Biochar for Soil and Planet Health

ALEX GRAY

https://www.swiss-biochar.com/?lang=en

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THE NEXUS PROJECT

What is biochar?

Biochar starts with a feedstock, which can be virtually any dry biomass. It is heated to temperatures over 250 C (480 F) in a low or no oxygen environment. Much of the feedstock's mass is converted to a gas, which escapes. This leaves behind biochar!

Biochar is a highly porous, high carbon material with a negative surface charge. Much of its utility comes from these three characteristics. In soil, the porosity and negative charge help retain a good balance of air, moisture, and nutrients, which can help build healthy soil and meet the needs of healthy plants. Because biochar is mostly carbon, it is gaining attention as a carbon sequestration tactic, helping us store carbon in the soil and fight climate change.

Biochar made from *Miscanthus* grass

Biochar is generally characterized as a soil amendment, but has been used for hundreds of things, such as for water filtration, humidity regulation, or odor reduction. It is essentially the same as charcoal, although may be cleaner and have less residual oils than charcoal, which is used for heating rather than as a soil amendment.

To summarize, biochar provides a means of turning waste biomass into a useful medium for soil regeneration, agricultural yield increase, and carbon sequestration. When properly applied, biochar can help build healthy soil, which helps grow healthy plants. In some situations, yields can increase by four or five times due to the addition of biochar. Occasionally, plants that would not grow under certain soil, climate, and growing conditions will be able to thrive due to the addition of biochar. Not all biochar is the same, however, and its use is not a one-size-fits-all approach. This document is aimed at familiarizing gardeners, farmers, foresters, and planet healers with the process of making biochar, preparing it for soil application, and applying it to soil for the best results. Hopefully, it will help you feel confident in making and using biochar!

Why is biochar interesting? How do we know it works?

The Amazon rainforest is not known for high soil fertility. Warm temperatures cause quick decomposition and constant rain leads to heavy leaching, so soil is poor and contains little organic matter. However, isolated hotspots of dark, highly fertile topsoil – sometimes over three feet deep - have been found throughout the Amazon. These patches of high-carbon soil coincide with signs of human settlement, such as pieces of pottery. These *Terra Pretas*, or "dark earths" are the result of centuries of people producing biochar from fires and slash-and-burn (or slash-and-char) agriculture and incorporating it with food and crop wastes, human waste, ashes, and soil. While the Amazon is noted for historical uses of biochar, sites around the world – in Germany, Russia, China, Japan, Australia, and more – exhibit highly fertile soil with high amounts of man-made pyrogenic carbon.

https://www.allotment-garden.org/composts-fertilisers/biochar-terra-preta/

Terra Preta shows us two things. First, adding biochar to soil can be highly beneficial to the accumulation of organic matter, to nutrient availability and retention, and ultimately long-term fertility and topsoil growth. Second, many of these soils have not been treated with biochar for 500+ years, but the biochar still persists and the soil continues to exhibit high fertility. This demonstrates that biochar is extremely persistent in soil. It doesn't decompose quickly like other organic matter, such as wood or leaves. This makes biochar massively powerful as a means of transforming the health and fertility of soil for generations to come. What you can make for free in a few hours in your backyard has the power to persist, sequestering carbon and benefitting soil and ecosystem health on a geological time scale.

Sometimes when we find something new and powerful, we're quick to ascribe it with almost mystical powers. Used correctly, biochar can be immensely powerful in a wide variety of ways, but it is not a panacea. No one tactic alone will heal the Earth or our relationship with it. A vast array of practices, technologies, relationships, and cultural shifts will be necessary to solve the many challenges we face as a people and a planet. Biochar must be coupled with holistic soil management, proper nutrient cycling, and other organic agriculture practices. Biochar will, however, be instrumental in regenerating healthy soil, which is the foundation for healthy ecosystems and productive agriculture. It will also be a powerful tactic for sequestering carbon, which can help limit climate change.

Effects of biochar in soils

Effects of biochar on wheat

https://nwcasc.uw.edu/science/project/assessing-the-use-of-biochar-for-drought-resilience-and-crop-productivity/

Biochar has many effects on soil and is often misunderstood. This is partly because biochar can offer so many different benefits, but also because different types of biochar can vary significantly depending on feedstock, production process, and post-production preparation.

Biochar is not quite a fertilizer. While it can offer some nutrient value, it generally does not offer the nutrients that organic material like compost or organic fertilizers. Biochar consists mostly of carbon that is highly recalcitrant and can take centuries to break down. This means it isn't quite feeding the soil or feeding plants. Instead, it creates a foundation for the regeneration and growth of healthy soil.

Biochar is highly porous. This allows it to hold lots of water – easily up to 6 times its weight! This means it can keep soil from drying out, providing more water to plants with less need to water. Equally important, it provides a good balance between water and air. Biochar facilitates good drainage, which can be especially beneficial to soils with high clay contents. By opening up space in the soil, it allows water to infiltrate soil and move through the soil column.

Greater infiltration helps maximize the water retained from rain and watering while minimizing runoff and erosion. Healthy soil acts like a sponge, sucking up as much water as possible. Biochar allows this to happen while preventing nutrient and soil loss from erosion. It also facilitates better soil aeration, which is necessary for healthy soil microbial life. Additionally, biochar helps form stable soil aggregates, which further prevents erosion, intakes water, and creates healthy soil structure.

Soil is alive! The ***soil food web*** is the community of bacteria, mycelium, nematodes, earthworms, and others that fulfill the cycle of life. Without these tiny beings, soil would just be dirt – nothing would grow or decompose, and all terrestrial life would be in severe trouble. The soil food web breaks down dead organic matter, which provides plant-available nutrition and creates the potential for new life to sprout forth. The wide variety of pore sizes in biochar provides shelter and protection for many of these tiny creatures, simultaneously providing them with a balance of air, water, and nutrition. Treating soil with biochar can stimulate the soil food web, resulting in greater nutrient cycling, better accumulation of organic matter, greater plant-available nutrition, and ultimately the building up of healthy soil.

