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Application of Biochar as a Potential Substrate for Green Vegetation

A Sustainable Solution to Current Challenges of Soil Degradation, Nutrient Depletion and Global Climate Change

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Abstract

Biochar, a carbon-rich material produced through the pyrolysis of biomass, has gained attention in recent years due to its potential benefits for agriculture, environmental remediation, and renewable energy production. Biochar can improve soil health, sequester carbon, and reduce greenhouse gas emissions. It can also serve as a substrate for green infrastructure and vegetation. This paper provides an overview of the production techniques, sources, modification and activation, and environmental and agricultural applications of biochar. The performance of biochar as a substrate for green infrastructure and vegetation is also discussed.

Keywords: *Biochar; Pyrolysis; Greenhouse gas; Global Climate Change; Carbon sequester*

1. Introduction

Biochar is a carbon-rich material produced by heating organic material such as wood, crop residues, or animal waste in the absence of oxygen through a process called pyrolysis. The resulting material is stable and resistant to decomposition, making it a promising soil amendment for improving soil health and sequestering carbon in the soil (Lehmann *et al*., 2011). In addition to being high in carbon, biochar also includes tiny levels of calcium (0.1-8.5%), phosphorus (1-4.5%), potassium, and nitrogen (0.5-2%) as reported by Hue, (2020). (The potential of biochar to mitigate climate change and improve soil fertility has attracted significant research attention in recent years. The ash component of biochar contains elements such as S, P, K, Ca, Mg, Na, and Si, as well as a balanced combination of carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) (Chen *et al*., 2019). Biochar has been used as a soil amendment for thousands of years, particularly in the Amazon Basin where indigenous people created terra preta de índio, or "dark earth," by adding biochar to the soil (Glaser *et al*., 2002). However, the modern use of biochar as a soil amendment has gained attention in recent years as a potential tool for mitigating climate change. The production and application of biochar have been shown to have several potential benefits, including increasing soil fertility, improving water holding capacity, reducing greenhouse gas emissions, and carbon sequestration in soil for hundreds or even thousands of years (Lehmann *et al*., 2011).

The use of biochar as a soil amendment has been shown to improve soil fertility by providing a habitat for beneficial microorganisms, increasing nutrient retention, and improving water-holding capacity (Lehmann *et al*., 2011). However, there are also concerns about the potential environmental impacts of biochar production and use, such as the release of pollutants during production and the potential for biochar to alter soil pH and nutrient availability. It is therefore important to carefully evaluate the potential risks and benefits of biochar in specific contexts. Ongoing research is focused on understanding the potential of biochar to improve soil health and reduce greenhouse gas emissions, particularly in agricultural settings. Due to changes in the lignocellulosic content of the biomass and preparation processes, which eventually affect the properties of the biochar, each biochar behaves or responds differently towards the end application (Shakya *et al*., 2022). Research is also being conducted on the potential of biochar for other applications, such as water treatment and energy storage (Beesley *et al*., 2011). Overall, biochar has the potential to be a valuable tool for mitigating climate change and improving soil health. Ongoing research and careful evaluation of its potential risks and benefits will be critical to ensuring that biochar is used effectively and sustainably.

Figure 1: Biochar

2. Production Techniques of Biochar:

Biochar is produced through a process called pyrolysis, which involves heating organic materials such as wood, crop residues, or animal waste in the absence of oxygen. This process produces biochar, along with a mixture of gases and liquids, which can also be used for energy production (Mukherjee and Zimmerman, 2013). The kind of thermal treatment, processing circumstances (heating temperature, retention time, heating rate, pressure), and feedstock have a major impact on the physicochemical characteristics of the biochar that determine the application variety of the material (Enders *et al*., 2012). There are several techniques for producing biochar, including traditional methods such as pit burning, and more modern methods such as gasification, slow pyrolysis and fast pyrolysis.

2.1 Pit burning: Pit burning is a traditional method of producing biochar that involves burning organic materials in a pit, covered with soil or other insulating material to exclude oxygen. This method is still used in some parts of the world, particularly in developing countries, but has several limitations including low efficiency and air pollution

2.2 Gasification: Gasification is a modern method of producing biochar that involves heating organic materials in the presence of a gasifying agent such as air or steam, producing a gas mixture that can be used for energy production. The biochar produced in this process has high purity and uniformity, but the process requires high temperatures and may be energy-intensive (Mukherjee and Zimmerman, 2013).

