Enhancing Soil Health and Crop Yields with Biochar: Techniques and Applications

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ABSTRACT

Charcoal known as "biochar" is added to soil to improve soil health and sequester carbon. Rich in carbon, biochar is a stable solid that may persist in soil for millennia. Similar to other forms of charcoal, biochar is a solid residue that is made by the controlled process of pyrolysis, which involves burning organic material from forestry and agricultural wastes (also known as biomass). By sequestering carbon, the use of biochar has the potential to reduce global warming while simultaneously improving soil quality via nutrient addition, greater water retention, and liming effects. The conditions and feedstocks employed during the process of pyrolysis might affect the physical and chemical characteristics of biochar. Because of its expansive surface area, charged surface, and functional groups, biochar presents a viable option for the adsorption and immobilisation of heavy metals and organic molecules from polluted soils. In general, adding biochar to soils reduces the bioavailability of organic molecules and heavy metals. The primary topic of this research is the pyrolysis and castor stock-based biochar manufacturing process.

Keywords: Heavy Metals, Biomass, Pyrolysis, Biochar, Soil, Castor Stock.

INTRODUCTION

The carbonaceous solid residue left behind after heating biomass in an oxygen-starved environment is called biochar. It is recognised as a nutrient recycler, soil conditioner, and agri-waste recycler with the ability to sequester carbon in a long-term, cost-effective, and healthful manner. Brewer (2012).It has been shown that biochar is useful for enhancing soil characteristics and raising crop biomass. Furthermore, there have been suggestions that it may even strengthen crops' resilience to disease. According to Jingchun Tang (2013), biochar has recently been used to treat soil containing both organic and heavy metal contaminants.

ORIGIN OF BIOCHAR AND ARCHAEOLOGY

The first focus of biochar study was to decipher the mysteries of terra pretta, or black, persistently productive soils found in the centre Amazon. Patches of pre-Columbian black earth-like anthropogenic soil, known as terra pretta, can span up to 350 hectares in central Amazon. They are distinguished by a persistently increased fertility brought about by high concentrations of SOM and nutrients like N, P, and Ca (Glaser, B., 2007). (Glaser, B. & Birk, J. J., 2011).

However, the enormous contribution of carbonated organic materials, or "biochar," which may include up to 35% SOM and 50 Mg/ha on average, is essential to the creation of terra pretta (Glaser, Haumaier, & Guggenberger, 2001).

Biochar functions as a stable C compound with a mean residence time that only slowly degrades over a millennial time period. Because of its large specific surface area (400–800 m2/g), biochar offers soil microorganisms a place to live that allows them to break down more labile SOMs. Higher microbial activity also accelerates soil stability.

Moreover, biochar itself and increased mineralization of labile SOM supplied vital nutrients for plant development (Daniel Fischer, Bruno Glaser, 2012).

IMPROVEMENT OF SOIL USING BIOCHAR

Due to its ability to increase soil quality, soil fertility, and carbon storage, biochar has garnered a lot of interest. Soil erosion and nutrient leaching are the primary causes of soil mineral depletion, which is a serious problem. Because biochar has been shown to enhance soil fertility, encourage plant development, raise agricultural output, and lessen contaminations, adding it is a solution.

By using pyrolysis, biochar made from a variety of organic resources may enhance agricultural yield and the physical fertility of the soil.Through raising the pH and water-holding capacity of the soil, biocharamendment enhances soil quality.

The addition of biochar increases the concentration of total nitrogen and phosphorus as well as the availability of basic cations. Biochar is a compost addition that has many advantages, such as boosting microbial activity, lowering greenhouse gas and NH4 emissions, increasing composting efficiency and humification, and immobilising organic contaminants and heavy metals. Biochar performs well as a soil enhancer, enhancing plant development and reducing the effects of salt and drought.

Enhancing Soil with Biochar Composting

Improved humification process; enhanced nitrogen retention; reduced greenhouse gas and NH4 emissions; inactivation of heavy metal and organic contaminants; increased water holding capacity; and enhanced nutrition retention

The pollutants become immobile. In order to find out whether applying biochar to agricultural soils may increase soil moisture content and fertility, a plot-scale study of this practice was carried out in Tamil Nadu, India's Tirunelveli.