Cation exchange capacity reflects a soil's ability to hold cations. Cations are positively charged ions. Many important soil nutrients, such as potassium, calcium, ammonium, and magnesium, are cations. Soil particles, such as clay or organic material, are negatively charged and hold cations in the soil. A soil's cation exchange capacity defines how many parking spots it has for these important cations. Sandy soil, which has very little clay particles and low surface area, has a very low cation exchange capacity, meaning it can hold far less cations than soil with greater clay or organic matter content. Sandy soil would require more constant addition of compost to maintain fertility and sustained crop growth. When more cations are present than a soil can hold, they quickly leach away. Biochar has a high cation exchange capacity. When added to soil – especially sandy soil – it helps retain these important nutrients and prevent leaching, making any fertilizing or compost-adding you do go further. As biochar ages in soil, it oxidizes, further increasing its cation exchange capacity and ability to retain nutrients.

pH reflects how acidic or alkaline a soil is. Different plants thrive in different ranges of pH and different nutrients are most available to plants in a specific ranges of pH. Many farmers add lime to their soil each year to keep the pH up. Biochar can affect soil pH in two ways. First, biochar is generally alkaline. This means it can be used to change the pH of soil, helping shift it into the most productive range for the plants grown in it. It can offset the use of lime, which is often produced through extractive industry. Second, biochar helps buffer soil pH, which means it helps prevent the soil's pH from easily changing. This adds resilience to the soil and can lessen the future need for lime or other additives. When using biochar in soil that is already more alkaline than you want, it would be best to be sparing and also use acidic materials to offset the pH of the biochar. Soil tests are helpful at gauging soil pH and will recommend applications of lime and other pH-adjusting materials.

Biochar also generally has a high ***electrical conductivity***. When added to soil, it helps with ion transfer, which increases nutrient cycling between microbes, mycelium, and plant roots.

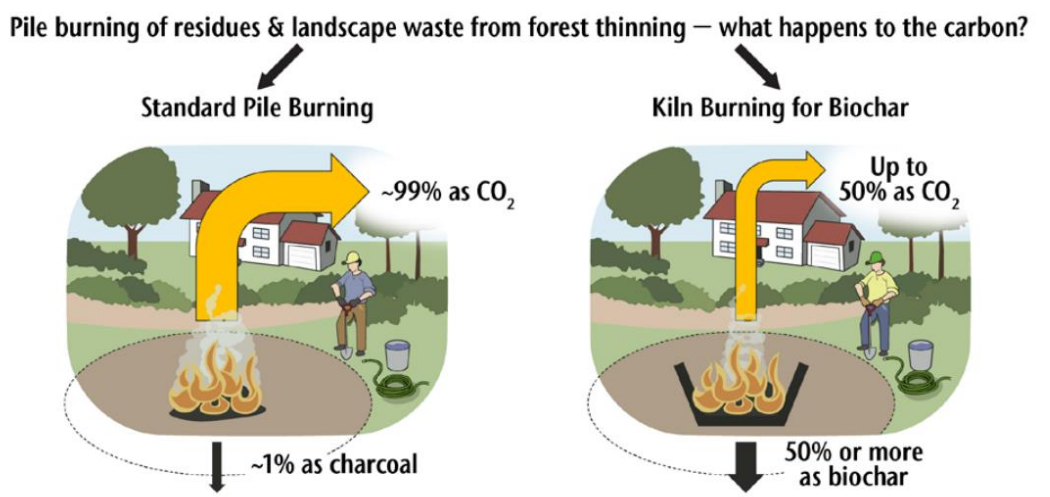
Biochar can occasionally also provide important ***nutrients***. Different feedstocks can offer a variety of nutrient levels, but biochar can offer N, P, K, Ca, Mg, and more. While these levels are generally not as high as compost or other organic forms of fertilizer, they can be an added benefit.

So what does this mean for ***crop yields***? In general, even a random application of biochar is likely to increase your yield. With proper biochar production and charging, you are likely guaranteed some increase in crop yield. Sometimes that's only 20-30% and sometimes it's greater than a 400% increase in yield! Your soil conditions are a major factor here – the more degraded your soil is, the greater the increase in yield could be. In some cases, biochar can help plants grow where they were unable to before. Even healthy, well managed soil can see greater crop yields due to biochar!

Making biochar

When considering making biochar, there are a few important considerations:

- *Soil needs:* What is your soil like? Soil testing is either cheap or free depending on the season. You can visit your local Cooperative Extension office to pick up boxes for soil samples. The extension agents can also help you decipher your soil tests. Soil testing will tell you about your soil pH, nutrient levels and deficiencies, cation exchange capacity, and more. This will help you define what deficiencies, if any, you want to address with biochar. Additionally, issues like leaching, poor drainage, and poor water infiltration can be addressed with biochar.
- *Quantity:* Are you planning to make a little biochar for use in your garden or a few tons for your farm?
- *Feedstock type and availability:* The type of feedstock you want to use can dictate the method of biochar production that fits you best. What feedstock will make the best biochar for your soil? What feedstock do you have the most access to? What sort of waste feedstocks could you remove from the waste stream?
- *Space, money, and time:* You will need open space to make biochar safely. Some methods would work fine in a small backyard, while others are better suited to a larger open area. Making biochar can be very inexpensive, but budget is an important consideration. Time is also important. Do you want to do a few large burns a year or a few small batches a month?



https://csanr.wsu.edu/bioass2biochar/

The graphic above gives a good comparison between a biochar burn and a campfire or a burning slash pile. With the slash pile on the left, most of the carbon initially present in the feedstock is burned and escapes, leaving very little biochar and lots of ash – and funneling harmful emissions into the atmosphere. Simply surrounding the burning feedstock and restricting airflow through the char, such as with the kiln in the image above on the right, restricts airflow. This creates the conditions necessary to produce biochar.

