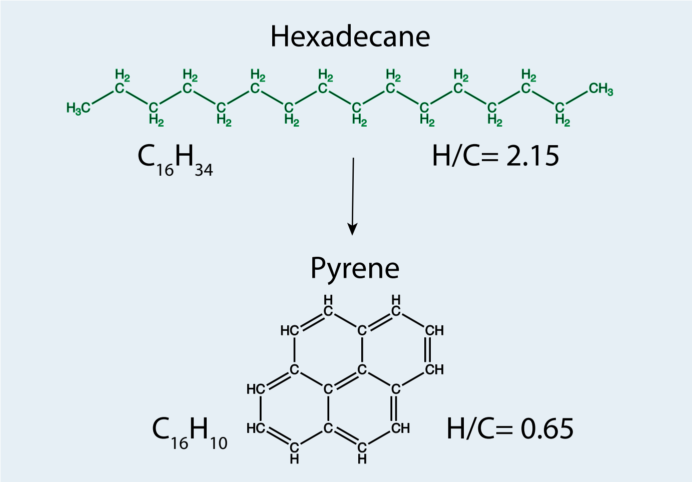
5 Organic carbon (C_{org}) and carbonates (as $CaCO_3$)

Total carbon analysis measures both organic carbon and inorganic carbonates, the latter of which is contained in the ash fraction (typically in the form of carbonates). Most laboratory reports separate total carbon into organic carbon (C_{org}) and carbonates (as $CaCO_3$). Both values are important, so confirm that the laboratory separates these values.

Manure biochars tend to be lower in C_{org} than wood-derived biochars, and for all feedstocks C_{org} generally increases with increasing production temperature. The carbon sequestration potential of biochar is directly related to C_{org}, and this analysis is required under all existing carbon removal methodologies for biochar and for use as a soil amendment under USDA incentive payment programs for biochar such as USDA Natural Resources Conservation Service (NRCS) Conservation Practice Standard (CPS) 336.

6 H:C ratio and fixed carbon

The ratio of hydrogen (H) to carbon (C) atoms, abbreviated as H:C_{org} (sometimes reported as H:C or H/C) ratio, is an indicator for biochar stability. Lower H:C ratios generally correspond to stronger bonds between carbon atoms, reducing susceptibility to microbial and chemical decomposition, therefore indicating a greater long-term carbon sequestration potential. Many biochar standards and carbon removal methodologies require an H:C ratio less than 0.7.



7 Total ash

The ash fraction of biochar contains mineral carbonates and oxides that can react in soil to increase pH, provide nutrients to plants, and bind metals and phosphorus. The ash fraction is comprised of elements that do not volatilize (calcium, potassium, magnesium, silicon, phosphorus and trace metals) at typical biochar production temperatures. Some of these elements are discussed in detail under soil fertility.

8 Volatile matter

Volatile matter is composed of compounds that volatize from the biochar in the absence of oxygen at 950 °C. Volatile matter may contain gases like carbon monoxide and methane; organic hydrocarbons, acids, and tars; and some inorganic compounds. Volatile matter can be an important food source for microbes, which can improve soil fertility.

Typical lab report

Laboratory analytical reports for biochar vary depending on which laboratory performed the analysis, however each report should contain similar information including parameters analyzed, analytical methods used, and results. A typical report is shown below.

International BioChar Initiative (IBI)
Laboratory Tests for Certification Program

No.	Parameter	Dry Basis Unless Stated:	Range	Units	Method
1	Moisture (time of analysis)	56.9		% wet wt.	ASTM D1762-84 (105c)
2	Bulk Density	9.9		lb/cu ft	
5	Organic Carbon	77.8		% of total dry mass	Dry Combust-ASTM D 4373
6	Hydrogen/Carbon (H:C)	0.68	0.7 Max	Molar Ratio	H dry combustion/C(above)
7	Total Ash	1.2		% of total dry mass	ASTM D-1762-84
9	Total Nitrogen	0.38		% of total dry mass	Dry Combustion
10	pH value	6.76		units	4.11USCC:dil. Rajkovich
12	Electrical Conductivity (EC20 w/w)	0.074		dS/m	4.10USCC:dil. Rajkovich
11	Liming (neut. Value as-CaCO3)	7.6		%CaCO3	AOAC 955.01
5	Carbonates (as-CaCO3)	0.2		%CaCO3	ASTM D 4373
	Butane Act.	0.8		g/100g dry	ASTM D 5742-95
3	Surface Area Correlation	157		m2/g dry	G