Locally and sustainably obtained feedstock for biochar was used. As suggested soil additions, a number of locally accessible feedstocks, including sawdust, rice husk, cassia stems, and palm leaves, were examined to ensure that no one biomass source is exhausted in order to sustain the addition of biochar. The biochars derived from various biomass feedstocks had significant levels of macro- and micronutrients and included more than 20% carbon. The findings indicated that 6.6 metric tons/ha of cassia biochar application rate was sufficient to start C-accumulation, as shown by an increase in organic matter and a net decrease in soil bulk density. Mankasingh Utra (2011).

Figure 1.1 illustrates the function of biochar in the environment and in agriculture. Biochar has been progressively connected to the development of sustainable agriculture and soil management. It is a solid product made from biomass that has undergone a thermochemical reaction using pyrolysis to eliminate all environmental pollutants and lower greenhouse gas emissions.

Fig. 1.1 Framework of Biochar Applications (Wenfu Chen, 2018).

THE ROLE OF SOIL ORGANISMS

Carbon-dating charcoals discovered by the researchers in terra pretta soils date back hundreds to thousands of years, suggesting that carbon was taken out of plant biomass long ago as a stable solid. Leon, M.; Gaunt, J.; Lehmann, J. (2006).Ogawa (1994) states that since biochar has a porous structure that gives soil bacteria a suitable home, it typically has a proliferative impact on many symbiotic microorganisms (Steiner & Teixeira, 2004). Moreover, after the addition of biochar, a shift in the makeup of the soil microbial community and an increase in soil microbial biomass were noted (Birk, Steiner, Teixiera, & Zech, 2009).

Soil respiration rates were not greater in soils supplemented with Biochar, despite an increase in microbial reproduction rates after the addition of glucose (Steiner, C.; Teixeira, W. & Zech, W, 2011). The contrast between limited soil respiration and strong potential for microbial population expansion is one of Terra pretta's features. These findings demonstrate that the microbial population may expand in the presence of adequate soil nutrients and a low biodegradable soil organic matter (SOM).

Birk et al. (2009) state that these effects may be attributed to various habitat features in the porous structure of biochar. In decreasing order, the following reasons may account for the present evidence supporting them:

A high surface area and porous structure make Biochar a perfect home and refuge for a variety of microorganisms.

Enhanced capacity to retain water and nutrients, leading to the stimulation of microorganisms • Creation of "active" surfaces coated in a layer of water, dissolved nutrients, and other substances, offering the best possible habitat for microorganisms; these particular surfaces function as a matrix for the exchange and storage of water and substances between soil fauna, microorganisms, and root hairs.

weak alkalinity

Preserving qualities against deterioration may lead to the (partial) suppression of some "destructive" and pathogenic species while concurrently fostering helpful bacteria.

Based on these potential stimulating effects, biochar encourages the proliferation of beneficial microbes, such as free-living nitrogen fixing bacteria (Tryon, 1948; Ogawa, M., 1994; Rondon, Lehmann, & Ramirez, 2007).

The fundamental mechanism by which Biochar transforms into a safe haven for microorganisms and stores nutrients and moisture is shown in Fig. 1.2b. It also illustrates the symbiotic interaction between plants, fungi, and microorganisms as well as how plants provide carbohydrates to these microorganisms in exchange for moisture and nutrients.

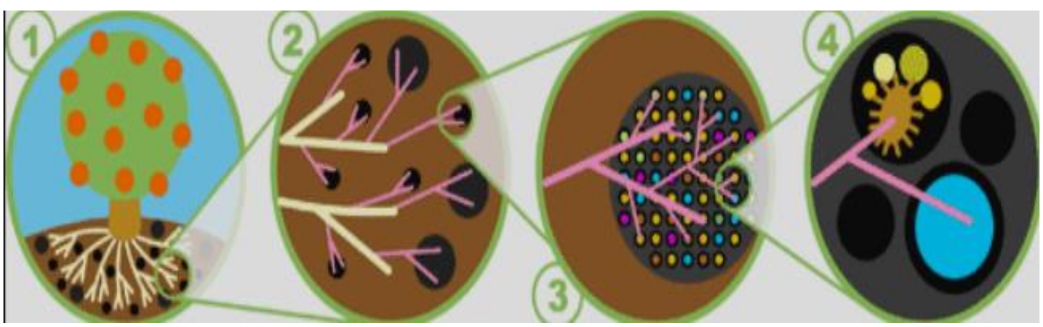


Fig. 1.2 Biochar as a habitat of a microorganism (The Biochar Factory, 2013)

Phases in the microorganism process for improving soil,

1. Applying biochar to a tree's drip line or root zone.
2. White plant roots interacting with a typical pink stringy soil fungus. In exchange for nutrients and moisture, the fungus receives the carbohydrates that the plant produces via photosynthetic processes.
3. A fungus that is rich in moisture, nutrients, and microorganisms fuses with biochar.
4. Fungi receives nutrients from microorganisms contained in the porous structure of Biochar in exchange for carbohydrates generated by plants.