When a feedstock is heated, it first dries out completely. Second, *pyrolysis* occurs as organic molecules decompose into smaller gaseous molecules and escape, leaving solid char behind. Many of these gaseous molecules are flammable and can burn, helping create the heat to continue the process. If the process were allowed to continue without being quenched, the remaining char would burn, but it needs oxygen to do this. During the pyrolysis process, the char doesn't burn because the escaping gases are using most of the oxygen up as they combust. Towards the end of the process, as less and less gas escapes, the char can begin to burn. It is important to stop the process before this happens to maximize the biochar produced and minimize emissions. This is done by cutting off air. Water quenching is generally the easiest and best method of completing a biochar burn. It also washes away ash and opens up pores in the biochar. Smothering a burn with either soil or a sheet of metal with soil to fill any gaps also works when large amounts of water aren't available, but it can take up to a week for the fire to go out and the biochar to cool.

Safety first! When making biochar, it's important to have water close by. Temperatures can get extremely high and material can easily fall out of the reactor. It is a good idea to pour a little water around the reactor to prevent anything from catching fire. Never leave a reactor unattended, as fire can spread very quickly. Fire ecology is important, but making and dispersing biochar replicates much of that process, so you don't need to start any forest fires. It is also important to be careful of the flames produced during a burn. They can get quite tall and, when the wind blows, can shift. Be careful when within 10 feet of a burn and avoid getting within 2 or 3 feet if possible.

Let's look at a few simple, low-budget biochar reactors.

Open pit

The **open pit, kon-tiki kiln, flame-cap kiln, or Oregon kiln** is the simplest biochar reactor and arguably the best for most small-to medium-scale producers. It is basically a slightly tapered fire pit with a removable drain in the bottom. Feedstock is loaded and lit. As it burns down, it reduces in volume and more feedstock can be added. Because of its size, the open pit can get quite hot and quickly reduce a large brush pile into biochar.

The open pit can be started by lighting a small teepee or log cabin of kindling, much like a campfire. The goal is to quickly create coals and then begin adding larger amounts of feedstock. Once the burn is going, there are hot coals at the bottom of the kiln and flames at the top. Feedstock is repeatedly added and allowed to burn down. When flames die down and you begin to see ash forming on the surface of the feedstock, it is time to add more material. When nearing the end of a burn, it can help to add smaller pieces of wood or feedstock to ensure any larger pieces have the time and heat they need to fully char.

At the end of the process, the burn must be quenched. Generally, this is done with water. Buckets of water are more effective than a hose, but either can work. It's important to make sure a burn is completely quenched with no pockets of smoldering embers before leaving it. Mixing the biochar with a shovel can help ensure it's all completely quenched. Be careful of hot steam when quenching!

If water access is limited, a little can be poured on to reduce the heat before a metal sheet, such as corrugated metal roofing, is added to cover the top. Around the seams, soil can be packed to fully smother the burn. Alternatively, soil can be piled until the char is completely covered. Quenching with water can be done in a few minutes, but smothering the fire can take a day or more to put the fire out completely and cool down.

The open pit is a very simple design. The four walls and bottom of the kiln restrict oxygen from the bottom of the burn, where the coals are. This creates two zones – the lower zone in the kiln where oxygen is restricted and the upper zone where oxygen is plentiful. High heat causes decomposing gases to rise from the coals. When you see flames, you're seeing the escaping gases react with oxygen, burning to produce light and heat. The flames shield the char from oxygen, which keeps the char from burning and turning to ash. The majority of feedstock turns to char and not ash because it is kept in an environment with minimal oxygen. It's hot enough for it to pyrolize, but does not have the oxygen it needs to combust and turn to ash. Above the burn, emissions are kept to a minimum because escaping gases, some of which can be harmful, meet oxygen and high heat and fully combust, producing water and carbon dioxide.

There are many different adaptations of the open pit. The simplest is a hole dug in the ground, which is easily covered with dirt to quench. Pits such as those pictured above can be welded and will last many years. A drain plug in the bottom is very useful in draining water after quenching a burn.

The main advantage of the open pit is its simplicity. It is easy to operate and can take a wide variety of feedstocks. It can reduce large volumes of waste biomass relatively quickly, especially because it can be continuously loaded. It is not the most efficient method of biochar production and a conversion efficiency of around 5-15% should be expected (dry biochar/dry feedstock). However, it takes far less time and effort than other reactors and releases minimal emissions.

There are a few important considerations when building a fire on the ground. First, fire kills soil life, which will regenerate but is best to preserve if possible. Second, when the soil is dry, fire can travel underground through roots and surface other places. This necessitates care and attention to prevent unwanted fire and ensure water is handy, especially in arid regions or dry seasons.

TLUD

The **TLUD,** or top-lit updraft gasifier, is another relatively simple reactor. It consists of one and a half 55-gallon steel drums, angle iron, and HVAC ducting. The bottom of the bottom drum is covered in holes. These can be drilled or cut with a plasma cutter. Slits can alternatively be made with an angle grinder. The bottom drum is loaded with feedstock and lit on top. As it burns down, it pyrolyzes much of the feedstock like in the open pit.