15 — All units mg/kg dry unless stated:

Element	Symbol	Results	Range of Max. Levels	Reporting Limit (ppm)	Method
Arsenic	(As)	**ND**	13 to 100	0.37	J
Cadmium	(Cd)	0.26	1.4 to 39	0.15	J
Chromium	(Cr)	0.73	93 to 1200	0.37	J
Cobalt	(Co)	**ND**	34 to 100	0.37	J
Copper	(Cu)	2.4	143 to 6000	0.37	J
Lead	(Pb)	0.26	121 to 300	0.15	J
Molybdenum	(Mo)	**ND**	5 to 75	0.37	J
Mercury	(Hg)	**ND**	1 to 17	0.001	EPA 7471
Nickel	(Ni)	0.6	47 to 420	0.37	J
Selenium	(Se)	**ND**	2 to 200	0.74	J
Zinc	(Zn)	32.3	416 to 7400	0.74	J
Boron	(B)	8.2	Declaration	3.7	TMECC
Chlorine	(Cl)	22.7	Declaration	20.0	TMECC
Sodium	(Na)	**ND**	Declaration	370	E
Iron	(Fe)	65.1	Declaration	18.5	E
Manganese	(Mn)	118	Declaration	0.37	J

Particle Size Distribution (4)

Size	Results	Units	Method
< 0.5mm	18.4	percent	F
0.5-1mm	4.1	percent	F
1-2mm	7.5	percent	F
2-4mm	18.6	percent	F
4-8mm	37.5	percent	F
8-16mm	13.9	percent	F
16-25mm	0.0	percent	F
25-50mm	0.0	percent	F
>50mm	0.0	percent	F

Basic Soil Enhancement Properties

Property	No.	Results	Units	Method
Total (K)	13	2072	mg/kg	E
Total (P)	14	186	mg/kg	E
Ammonia (NH4-N)		11.9	mg/kg	A
Nitrate (NO3-N)		3.6	mg/kg	A
Organic (Org-N)	9	3767	mg/kg	Calc.
Volatile Matter	8	27.9	percent dw	D

* "ND" stands for "not detected" which means the result is below the reporting limit.

Method A Rayment & Higginson
D ASTM D1762-84
E EPA3050B/EPA 6010
F ASTM D 2862 Granular
G Butane Activity Surface Area Correlation Based on McLaughlin, Shields, Jagiello, & Thiele's 2012 paper: Analytical Options for Biochar Adsorption and Surface Area
J EPA3050B/EPA 6020

This typical laboratory report details the physical and chemical properties of biochar. Colored numbers correspond to the description of physical properties (green numbers), chemical properties related to carbon (orange numbers), and fertility and heavy metals (blue numbers).

Soil fertility

9 Nitrogen

Total nitrogen is the sum of organic nitrogen, ammonia, and nitrate. Even when raw biochar is applied at very high rates, it will not provide sufficient nitrogen for optimal plant growth.

Biochar is extremely effective at retaining nitrogen in soil and making it more available for plant uptake, which can increase the nitrogen use efficiency of applied fertilizers. If biochar is applied as a co-composted or nutrient-charged product, it can supplement other forms of nitrogen to meet crop demand. Pelletized and prilled biochar-enhanced fertilizers can contribute to crop nitrogen needs and improve fertilizer efficiency. Consult with your laboratory and crop advisor to estimate nitrogen contributions from raw, composted, or charged biochars to better understand the effect of biochar on nitrogen application requirements.