COMPOSITION OF BIOCHAR

The components of biochar are both labile and stable, making up its very diverse makeup. Its principal components are generally understood to be carbon, moisture, reactive material, and mineral matter (ash). The overall chemical and physical behaviour and function of Biochar are determined by the relative percentage of its constituent parts, which also defines whether or not it is appropriate for a certain location. Moisture is another crucial component of biochar; with greater moisture contents, biochar production and transportation costs might vary. Biochar is a black substance with a huge surface area, high porosity, low weight, and tiny particle size. Carbon makes up around 70% of its makeup. The remaining proportion is made up of oxygen, hydrogen, and nitrogen among other components. The feedstock used for manufacturing and the heating techniques have an impact on the chemical composition. It is created during the thermal breakdown of biomass during pyrolysis in an oxygen-limited environment. According to Brewer (2012), Catherine Elizabeth, the thermochemical processes, typical reaction settings, particle residence durations, and principal products are all described in Table 1.1.

Sr. No	Thermochemical Process	Temperature Range (°C)	Heating Rate	Residence Pressure	Residence Time	Primary Product
1	Slow Pyrolysis	350-800	Slow (<10°C/min)	Atmospheric	Hours-Days	Char
2	Torrefaction	200-300	Slow (<10°C/min)	Atmospheric	Minutes-Hours	Stabilized, friable biomass
3	Fast Pyrolysis	400-600	Very Fast (~1000°C/sec)	Vacuum-Atmospheric	Seconds	Bio-oil
4	Flash Pyrolysis	300-800	Fast	Elevated	Minutes	Biocarbon/ Char
5	Gasification	700-1500	Moderate-very fast	Atmospheric-elevated	Seconds-Minutes	Syngas/Producer gas

Table.1.1 Thermochemical processes, their representative reaction conditions, particle residence times, and primary products (brewer, catherine Elizabeth, 2012).

THE PROPERTIES OF BIOCHAR

If char is thought of as having two fractions—the fraction of "carbon" and the proportion of inorganic ash—its attributes may be specified more readily. The percentage of "carbon" includes oxygen, hydrogen, and other elements bound to carbon, which is mostly affected by reaction circumstances. temperature, heating rate, reaction time, etc. Convert the mostly organic carbohydrate components, to some degree, into a Char characteristic of condensed aromatic compounds. The characteristics of the feedstock and the reaction's environment have the greatest impact on the quantity of inorganic ash. No matter what mineral components are in the biomass, they all get concentrated in the ash, with some impact on the char's ash characteristics and ash-to-carbon ratio (Brewer, 2012).

Techniques for Producing Biochar

The following stages outline the standard procedure for creating biochar:

1. Dried biomass
2. Biomass added to the kiln for pyrolysis
3. Biomass is heated in a pyrolysis kiln without oxygen.
4. It takes four to six hours for biomass to turn into biochar.
5. Biochar was taken out of the pyrolysis kiln.
6. Biochar kept in storage for use in soil.

The pyrolysis of organic feedstocks produces biochar.

The process of heating an organic substance without oxygen results in its chemical breakdown, known as pyrolysis. The name comes from the Greek words "pyro," which means fire, and "lysis," which means breakdown or disintegration.

The degree of oxidation of the organic matter is relatively high compared to combustion, where almost complete oxidation of organic matter occurs. As a result, a significantly greater portion of the carbon remains in the feedstock and is not released as carbon.

The process of pyrolysis transforms organic materials into three distinct elements, which can be gas, liquid, or solid in varying quantities based on the conditions used for the feedstock and pyrolysis. The charcoal that remains solid after pyrolysis is called biochar when it is produced with the intention of improving the soil.

PROCESS / METHODOLOGY

In a modified process, a pyrolysis kiln is used to produce char.