The top, which fits into the bottom drum, consists of half of a steel drum with a chimney made of HVAC ducting. The chimney helps create a draft, pulling air through the holes in the bottom of the larger bottom drum. The purpose of the second half-drum is to reduce emissions. Within the reactor, there is not enough oxygen to fully combust all of the gases that are escaping the feedstock. Many of these gases – methane, carbon monoxide, etc. - are far more harmful to the climate than carbon dioxide. The holes in the half-drum allow air to come in and, when mixed with heat and these gases, allow a full combustion. When the TLUD gets going, you'll see thick smoke within the half-drum, but mostly clear smoke coming out of the chimney. These harmful gases are combusted, converting mainly to carbon dioxide and water.

The TLUD is an effective method for converting logs, brush, and wood chips to biochar. It is important that it is packed tightly, but if it is too tightly packed the airflow will be so limited that it cannot burn well. Sometimes mixing feedstock – wood chips and branches, for example – can help attain a good amount of airflow.

Depending on feedstock, the TLUD will run for 30 to 90 minutes. It should be sitting on bricks, allowing airflow into the bottom of the reactor. When you see that the feedstock in the bottom of the drum is glowing red, generally wait around 5 or 10 minutes and then remove the top drum and quench it. The TLUD can be quenched with about five 5-gallon buckets of water. Buckets of water work better than a hose at ensuring all pockets of fire are doused.

The TLUD increases efficiency to around 10-30%, which is an improvement over the open pit. It also releases minimal emissions. It is a little less versatile in feedstock. Grasses do not char well in the TLUD. It is also a batch system, so it isn't as quick to make large amounts of biochar or reduce large amounts of brush because, once started, additional feedstock cannot be added to the reactor.

Retorts

TLUD with top removed to show retort inside

Slits cut in the bottom of the retort allow gas to escape, preventing explosion

A slightly more complex biochar kiln involves the use of a **retort**. A retort is an enclosed chamber which holds the feedstock and is externally heated. Unlike in the TLUD or the open pit kiln, the feedstock is not burned. As it is heated, it undergoes pyrolysis, decomposing and releasing volatile compounds. These gases are vented, often directly into the source of heat where they burn and contribute to the heat needed for pyrolysis. Meanwhile, the remaining solids are converted into a more persistent form – biochar!

Retort-style biochar kilns can be simple or complex. You could fill a small metal container with your feedstock, provide a hole or another means of venting gases, and place it in a wood stove or campfire and make a small batch of biochar. This won't take away any heat from your fire – actually, the gases escaping from the feedstock will add fuel to the fire. Another example would be placing a retort into a TLUD. In this case, the retort is made from a smaller 35-gallon drum, which is closed but has holes drilled on the bottom for gas to escape. This retort fits into the TLUD and is surrounded by firewood. The firewood is lit and burns down, providing the heat to pyrolyze the feedstock within the retort. Gases leaving the feedstock escape the retort through the holes in the bottom and are fed into the flames, contributing heat to further drive pyrolysis.

The main advantage of the retort is that it has a much higher conversion efficiency – generally 30% or greater and often over 50% of the feedstock within the retort being converted to biochar. This would be a reasonable method for a higher value feedstock or one that doesn't burn well, such as wood chips or bone. It also doesn't require quenching, so if it's in a safe area, it can be lit and left. A retort can often be added to a heating source, especially a fire, without sacrificing any heat.

It is very important to ensure the retort has holes in the bottom for gas to escape. If the gas has nowhere to go, the retort could burst and create an explosion. The escaping gas is also fed into the fire, which adds to the heat.

Retorts are often not the best way to make biochar. Volatile gases can recondense on the biochar, clogging pores and adding potentially harmful chemicals. They also require firewood or other fuel to heat, which is somewhat wasteful compared to an open pit kiln or TLUD. They also produce a relatively low volume of biochar and are more complex to make and operate. However, when stacking functions such as making a batch of biochar in a retort while using a woodstove to heat your home, the retort method shines.

Feedstocks

Virtually any dry biomass can be converted into biochar. Feedstocks can include wood, grasses, agricultural wastes, manure, and bone. Different feedstocks result in different characteristics of biochar, so selection of feedstock is important. The effects of feedstock on biochar qualities are explored in greater detail later in the "designer biochar" section. Wood waste, the most common biochar feedstock, provides a good general purpose biochar.

A good moisture content is around 20% or less. You can estimate this with a wood moisture meter if it's a larger feedstock. If it isn't dry, it won't burn hot enough and might not burn at all.

Feedstocks can be dried in a solar dryer, which is essentially a mini greenhouse that traps heat and allows enough airflow for moisture to escape. Solar dryers can be made with mesh shelves and polycarbonate glazing or by using a caterpillar tunnel. In summer months, when greenhouses are in less intensive use, they can provide a good place for drying feedstock without worrying about rain.

Wood is the most common feedstock, especially in a heavily forested region, and is easy to make into biochar. Wood waste can often be sourced for free from landfills or from landscapers (Look up "chip drop" to find local sources of free wood waste). Wood chips, however, can be difficult to burn.

Tall grasses such as *Miscanthus* (silver grass), *Arundo donax* (giant reed), or bamboo can be easily charred as well. *Miscanthus* and *Arundo donax* are often grown as *energy crops* because they quickly produce lots of biomass. They dry quickly and light easily. A little bit of miscanthus is a great fire starter for other feedstocks in the TLUD or open pit.

Agricultural wastes are also a good source of feedstock. Burning them can reduce pest or disease risk while producing value in biochar. Corn stover, rice husks, nut shells, bagasse, and hemp stalks are commonly used for biochar.

Manure and ***bone*** can make more nutrient-dense chars and can often be sourced for low-cost or free.

Miscanthus, a common energy crop and biochar feedstock

When sourcing feedstocks, it is important to consider the source. Plants on the side of roads can accumulate heavy metals from car exhaust. These contaminants remain in the biochar and can pose a risk to your soil and your health, so it is best to avoid roadside trimmings. Treated woods, such as from some pallets or pressure treated lumber, should also be avoided when making biochar. Pallets marked with a stamp that includes "HT" are heat treated and are generally free from harmful chemicals. There is an abundance of potential feedstock, so when in doubt, avoid anything that could potentially carry anything harmful.