⑩ pH and liming

Biochars generally have alkaline pH (above pH 7), but acidic and neutral pH biochars can also be produced under certain production conditions. As the ash fraction of the biochar increases, salts, oxides, hydroxides, silicates, and carbonates also increase, which contributes to biochar alkalinity.

Biochar pH does not directly describe the potential of biochar to change the pH of soils. Soils have pH buffering capacity that allows soils to resist pH changes. Liming equivalent estimates biochar's ability to impact the pH of soil, soilless media, and other media blends.

⑪ Liming equivalent

$CaCO_3$ equivalence, the most common form of lime used by farmers, indicates the liming effect of a unit mass of biochar compared to pure $CaCO_3$. High ash biochars, such as those derived from manures, typically have higher lime equivalence than wood biochars. Higher temperatures tend to produce biochars with a higher pH and liming eqivalence.

The ash content of biochar may contain calcium carbonates ($CaCO_3$) and hydroxides. In soil, these compounds react with exchangeable hydrogen ions (part of the soil's reserve acidity) to form carbonic acid and water. Like agricultural lime, this reaction alleviates soil acidity because the strongly acidic exchangeable hydrogen ions are incorporated into weaker carbonic acid. In places where agricultural lime is scarce, biochar may be a good option for increasing soil pH. However, prior to application, the liming potential of the biochar (measured as liming equivalence) and the pH-buffering capacity (usually measured as SMP or Sikora) should be tested to ensure that the post application soil pH is within the ideal range for crop growth.

⑫ Electrical conductivity

Electrical conductivity (EC) measures soluble salt content in biochar. A low EC indicates that biochar is low in soluble salts and vice versa. The impact of biochar salts on salinity is typically short-lived in applications where water percolates through media. That is the case in stormwater treatment, nursery and seedling production, and most farming except in drier regions. Intentionally rinsing biochar with fresh water can be used to reduce biochar EC.

High amounts of salt can cause plant toxicity, especially in seedlings, transplants, and nursery crops. However, high EC may indicate that the biochar has high levels of plant nutrients, so higher EC biochar may be a good choice for established crops.

⑬ Total potassium (K)

Biochar produced from certain feedstocks, such as manure, can contain substantial amounts of potassium (K). Potassium in biochar is readily available to plants and can meet a portion of crop potassium needs.

⑭ Total phosphorus (P)

The P found in biochar is generally present as calcium and magnesium-phosphate complexes. In these forms, biochar can act like a slow release fertilizer, and allow plants to uptake available P. Their availability depends on which phosphate compounds are present in biochar but also on inherent soil properties, such as the minerology of the soil and dynamic soil properties, like pH. Some studies have shown that applying biochar produced from manures or biosolids can meet a significant portion of crop P demand.

⑮ Metals

IBI[1] and NRCS[2] standards require that biochar be analyzed for a broad suite of metals. Many state departments of agriculture also maintain standards for heavy metal application rates via soil amendments, typically expressed as limits on total metals mass applied per acre. The IBI and NRCS standards for biochar include a range of maximum allowable concentrations for metals based on a review of regulatory values, however, state and local regulations may be more stringent than IBI and NRCS standards. A review of applicable regulations is recommended if heavy metal concentrations are above minimum values listed in the IBI and NRCS standards.

Some metals (e.g., arsenic, chromium, mercury) are phytotoxic and/or pose human health hazards, while other metals are plant micronutrients (e.g., nickel, zinc, boron) and contribute to the growth and health of crops.

What tests are important?

There are no federal standards for biochar specifications. However, to qualify for certain incentive payments, including the NRCS CPS 336[2], certain criteria must be met. These generally align with standards suggested by the International Biochar Initiative[3] (IBI). Biochar used for other end uses may need to comply with state, local or industry requirements including agricultural and environmental regulations, specifications in stormwater manuals and carbon removal credit methodologies (e.g., Puro.earth, Verro, and the European Biochar Certificate). Depending on the biochar end use, different lab tests are needed. A general framework for various end uses is presented below.