1. The arrangement

A 200 L capacity cylindrical metal drum that was unbroken on both sides was purchased from a nearby market and adapted for use as a charring kiln.

b. To load the fuel wood, a square-shaped hole measuring 10 cm by 10 cm was cut out of the bottom side of the drum.

b. To load crop waste and create the appropriate seal cover, a second small metal cylindrical drum with a capacity of thirty litres was used.

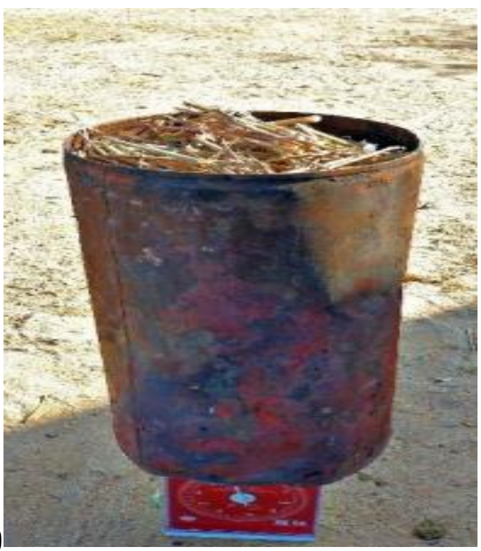
d. To promote even air circulation, a 10-by-10-cm square hole was drilled in the middle of the upper side of the drum.

Following the modifications, the inside of the charring kilns were measured, and an appropriate seal lock lid with an exhaust facility was made. The drum's top surface will aid in the even distribution of airflow. When the burning process came to a close, another 5 cm by 5 cm metal sheet was prepared to cover the top square hole and prevent air circulation. Enough clay dirt was gathered for the purpose of sealing. The study's specifics and measurement results are shown below.

2. Filling the kiln with char.

A platform balance was used to record the starting weight of the charring kiln prior to loading the modified kiln with the Castrol stalk (fig. A). A little kiln was filled with dried castor stalk. Castor stalks with a diameter of 3 to 5 cm were added, and the stalks were placed into the kiln in numbers of 3.300 kg. The weight of the filled kiln was measured using a platform balance, and the lid of this little drum was sealed with clay (fig. B).

A)



B)

Sealing and firing charring kiln

Prior to starting the burning process, fix the large drum, add the fuel wood using the first weigh, and arrange the wood in a straight layer. The loaded small drum was then positioned on three stones, each approximately 10 cm high, to allow air to pass through the openings on the bottom (fig. D). Following setup, fill the tiny drum completely with neem wood or any other heating wood using an initial weigh. Then, secure the large drum's lid and seal it with a metal lock ring (fig. C). The wood was lit via the bottom hole, and after the thickness of the smoke had decreased, a metal sheet was partly put over the top hole of the kiln to slow down the airflow into the drum. This decreased the oxygen flow, which was necessary for the stalks to burn effectively. The lid was opened to let in additional air whenever the smoke content rose. the metal sheet's edge that covers the top and bottom holes, as well as the drum's sealing (fig. E).



(c) (d) (e)

3. Biochar Output


(f) (g)

Four hours were spent charring in a regulated anaerobic environment. Following the burning process, the drum cools under enclosed circumstances. The seal clay is removed from the little drum and the kiln is allowed to cool overnight. After forming, the biochar is removed from the kiln and weighed (fig. F-G). It is kept in an airtight container so that farmers may apply it to their soil.

Conclusion

Applying biochar to agricultural soils may greatly enhance the soil's chemical, biological, and physical properties. The effects of biochar on the soil are long-term phenomena that increase the organic carbon, pH, nitrogen, potassium, and phosphorus in particular. It also helps the soil retain moisture for extended periods of time, even in hot and dry conditions and climates. The use of biochar has significantly improved tropical soils, which benefits soil fertility and disease resistance. Carbon-negative processes, such as the processing of biomass to create biofuels and biochar for soil carbon sequestration, remove more carbon dioxide from the atmosphere than they release, allowing for long-term storage. Agriculture wastes need longer composting durations and extra N fertilisation since they are not easily broken down. Consequently, agricultural waste is regularly dumped in landfills or burnt open on farms for no purpose other than to get rid of it. These biomass sources may be applied directly to soil or combined with compost to produce biochar, which is well suited for the creation of biochar.

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