2.3 Slow pyrolysis: Slow pyrolysis is another modern method of producing biochar that involves heating organic materials at a relatively low temperature (between 350 and 700°C) in the absence of oxygen. This method produces high-quality biochar with a high surface area and porous structure, making it ideal for use as a soil amendment (Lehmann *et al*., 2011). The process is also energy-efficient and can produce bio-oil and gases as byproducts that can be used for energy production.

2.4 Fast pyrolysis: Fast pyrolysis involves heating biomass to temperatures between

400°C and 600°C for a few seconds to minutes in the absence of oxygen. This technique produces biochar, bio-oil, and syngas. The biochar produced by fast pyrolysis has a lower carbon content and higher ash content compared to slow pyrolysis, but it can still be used for agricultural applications.

2.5 Hydrothermal carbonization (HTC): HTC is a process that involves heating organic materials in the presence of water under high pressure and temperature. The process produces a solid carbon-rich material known as hydrochar, along with a liquid byproduct that can be used as a biofuel or fertilizer. HTC has several advantages over other biochar production methods, including a shorter processing time and the ability to process a wide range of feedstocks, including wet materials. However, the process is energy-intensive and may require additional drying steps before use (Bridgwater *et al.*, 1999).

2.6 Microwave pyrolysis: Microwave pyrolysis is a process that involves heating organic materials in a microwave oven in the presence of a catalyst, producing biochar with high surface area and porosity. The process is relatively fast and energy-efficient and can produce biochar with high yields and uniform properties. However, the process may require additional processing steps to remove ash and impurities from the final product.

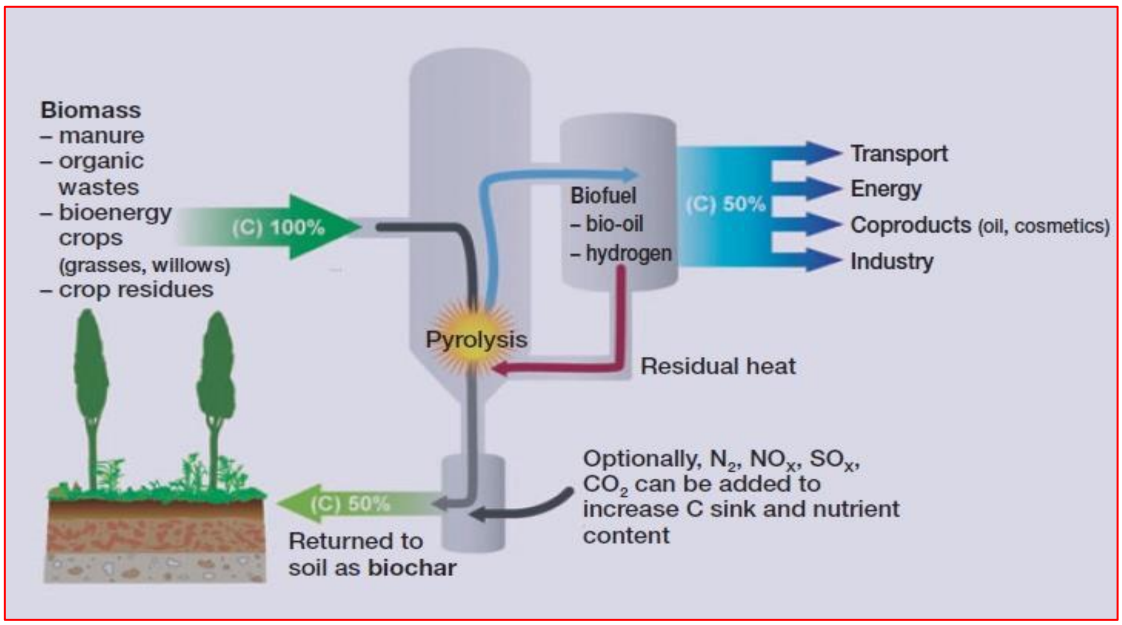

Figure 2: Concept of pyrolysis process with biochar sequestration. Normally, biochar is created from approximately half of the pyrolyzed biomass and may be added back to the soil. (Lehmann, 2007).

3. Biomass and its Sources of Biochar Production

Biomass is a renewable organic material that can be converted into biochar through various production methods. Biochar can be made from a wide range of biomass feedstocks, including agricultural residues, forestry waste, energy crops, and municipal solid waste (MSW). The choice of feedstock can impact the properties and potential applications of the resulting biochar.

3.1 Agricultural residues: Agricultural residues are commonly used feedstock for biochar production. These residues include crop residues (e.g. corn stover, rice straw), animal manure, and food processing waste (e.g. grape pomace, olive cake). These materials are typically abundant and readily available, making them an attractive feedstock option for biochar production.