General testing framework

	Soil amendment NRCS, IBI*	Compost	Carbon credits Verra, Puro.earth, EBC*	Stormwater	Remediation	Concrete	Soilless media
Moisture content	always recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required
Bulk density	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	not recommended/required	always recommended/required
Surface area	sometimes recommended/required	sometimes recommended/required	not recommended/required	sometimes recommended/required	always recommended/required	not recommended/required	sometimes recommended/required
Particle size	always recommended/required	sometimes recommended/required	sometimes recommended/required	always recommended/required	sometimes recommended/required	always recommended/required	sometimes recommended/required
Organic carbon	always recommended/required	sometimes recommended/required	always recommended/required	sometimes recommended/required	not recommended/required	always recommended/required	not recommended/required
H:C ratio	always recommended/required	not recommended/required	always recommended/required	sometimes recommended/required	not recommended/required	not recommended/required	not recommended/required
Ash	always recommended/required	not recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	always recommended/required	not recommended/required
Volatile matter	sometimes recommended/required	not recommended/required	not recommended/required	not recommended/required	not recommended/required	always recommended/required	not recommended/required
Nutrients (N, P, K)	always recommended/required	sometimes recommended/required	sometimes recommended/required	always recommended/required	sometimes recommended/required	not recommended/required	always recommended/required
pH and liming	always recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	always recommended/required	sometimes recommended/required	always recommended/required
Electrical conductivity	always recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	sometimes recommended/required	always recommended/required
Metals	always recommended/required	sometimes recommended/required	sometimes recommended/required	always recommended/required	always recommended/required	sometimes recommended/required	sometimes recommended/required

A framework indicating the importance of each analytical test for various end uses. The importance of each testing procedure is indicated by:

- **always recommended/required**
- **sometimes recommended/required**
- **not recommended/required**

**The regulatory agency or organization that developed the recommendations are listed under the related end use. If no agency is listed recommendations are based off the general scientific literature and standard practices.*

Collecting a composite sample

Use a composite sample collection approach to produce a representative biochar sample, which improves the reliability of the laboratory testing results. Collect 10-15 subsamples and combine them to create a composite sample. The weight of each subsample should be no less than the laboratory requested sample weight divided by the number of subsamples. If the biochar is moist double the weights. These are general guidelines. Always follow directions from the laboratory you are using.

If the biochar is stored in piles and thorough mixing of the pile is possible:

1. **Turn the pile at least 10 times to mix the biochar**
2. **Take samples from 15 different areas in the pile**
3. **Place all biochar subsamples into a 5-gallon bucket and thoroughly mix them, so they don't stratify**
4. **Collection the lab requested sample weight from the 5-gallon bucket. Mark the name of the biochar, sampling date and time, and place it in a reusable plastic bag.**

When piled biochar cannot be mixed:

1. **Select five random areas to collect subsamples near the top of the pile, five areas to collect in the middle of the pile and five areas from the bottom for a total of 15 subsamples.**
2. **See steps 3-4 above.**

When biochar is stored in containers/bags:

1. **Select five random biochar containers/ bags to be sampled**
2. **Open the containers and mix their contents thoroughly**
3. **Take three subsamples from a different depth in each container**
4. **See steps 3-4 of the scenario when mixing of the pile is possible**

Selecting a laboratory and analysis package

There are currently only a small number of laboratories that offer analytical packages specifically tailored for biochar analysis. Yet, many compost, soil, coal, and activated carbon analysis labs can perform all biochar analyses presented in this guide. A list of laboratories[1] is maintained by IBI, and these labs tend to offer different analytic packages. It is important to make sure the laboratory is using an acceptable analysis method for biochar. Confirm that they follow IBI testing guidelines.

Selecting a biochar package, or suite of analyses depends on the end use of the biochar, but also on relevant regulations and standards that may apply. A summary of recommended and required laboratory analysis methods for different end uses is shown in "General testing framework" table.