Crushing biochar

A handful of crushed pine biochar

It is important to crush biochar before applying it to soil. This increases the surface area, which helps it adsorb more water and nutrients, and allows for a better mixture of soil, organic matter, and biochar. In general, a texture that's coarser than sand but finer than pea gravel is desired. It can be surprisingly difficult to crush biochar in bulk.

Dry biochar crushes easiest, but this can cause it to make a lot of dust. Be careful of dust! Biochar doesn't decompose, so it'll stick around in your lungs like coal dust, which is less than desirable. Wear a respirator if you're exposed to biochar dust.

Here are some methods for crushing biochar:

- *Crush inside bag with stick, feet, car tires*
- *Roto-tiller:* with a roto-tiller, you can incorporate biochar into soil while crushing it
- *Garbage disposal:* a sink garbage disposal can be used for biochar crushing, but this is best done outdoors!
- *Hammer mill* – great for bulk crushing, requires char to be dry
- *Wood chipper* – basically the same as a hammer mill, requires char to be dry
- *Tumbler*: much like a rock tumbler, biochar can be loaded along with rocks and turned until it is crushed. This is best for smaller amounts.
- *Coffee grinder:* larger, industrial coffee grinders grind biochar to a nice consistency
- *Lawn roller*
- *Leaf vacuum*

Charging biochar

Biochar is like a battery that can hold extra nutrients in soil, but it doesn't come fully charged. When applied to soil in its raw form, biochar can adsorb nutrients and keep them from plants in the first season or two after application. While addition of uncharged biochar doesn't generally decrease plant growth, biochar is more immediately useful to soil and to plants when it is charged.

Charging biochar packs it with organic material and nutrition, maximizing its potential to benefit plants. To charge biochar, it is mixed with some form of organic material, often compost, manure, compost tea, urine, or anaerobic digester effluent. Residence times and ultimate nutritional value vary depending on which organic amendment is used to charge biochar.

Charging biochar is not necessarily the same as inoculating biochar. While charging biochar is done to pack it with organic material and nutrients, inoculating biochar adds microbial life – bacteria, mycelium, and more. These are often done simultaneously, such as when biochar is charged with compost, which contains nutrients and a wide variety of microbial life. Compost tea is a very dilute form of nutrition and is primarily used for inoculation. Anaerobic digester effluent is more of a charging method, containing little to no aerobic bacteria or mycelium.

Charging biochar with compost

Compost is one of the most common and most synergistic charging methods for biochar. Biochar can be mixed with mature compost anywhere between 20% and 50% by volume and allowed to sit for at least two weeks. (It is far more accurate to measure biochar by volume than mass because biochar mass can vary greatly depending on water content). Similar processes would be used for other solid amendments, such as manure. While biochar is high in carbon, it should not be counted as carbon in the compost pile because it is mostly recalcitrant carbon that will not break down.

Biochar and mature compost before mixing

For many of the same reasons biochar is so beneficial in soil, biochar can be greatly beneficial to the composting process. *Co-composting* involves mixing biochar with compost at the beginning of the composting process. This results in higher composting temperatures, which leads to faster composting. It also helps create higher quality compost. Biochar reduces the emissions of a compost pile by reducing anaerobic, methane-creating bacteria. While co-composting is not the quickest form of charging, it is certainly one of the most synergistic.

Biochar co-composted in windrows

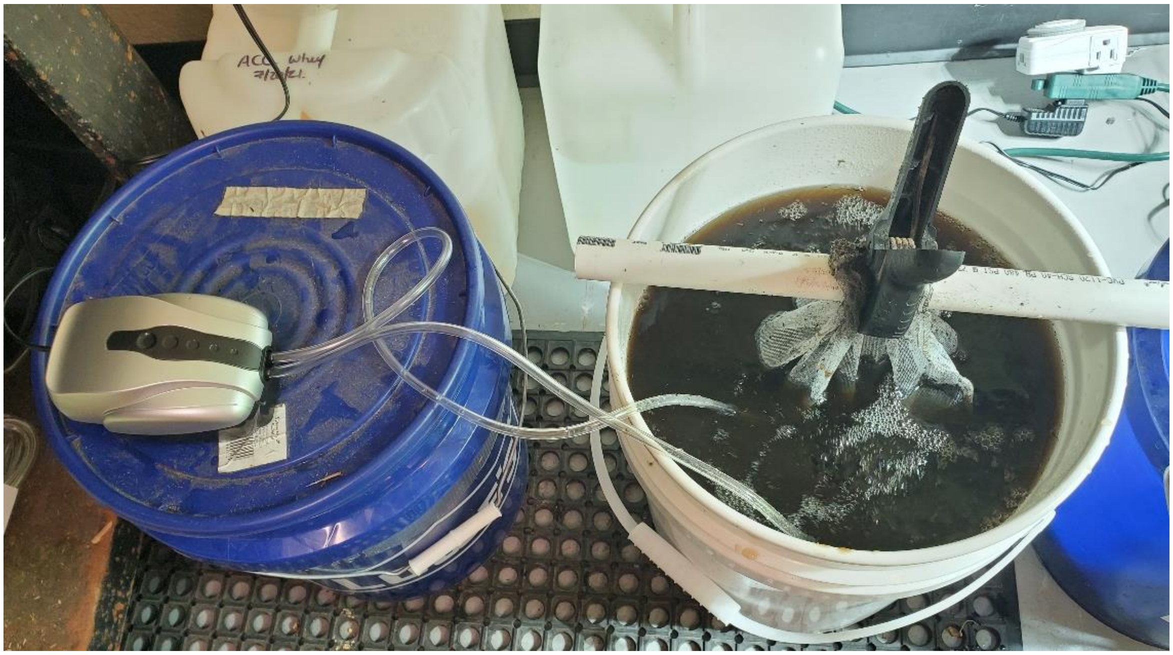
https://artemisthai.com/organic-farming-in-greenhouses/

Charging biochar with liquid amendments

While they generally don't offer the nutritional density of a solid amendment like compost, liquid amendments can greatly reduce the charging time for biochar. They also benefit greatly from biochar because, without solid matter to anchor them in the soil, they are highly prone to leaching. Let's look at *aerobic compost tea* and *anaerobic digester effluent*, two common liquid amendments that provide effective means of charging biochar. We'll also consider urine, which biochar can help in returning to the soil and closing the loop.