3.2 Forestry waste: Forestry waste, such as sawdust, bark, and wood chips, can also be used as feedstock for biochar production. This type of feedstock is often readily available near timber processing facilities and can be produced in large quantities.

3.4 Energy crops: Energy crops, such as switchgrass and miscanthus, are another potential feedstock for biochar production. These crops are grown specifically for energy production and have the potential to provide both biochar and bioenergy.

3.5 Municipal solid waste (MSW): MSW is another potential feedstock for biochar production. MSW includes a variety of organic materials, such as food waste, yard waste, and paper products, which can be converted into biochar through pyrolysis or gasification (Bridgwater *et al*., 1999).

The choice of feedstock can impact the properties and potential applications of the resulting biochar. For example, biochar produced from agricultural residues tends to have higher levels of nutrients and a lower pH compared to biochar produced from forestry waste.

4. Modification and Activation of biochar

Biochar can be modified and activated to enhance its properties and improve its potential applications. Modification refers to the physical or chemical alteration of biochar, while activation refers to the process of enhancing its porosity and surface area. These processes can improve the adsorption capacity of biochar for pollutants and nutrients, as well as its ability to support microbial activity.

There are several methods for modifying and activating biochar, including physical, chemical, and biological approaches. Physical methods include grinding, milling, and sieving, which can reduce the particle size and increase the surface area of biochar. Chemical methods involve treating biochar with acids, bases, or oxidizing agents, which can introduce functional groups and enhance its reactivity. Biological methods involve inoculating biochar with microorganisms, such as bacteria or fungi, which can promote the formation of microbial communities and enhance its nutrient-cycling potential. Activation of biochar can be achieved through physical or chemical means. Physical activation involves heating biochar to high temperatures in the presence of inert gas, such as nitrogen or carbon dioxide, to create a highly porous material. Chemical activation involves treating biochar with an activating agent, such as potassium hydroxide or phosphoric acid, which can create additional micropores and increase its surface area. The choice of modification and activation method depends on the intended use of the biochar. For example, chemical modification may be preferred for enhancing the adsorption capacity of biochar for specific pollutants, while physical activation may be preferred for improving its water-holding capacity and nutrient retention properties.

5. Properties of Biochar:

1	Carbon content	Ranges from 50-95% of its total weight depending on the feedstock used and production method
2	Ash content	Less than 1% to over 50% depending on the feedstock used and production method
3	pH	7-10
4	Surface Area	High (due to its porous nature); ranges from 100-1500 m^2g^{-1}
5	Stability	Carbon in a stable state that can last in soil for hundreds to thousands of years.
6	Functional groups	Carboxylic acids, phenols and quinones
7	Hydrophobicity	Can be hydrophobic due to presence of aromatic compounds
8	Nutrient retention	High cation exchange capacity
9	Water retention	High
10	Microbial habitat	Provides a habitat for beneficial microbes thus reducing disease incidence
11	pH buffering	Buffer soil pH by neutralizing both acidic and alkaline soils
12	Heavy metal immobilization	Immobilize heavy metals thus reducing their toxicity

6. Application of Biochar in the Environment

Biochar has been found to have numerous environmental applications due to its unique properties, such as high porosity, large surface area, and high adsorption capacity. The use of biochar can help address issues such as soil degradation, water pollution, and greenhouse gas emissions. One of the most common environmental applications of biochar is in soil remediation. Biochar has been shown to improve soil fertility and productivity by increasing water retention, nutrient retention, and soil microbial activity (Laird *et al*., 2010). It can also help to reduce soil erosion and the leaching of nutrients and pollutants by increasing soil aggregation and stability. Biochar has also been used in the treatment of wastewater and contaminated water. Due to its high adsorption capacity, biochar can effectively remove pollutants such as heavy metals, pesticides, and pharmaceuticals from water. Biochar can also be used to treat acid mine drainage and other contaminated waters by adsorbing and immobilizing toxic metals. In addition to its use in soil remediation and water treatment, biochar can also be used to mitigate greenhouse gas emissions. Biochar production can be combined with biomass energy production to create a closed-loop carbon cycle, where the carbon dioxide released during biomass energy production is captured and stored in biochar. The resulting biochar can then be used as a soil amendment to sequester carbon and reduce atmospheric carbon dioxide levels.