References

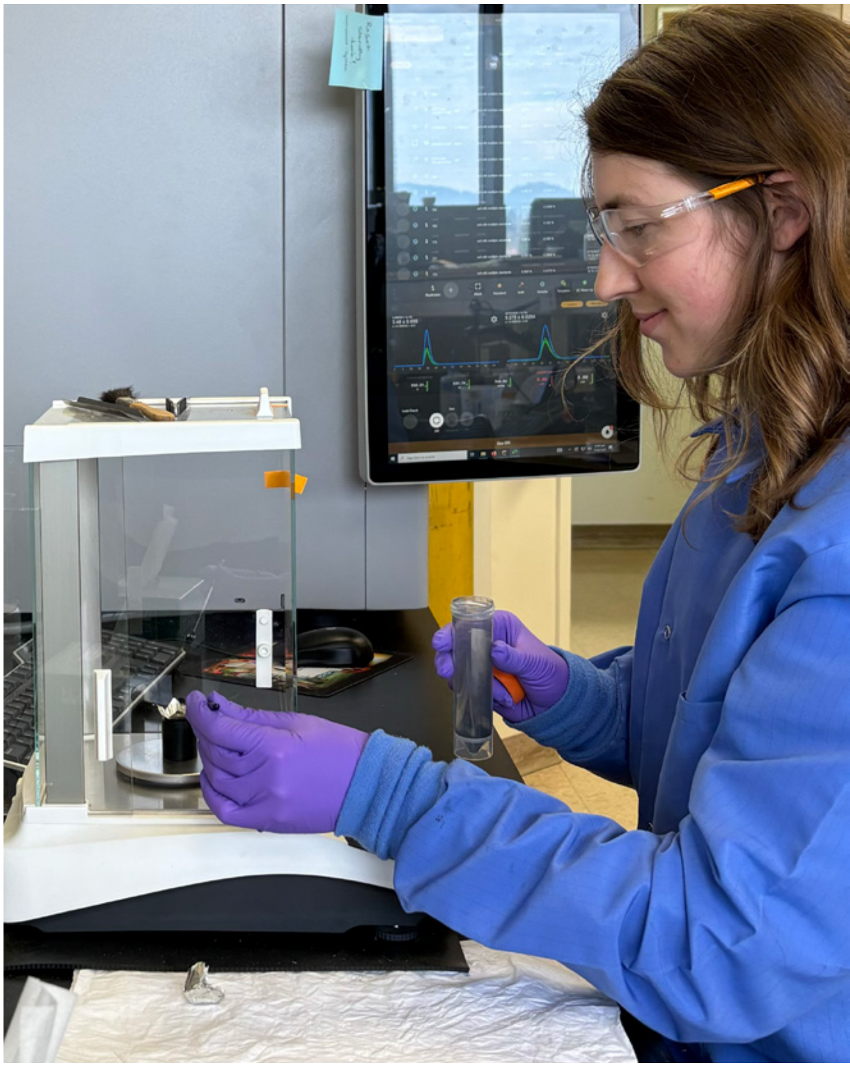
1 International Biochar Initiative. 2023. Testing laboratories for IBI biochar certification. https://biochar-international.org/testing-laboratories-for-ibi-biochar-certification

2 USDA Natural Resources Conservation Service. Conservation Practice Standard. *Soil Carbon Amendment Code 336.* 2022. Available at: https://www.nrcs.usda.gov/sites/default/files/2022-11/336-NHCP-CPS-Soil-Carbon-Amendment-2022.pdf

3 International Biochar Initiative. *Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil (aka IBI Biochar Standards) Version 2.1.* 2015. Available at https://biochar-international.org/wp-content/uploads/2020/06/IBI_Biochar_Standards_V2.1_Final2.pdf

Suggested citation: Trippe, K., Aller, D., Gray, M., Delaney, M., Smith, B., Baschieri, R., Miles, T., Slezak, K., and Cawood, L..