Aerobic compost tea is a powerful soil inoculant and a dilute fertilizer. It brings important microbial life and diversity to the soil, helping build a healthy soil food web. You can download Elaine Ingham's *Compost Tea Brewing Manual* for free here. Charging with biochar only adds a few extra steps to the process. Here's an example of a recipe for charging biochar with a bacterial compost tea:

- In a 5-gallon bucket, suspend a 1 gallon paint strainer bag full of healthy mature compost
- Fill the bucket with spring water or tap water that has stood for 48 hours or more to offgas any chlorine
- Add 3 tablespoons of black strap molasses and 1 ounce of soluble cold water kelp
- Aerate with an aquarium bubbler for 48-72 hours
- Remove the bag of compost and add biochar to the bucket and mix well with the compost tea
- Continue aerating the compost tea/biochar mixture for 2 hours, stirring occasionally, and then immediately add to soil. It is important the mixture is aerated and then quickly added to soil to avoid microbial die-off



Brewing aerobic compost tea: the aquarium pump on the left provides aeration while compost is suspended in a paint strainer bag in the solution

Anaerobic digester effluent provides another quick means of biochar charging. An anaerobic digester is essentially a big stomach. It is primed with manure and uses similar a similar bacterial community to the stomach of a cow to digest food waste. It produces methane, which can be used to cook, as well as effluent, which is like a liquid form of compost. It is more nutrient dense than compost tea and provides a reasonable alternative to a compost pile. Charging biochar with effluent is simple. The two are mixed and allowed to sit for about 72 hours, after which they can be applied to soil.

Biochar charging in anaerobic digester effluent

Urine is a very nutrient-dense substance. There is certainly uneasiness in many people about returning it to the garden, but it is an important consideration in closing the loop and attaining sustainable nutrient cycling. While it's not a balanced fertilizer, urine contains a significant amount of both nitrogen and phosphorus (N and P), which are two of the most important nutrients for plants. Rather than wasting these valuable nutrients, they can be reclaimed and pumped back into the soil. Charging biochar with urine can be as simple as peeing in a bucket of biochar and adding it to your soil. It is best to allow biochar to charge in urine for at least 72 hours to fully saturate. Alternatively, you could add it to your compost pile as a high nitrogen ingredient. Biochar will cut down significantly on odor, which also makes it an appealing addition to a composting toilet. It is best to dilute urine with water to avoid concentrations of nitrogen that could harm plants.

Other liquid amendments generally follow a similar procedure to anaerobic digester effluent or urine – allowing biochar to charge for at least 72 hours fully submerged, mixing occasionally, and then mixing both the biochar and remaining liquid into soil. Examples of other liquid amendments include, but are not limited to:

- Fish emulsion
- Liquid kelp
- Blood meal
- Fermented plant juice

A power harrow incorporates biochar into soil

Applying biochar to soil

Biochar application rates can vary significantly depending on availability, budget, and soil needs. Rates between 1/2 and 20+ cubic yards/acre are common. A general goal of 5-10 cubic yards/acre is a good goal, although this depends on soil needs and results and shouldn't necessarily be applied all at once. The table below shows common application rates.

It is best to start small and gauge effects. Test your soil and pay attention to cation exchange capacity, pH, and how nutrient levels are changing. Observe the way water flows and how it interacts with the soil. If you've had issues with leaching, erosion, lack of infiltration, or poor drainage, look at how these things change. While it is unlikely that a well-informed application of biochar will be detrimental to soil, subsequent applications could be adjusted to maximize effectiveness. We'll look at some of these tactics later in the "designer biochar" section. Biochar also oxidizes as it ages, increasing in its ability to retain nutrients. This means that, over time, its impact in soil grows.

When a forest fire occurs, biochar is created and falls only on the surface of soil. Over time, animal footsteps, worms, accumulating organic matter, and water flow help incorporate it into the soil column. To maximize immediate effectiveness, it's best to incorporate biochar in soil. This also prevents it from being carried away by the wind. First, biochar is broadcasted over the soil surface. No-till methods for incorporating biochar into soil include using a hoe, shovel, broadfork or power harrow. Biochar is generally mixed into the top 4-6" of soil.

Biochar can also be applied just around a plant's roots for more efficient use. When transplanting a start into soil, place charged biochar along with compost or soil around the roots of the plant.

If applying biochar that hasn't been charged, it is best to go with lighter applications applied over time. Ideally biochar would be added a few weeks before planting to allow it to charge and mix with soil.

Application rate	**Tons/acre**	**5 gallon buckets/ 100 sq. ft.**
Light	0.5 - 2.5	1/4 – 1 1/2
Average	4.5 - 10	2 - 6
Heavy	14 - 23	8 – 14

Designer biochar

Biochars produced with different feedstocks, pyrolysis techniques, and post-production preparation can be very different and can offer different benefits to soil. It is important to know about these differences in order to avoid unwanted soil changes and to maximize soil's potential. Designer biochar is biochar that is specifically tailored to a specific soil's needs and deficiencies. While much research on biochar has been performed, this is one of the frontiers and there is still a lot to learn about how different biochar affects different soil conditions. You can help the biochar community by learning about different biochar characteristics, amending soil with designer biochar, and recording data and observations.