7. Application of Biochar in Agriculture

Biochar has been found to have numerous applications in agriculture due to its ability to improve soil health and crop productivity. The use of biochar in agriculture can help to address issues such as soil degradation, nutrient depletion, and climate change. One of the primary agricultural applications of biochar is as a soil amendment. Biochar can improve soil fertility by increasing water retention, nutrient availability, and soil microbial activity. It can also improve soil structure by increasing soil aggregation and reducing erosion. Furthermore, biochar can help to reduce greenhouse gas emissions from agriculture by sequestering carbon in the soil. Biochar can also be used as a livestock feed supplement. Studies have shown that adding biochar to livestock feed can improve digestion and nutrient absorption, leading to increased growth rates and feed conversion. Additionally, the use of biochar in livestock feed can help to reduce greenhouse gas emissions from livestock by reducing methane emissions from enteric fermentation. Another agricultural application of biochar is in the production of bio-based fertilizers. Biochar can be combined with organic wastes, such as animal manure or food waste, to create a nutrient-rich fertilizer that can improve soil fertility and reduce waste. The resulting bio-based fertilizers can also help to reduce greenhouse gas emissions by diverting organic waste from landfills. Overall, the agricultural applications of biochar are numerous and promising. Further research is needed to explore the full potential of biochar in improving soil health and crop productivity.

8. Performance of biochar as a substrate of green vegetation

Biochar has shown promise as a substrate for green infrastructure systems, such as green roofs and bioswales. As a substrate for green vegetation, biochar has been shown to improve plant growth, nutrient availability, and soil health. Several studies have demonstrated the potential of biochar as a substrate for the green vegetation. In one study, tomato plants grown in a biochar-based substrate showed significantly higher yields and better nutrient uptake compared to plants grown in a traditional substrate (Gaskin *et al*., 2010). Another study found that biochar can increase soil microbial activity and promote the growth of beneficial microorganisms, which can enhance plant growth (Lehmann *et al*., 2011). Biochar can also improve soil water retention, which is particularly important in arid regions where water resources are limited. In a study conducted in a semi-arid region of China, a biochar-based substrate was found to improve soil water retention and plant growth compared to a traditional substrate. Furthermore, the use of biochar as a substrate can help to reduce the environmental impact of agriculture by reducing the need for synthetic fertilizers and pesticides. Overall, the use of biochar as a substrate for green vegetation shows promise for improving plant growth and soil health while also promoting sustainability in agriculture.

9. Cost of Biochar

Production of biochar is currently not thought to be affordable or commercially viable (Hašková, 2017). It has other advantages beyond soil remediation, such as carbon sequestration and nutrient retention, and might become more inexpensive when the technology behind its production grows less expensive or is supported by governments (Maroušek *et al*., 2015). The ultimate objective of biochar production is to create a cycle that uses agricultural or waste facility waste to produce additional biochar, as has happened in European nations (Carus and Dammer, 2018). An orchard system's waste and a portable pyrolysis unit were used to conduct a cost-benefit analysis, which revealed that the cost of producing one tonne of biochar ranged from 450 to 1850 $ (Nematian *et al.,* 2021). Over time, this might alter as carbon credits offset these expenses to the tune of 193-234 $ per tonne. Farmers would benefit greatly from this price reduction because the typical cost per tonne in the US is between 600 and 1300 $, which is too expensive for the majority of farmers to use (Thengane *et al*., 2021). The price might quickly rise above the point at which farmers would think about utilizing this as a product because these prices do not take into consideration alteration or microbial inoculation. Fortunately, certain improvements, such as alkaline washes and industrial-grade acid, may be made for less money, but the costs of other alterations are less obvious (Huang *et al*., 2021). By putting money into the necessary technology, it should be a top priority to lower the price of producing biochar. More study should be done on microbial species that are naturally occurring or have been genetically altered for particular purposes.

10. Future Prospects

Further research is needed to fully understand the potential of biochar and to optimize its production and application. This includes investigating the optimal conditions for producing biochar, exploring the use of new biomass sources, and examining the effectiveness of different modification and activation techniques. In addition, more studies are needed to evaluate the long-term performance of biochar in various applications and to assess the potential risks associated with its use. With continued research and development, biochar has the potential to become a widely used and versatile tool for addressing a range of environmental challenges.

11. Conclusion

Biochar has shown great potential as a sustainable solution for a variety of applications, including agriculture, environmental remediation, and renewable energy production. Its ability to improve soil health, sequester carbon, and reduce greenhouse gas emissions makes it an attractive option for mitigating climate change. The use of biochar as a substrate for green infrastructure and vegetation also offers promise for improving plant growth and promoting sustainability in urban environments.

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