Scan to visit US Biochar Initiative Learning Center



For more information, please visit
US Biochar Initiative: **biochar-us.org**

Published by: USBI in partnership with Nebraska Forest Service.
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High Temp 600C

Control Laboratories

42 Hangar Way
Watsonville, CA 95076
www.biocharlab.com
Tel: 831 724-5422
Fax: 831 724-3188

Account No:

Batch:
Jun 23 C
CODE:
BioChar IBI

Date Received: 6/12/2023
Sample ID: Sample 2
Lab ID. Number:

International BioChar Initiative (IBI) Laboratory Tests for Certification Program

Dry Basis Unless Stated:		Range	Units	Method
Moisture (time of analysis)	59.1		% wet wt.	ASTM D1762-84 (105c)
Bulk Density	12.1		lb/cu ft	
Organic Carbon	92.4		% of total dry mass	Dry Combust-ASTM D 4373
Hydrogen/Carbon (H:C)	0.13	0.7 Max	Molar Ratio	H dry combustion/C(above)
Total Ash	3.3		% of total dry mass	ASTM D-1762-84
Total Nitrogen	0.63		% of total dry mass	Dry Combustion
pH value	8.33		units	4.11USCC:dil. Rajkovich
Electrical Conductivity (EC20 w/w)	0.344		dS/m	4.10USCC:dil. Rajkovich
Liming (neut. Value as-CaCO3)	6.2		%CaCO3	AOAC 955.01
Carbonates (as-CaCO3)	3.4		%CaCO3	ASTM D 4373
Butane Act.	7.5		g/100g dry	ASTM D 5742-95
Surface Area Correlation	373		m2/g dry	G

All units mg/kg dry unless stated:		Results	Range of Max. Levels	Reporting Limit (ppm)	Method
Arsenic	(As)	**ND**	13 to 100	0.28	J
Cadmium	(Cd)	**ND**	1.4 to 39	0.11	J
Chromium	(Cr)	71.9	93 to 1200	0.28	J
Cobalt	(Co)	1.5	34 to 100	0.28	J
Copper	(Cu)	9.1	143 to 6000	0.28	J
Lead	(Pb)	0.23	121 to 300	0.11	J
Molybdenum	(Mo)	0.37	5 to 75	0.28	J
Mercury	(Hg)	**ND**	1 to 17	0.001	EPA 7471
Nickel	(Ni)	29.2	47 to 420	0.28	J
Selenium	(Se)	**ND**	2 to 200	0.57	J
Zinc	(Zn)	6.6	416 to 7400	0.57	J
Boron	(B)	12.7	Declaration	2.8	TMECC
Chlorine	(Cl)	67.4	Declaration	20.0	TMECC
Sodium	(Na)	369	Declaration	283	E
Iron	(Fe)	900	Declaration	14.2	E
Manganese	(Mn)	787	Declaration	0.28	J

Particle Size Distribution	Results	Units	Method
< 0.5mm	26.5	percent	F
0.5-1mm	35.5	percent	F
1-2mm	26.7	percent	F
2-4mm	7.4	percent	F
4-8mm	2.5	percent	F
8-16mm	1.3	percent	F
16-25mm	0.0	percent	F
25-50mm	0.0	percent	F
>50mm	0.0	percent	F
Basic Soil Enhancement Properties			
Total (K)	3074	mg/kg	E
Total (P)	493	mg/kg	E
Ammonia (NH4-N)	26.6	mg/kg	A
Nitrate (NO3-N)	5.9	mg/kg	A
Organic (Org-N)	6304	mg/kg	Calc.
Volatile Matter	9.0	percent dw	D

* "ND" stands for "not detected" which means the result is below the reporting limit.