We'll look at two main factors – feedstock and temperature – and how they affect biochar characteristics and quality.

Feedstock

Wood biochar is a good general purpose biochar, which is convenient because of how plentiful wood waste is. It generally has a fairly neutral pH of around 7.5-8, a high cation exchange capacity, high porosity, and high density. Hardwoods generally make denser and more structurally stable biochar that has a much higher electrical conductivity than softwood biochar. Softwood biochar offers a slightly higher surface area and cation exchange capacity.

Grass biochar is not a general purpose biochar. It is more alkaline than wood biochar with a pH generally around 8.5-9.5, making it a good choice for soil that needs liming due to low pH. It is not as porous as woody biochar, but does have a higher cation exchange capacity. It has a low density and a high electrical conductivity.

Bone biochar is a somewhat unique biochar that can help make minerals from bone more quickly available to plants, partially because it makes the bone much easier to grind into small pieces. It has a relatively mild pH of around 8 and a high porosity. It is exceptionally high in phosphorus, which makes up around 80% of its weight. It is often used for water filtration.

Manure biochar is also a more targeted biochar. With a pH in the range of 8.5-10, it can also be used to increase soil pH. It has high levels of N, P, K, S, and Ca, making it more valuable as a fertilizer than other biochars. It has a lower cation exchange capacity and lower porosity than other biochars, making it less useful for adsorbing and holding nutrients in the soil.

Temperature

High temperature biochar generally has a higher pH, higher electrical conductivity, higher porosity, and higher nutrient values. For soils that suffer from poor water retention, such as sandy soils, high temperature biochar can offer the greatest porosity and greatest water holding capacity.

Low temperature biochar generally has a higher cation exchange capacity and a lower pH, which can often even be acidic. At too low a temperature, especially without enough time, biochar will not be fully pyrolyzed. Some of the recondensed oils may be harmful in soil. A strong barbecue smoke smell indicates that biochar is not quite ready and that oils and wood vinegar have recondensed onto the char.

Other factors

There are many other tactics for tailoring biochar to soil needs. Quenching a burn late can result in high ash content, which can be useful in soil that needs liming (alternatively, a high pH biochar such as from grass or manure could be used). For soils that struggle with water infiltration and drainage, such as soils with high clay contents, biochar that is crushed more coarsely can help open up space for air and water in the soil, increasing infiltration and reducing heavy water flow and erosion. Very finely crushed biochar can actually do the opposite, filling up spaces between particles in soil and preventing water drainage, which could be of use in sandy soil where water drains too quickly.

Biochar is not stable in soil. While it is largely recalcitrant and does not decompose, it oxidizes and its properties change. Co-composting also helps quickly change biochar's properties, especially its cation exchange capacity. Biochar produced at higher temperatures, especially biochar produced in low-tech kilns such as a TLUD or open pit kiln, benefit greatly from co-composting because it helps increase the biochar's cation exchange capacity significantly, allowing it to hold more nutrients in soil.

Emissions

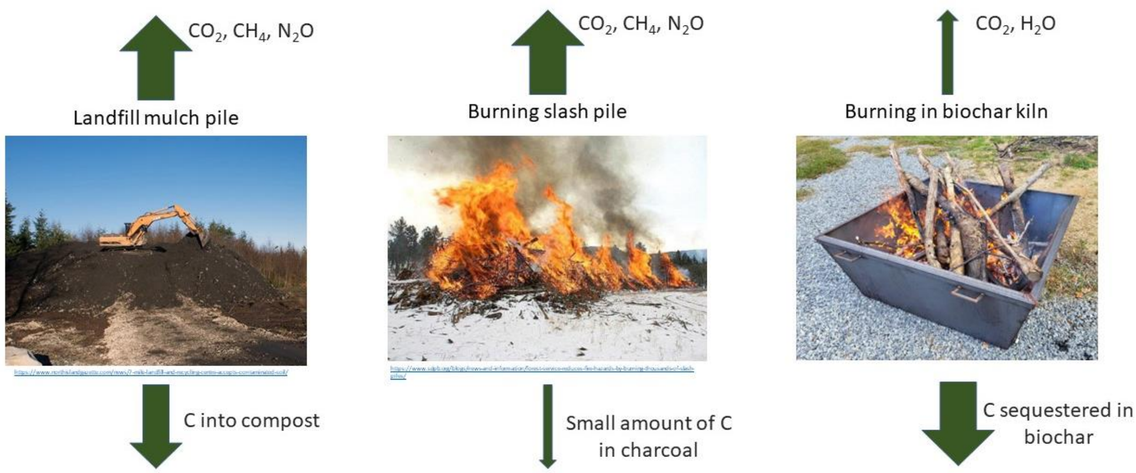
Emissions can vary greatly when producing biochar. The same feedstock can produce far more harmful emissions depending on the way the burn progresses. Full combustion produces mainly carbon dioxide and water. While this is not a positive addition to the atmosphere, it is far less harmful than the products of partial combustion, which produces larger hydrocarbons, such as methane, along with other harmful pollutants. Not only do these pollutants create a higher global warming risk, but they also are more harmful to human health.

To achieve full combustion, high heat and plenty oxygen is needed. Contrary to what you might think, a large fire burning dry feedstock produces limited emissions because the area above the kiln has a high amount of heat and plenty of oxygen for full combustion. In the TLUD, air is pulled into the top drum, mixing with high heat to fully burn any harmful gases.

Yellow smoke within the TLUD indicates methane and other harmful gases

When making biochar, a dry feedstock is crucial. Without sufficient dryness, the temperature of the burn won't get hot enough to fully combust many of these harmful gases and could also affect the quality of the char. A good fire on a dry feedstock creates a large flame, lots of heat, and mostly clear smoke. White smoke is an indicator of moisture in the feedstock. Blue smoke is an indicator of volatile gases, while yellow smoke indicates methane and other harmful gases. In the photo on the left, you can see yellow smoke within the top drum of the TLUD. These holes suck in air, fully burning these harmful gases and resulting in clear smoke coming from the chimney.

Apart from building high heat on a dry feedstock, quenching the biochar quickly when finished is important. A fire's greatest emissions are when it is building heat and going out, so it's important to build heat quickly and quickly quench it to limit this.



Where does the carbon go? Comparing three cases for the disposal of wood waste

Biochar production generally requires burning the biomass, so how does that help the climate? The graphic above compares biochar production to two alternative cases for the disposal of wood waste. The carbon cycle begins when trees grow, pulling carbon down from the atmosphere and sequestering it in organic compounds within wood. When the tree is trimmed or cut down, the wood waste is generally either composted in large piles at the landfill or burned in slash piles. In a large compost pile, which is generally quite anaerobic, large amounts of carbon dioxide, methane, and other harmful gases slowly escape as the wood breaks down. When a slash pile burns, most of the carbon initially present in the feedstock is immediately converted into carbon dioxide, carbon monoxide, methane, and other harmful gases. In the case of biochar production, roughly half of the carbon present in the feedstock is converted into carbon dioxide. While carbon dioxide is a harmful greenhouse gas, it is far less harmful than gases like methane, so while biochar production does release some carbon dioxide, it doesn't have nearly as high of a global warming potential as composting or burning wood waste. Half of the carbon is sequestered in the form of biochar, keeping it out of the atmosphere for millennia.

Other uses of biochar

Biochar has countless uses apart from soil amending. It would be impossible to list them all, so here are a few common uses that can increase its value and potentially be used prior to incorporation in soil.

- *Seed starting mix:* rather than using vermiculite, adding biochar to a seed start mix can help hold on to water and get seedlings off to a good start
- *Poultry bedding:* biochar can provide a great bedding for poultry, cutting down on odor and adsorbing nutrients from chicken manure for later application to soil. It can improve health conditions in a chicken coop for the chickens by reducing ammonia in the air as well.
- *Feed additive for cows and pigs:* Biochar can be added as a free choice additive to food for cows and pigs. It improves digestive functioning and charges while being digested.
- *Odor reduction:* Because of its high adsorptivity, biochar can be a great odor reducer. This could be useful for composting toilets, compost piles, or reducing animal odors. Oftentimes it can be charged while being used as an odor reducer.
- *Desiccant/humidity regulation:* Biochar can adsorb lots of moisture, making it a useful desiccant, and one that's more renewable than silica gel. In addition to adsorbing moisture, it can filter toxins from the air, resulting in higher air quality. Biochar has been mixed with earthen plasters to help regulate indoor humidity and offer dark pigmentation.

Biochar added to cattle feed

https://static.wixstatic.com/media/cc21d6_552e7217fac5401993f92b2a67a6e386~mv2_d_2238_1258_s_2.jpg/v1/fill/w_1000,h_562,al_c,q_90,usm_0.66_1.00_0.01/cc21d6_552e7217fac5401993f92b2a67a6e386~mv2_d_2238_1258_s_2.jpg

- *Water filtration:* Biochar can filter sediment and toxins such as heavy metals from water. Activated carbon, which is commonly used for water filtration, is essentially just highly oxidized biochar. You can learn about using biochar for water treatment here.
- *Bioremediation:* biochar can be instrumental in filtering toxins out of soil and water. It helps adsorb and immobilize them while allowing the microbial community to flourish, which helps further degrade or immobilize contaminants.
- *Energy production:* Biochar production creates heat, which can be used to heat a space, dry things, and even create power. There is a lot of investment in power plants creating clean energy from pyrolysis of wood waste

Biochar and planet healing

https://www.amazon.com/Biochar-Application-Essential-Microbial-Ecology/dp/0128034335

More than ever before, our generations are called to be planet healers. Rampant topsoil loss threatens agricultural production and the health and resilience of many terrestrial ecosystems. Forest, agricultural, and urban ecosystems are in peril, including the ecosystems within the soil. Climate change threatens every ecosystem and community on Earth. There is certainly hope, and ecosystem restoration, regenerative agriculture, and climate mitigation and major sources of hope for a brighter future. These are responsibilities for the current generations. We can rebuild a resilient and sustainable food system, provide for biodiversity to flourish, and redefine our connections with the Earth and with our own communities.

There are countless tactics to achieving success in these endeavors and no one thing will lead to success. Biochar does provide a powerful method of rebuilding healthy soil, which can prevent aridification and increase plant growth. Healthy soil is the foundation of a healthy ecosystem and a healthy farm. Biochar is also a great carbon sequestration tactic, storing carbon in the ground for millennia to come. Apart from the carbon sequestered within biochar, the addition of biochar to soil can help build more soil carbon in the form of the soil food web and, in turn, in the form of bigger and more healthy plants. And it all starts with redirecting waste material!

Questions?

If you have any questions about biochar or are interested in buying a biochar kiln or hosting a workshop, please contact me! I'd love to help you start making and using biochar.

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Resources

Biochar basics

Terra Preta

Composting with biochar

Living Web Farms blog

Ways of making terra preta

Making biochar in an open pit kiln

Choosing a biochar reactor

Properties of fresh and aged biochar

55 uses of biochar

Biochar and water treatment

The Biochar Solution by Albert Bates

International Biochar Initiative

US Biochar Initiative

AppState Nexus Project: Integrated Sustainable Energy for Enhancing Farm Productivity

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