Method A Rayment & Higginson
D ASTM D1762-84
E EPA3050B/EPA 6010
F ASTM D 2862 Granular
G Butane Activity Surface Area Correlation Based on McLaughlin, Shields, Jagiello, & Thiele's 2012 paper: Analytical Options for Biochar Adsorption and Surface Area
J EPA3050B/EPA 6020

Analyst: Nik Zumberge

Control Laboratories

42 Hangar Way
Watsonville, CA 95076
www.biocharlab.com
Tel: 831 724-5422
Fax: 831 724-3188

Lo Temp 350C

Account No:
10441
Batch:
MAY 22 C
CODE:
BioChar IBI

Date Received: 5/20/2022
Sample ID: VA Char 5 16 22 v1
Lab ID. Number: 2050474-01

International BioChar Initiative (IBI) Laboratory Tests for Certification Program

	Dry Basis Unless Stated:	Range	Units	Method
Moisture (time of analysis)	66.8		% wet wt.	ASTM D1762-84 (105c)
Bulk Density	10.3		lb/cu ft	
Organic Carbon	77.8		% of total dry mass	Dry Combust-ASTM D 4373
Hydrogen/Carbon (H:C)	0.30	0.7 Max	Molar Ratio	H dry combustion/C(above)
Total Ash	14.0		% of total dry mass	ASTM D-1762-84
Total Nitrogen	0.58		% of total dry mass	Dry Combustion
pH value	9.89		units	4.11USCC:dil. Rajkovich
Electrical Conductivity (EC20 w/w)	1.073		dS/m	4.10USCC:dil. Rajkovich
Liming (neut. Value as-CaCO3)	6.7		%CaCO3	AOAC 955.01
Carbonates (as-CaCO3)	5.5		%CaCO3	ASTM D 4373
Butane Act.	11.3		g/100g dry	ASTM D 5742-95
Surface Area Correlation	492		m2/g dry	G

All units mg/kg dry unless stated:		Results	Range of Max. Levels	Reporting Limit (ppm)	Method
Arsenic	(As)	**ND**	13 to 100	0.42	J
Cadmium	(Cd)	**ND**	1.4 to 39	0.17	J
Chromium	(Cr)	11.4	93 to 1200	0.42	J
Cobalt	(Co)	4.5	34 to 100	0.42	J
Copper	(Cu)	41.0	143 to 6000	0.42	J
Lead	(Pb)	1.5	121 to 300	0.17	J
Molybdenum	(Mo)	1.1	5 to 75	0.42	J
Mercury	(Hg)	**ND**	1 to 17	0.001	EPA 7471
Nickel	(Ni)	11.4	47 to 420	0.42	J
Selenium	(Se)	**ND**	2 to 200	0.83	J
Zinc	(Zn)	16.2	416 to 7400	0.83	J
Boron	(B)	36.9	Declaration	4.2	TMECC
Chlorine	(Cl)	1371	Declaration	20.0	TMECC
Sodium	(Na)	**ND**	Declaration	416	E
Iron	(Fe)	4488	Declaration	20.8	E
Manganese	(Mn)	4433	Declaration	0.42	J

Particle Size Distribution	Results	Units	Method
< 0.5mm	16.4	percent	F
0.5-1mm	18.9	percent	F
1-2mm	20.5	percent	F
2-4mm	22.9	percent	F
4-8mm	19.3	percent	F
8-16mm	2.1	percent	F
16-25mm	0.0	percent	F
25-50mm	0.0	percent	F
>50mm	0.0	percent	F

Basic Soil Enhancement Properties			
Total (K)	11248	mg/kg	E
Total (P)	2869	mg/kg	E
Ammonia (NH4-N)	5.5	mg/kg	A
Nitrate (NO3-N)	0.92	mg/kg	A
Organic (Org-N)	5817	mg/kg	Calc.
Volatile Matter	12.0	percent dw	D

* "ND" stands for "not detected" which means the result is below the reporting limit.

Method A Rayment & Higginson
D ASTM D1762-84
E EPA3050B/EPA 6010
F ASTM D 2862 Granular
G Butane Activity Surface Area Correlation Based on McLaughlin, Shields, Jagiello, & Thiele's 2012 paper: Analytical Options for Biochar Adsorption and Surface Area
J EPA3050B/EPA 6020

Analyst: Nik Zumberge