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Review of Potential Biochar Utilization on Soil Quality in Agricultural Environments

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Abstract: Land and environmental sustainability are two interconnected factors of long-term development. Former sand mining area that has been neglected and disused for many years can have a significant impact on environmental degradation. Sand mining activities previously conducted on this site employing trucks hauling mining goods may have had an impact on soil erosion and topsoil removal. The use of biochar is one promising invention in agriculture and land restoration. The purpose of this article is to investigate the usage of biochar as a substance for enhancing soil quality. Biochar is a carbon product derived from the pyrolysis (low or no oxygen heating) of organic biomass such as wood, straw, or other plant leftovers. Because of its numerous benefits in enhancing soil quality and promoting sustainable agriculture, the use of biochar in agriculture and land restoration has attracted extensive attention. Aside from that, biochar is thought to be more efficient than other techniques of enhancing soil quality due to its low cost.

Keywords: Biochar; Degradation; Environment; Sand Mining; Soil Quality

Introduction

In recent times, the mining industry has emerged as a significant cornerstone of many nations' economies. Generally, the mining sector holds substantial potential (Amelia et al., 2023). Mining operations yield favorable effects on societal and economic aspects. A range of mining methods is employed, such as subterranean extraction (Ansyar & Herdiana, 2023). However, sand mining can give rise to severe repercussions on the environment and local communities. The process of sand mining frequently leads to destructive erosion, resulting in the depletion of sand that functions as a natural "barrier" against ocean waves. These consequences may lead to coastal harm, encompassing alterations to shorelines and the endangerment of coastal infrastructure. Furthermore, sand mining has the potential to disrupt the ecosystem in rivers, lakes, and coastal regions by diminishing the native habitat for various species of fauna and flora. Additionally, this activity can contaminate groundwater and surface water with hazardous chemicals originating from the mining soil. In addition, sand mining can damage the landscape by forming deep holes, which can become dangerous areas and change the appearance of the environment. Social impacts include disruption to local communities, reduced access to natural resources, and changes in local people's lifestyles. To overcome the negative impacts of sand mining, sustainable mining practices, strict regulations and ongoing environmental protection efforts are needed (Nasution & Fitria, 2023).

Indonesia is known as a country rich in natural resources, including mineral wealth. One of the natural mineral resources is sand, which is used in the construction industry. The demand for sand increases along with the growth of infrastructure and development (Semwal et al., 2021). Although most people are aware of the importance of sand in the construction sector, they may lack understanding of the negative impacts of excessive sand mining on the environment (Aitken & Clarkson, 1987; Fernández-Morante et al., 2023; Silva et al., 2016), soil quality, and food security (Farahani & Rahimi, 2011).

Soil is a complex environment containing many interrelated elements, making it difficult to assess how

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any one factor affects the ecosystem as a whole. The impact of land degradation caused by mining activities is a serious problem that often occurs when minerals or minerals are exploited. Mining activities can have a variety of negative impacts on soil quality and the surrounding environment, including loss of vegetation, soil erosion, changes in soil structure, and heavy metal contamination. High concentrations of heavy metals can also affect soil microecology by reducing soil nutrient content and productivity, thus indirectly affecting plant growth (Min et al., 2019). The toxic impact of these heavy metals can also inhibit the activity of plant metabolic enzymes by disrupting soil microbes (Rizwan et al., 2016). Heavy metals cannot be decomposed naturally and are toxic; they can seep through plant roots, and can even damage plants and have a negative impact on human health (B. S. Chen et al., 2018). Therefore, there is an urgent need to develop approaches that can reduce high concentrations of heavy metals in plants and increase plant productivity (Gall et al., 2015). One promising approach is to overcome this problem by using additives such as biological materials, trace elements, adsorbents, carbon-based materials, and metal-based materials in anaerobic reactors to improve the operational stability of AD systems (Hawari et al., 2021; Liu et al., 2021).

Biochar, an additive that is currently being researched, is a stable substance, has a small particle size, and contains high levels of carbon. Biochar is made from various types of biomass through various processes such as pyrolysis, gasification, hydrothermal carbonization, and other thermochemical processes in conditions without oxygen or lacking oxygen. Biochar attracts special attention due to its simple manufacturing method, diverse raw material sources, multifunctionality, and positive impact on the environment (Beyene & Ambaye, 2019). Additionally, studies have shown that biochar contributes to increasing efficiency in organic matter processing and methane production in anaerobic systems (Semwal et al., 2021). The role of biochar in anaerobic systems can be categorized as follows: 1) providing a microenvironment for microbes, 2) reducing toxicity levels by absorbing inhibitory substances, 3) increasing the buffering capacity of anaerobic systems, and 4) supporting direct interspecies electron transfer (DIET) (Apliza et al., 2020).

Biochar, which is a carbon-rich material derived from lignocellulosic biomass, is emerging as a new solution to face various practical problems, such as environmental pollution and global climate change. This material has potential applications in various fields, including energy storage, adsorption, catalysis, gas storage, separation, and so on Borgohain et al. (2020). Biochar is a carbon-based material that has pores and is made through the thermal decomposition of organic materials in conditions without or partially without oxygen at moderate temperatures (350–700 ◦C) and atmospheric pressure (Bertschy et al., 2013) (. The popularity of biochar has increased in recent years due to its physicochemical characteristics, including high porosity and surface area. Biochar and activated carbon have high porosity and amorphous carbon, although they have different structures. Biochar also has a variety of surface functional groups (such as C–O, C–O, COOH, and -OH), which can be utilized in various carbon-based resource applications. Efforts to overcome soil problems involve a series of steps and strategies aimed at protecting, restoring and maintaining soil quality. This includes wise management, careful environmental monitoring and preventive measures to address problems that can affect soil, such as erosion, degradation, pollution and loss of soil fertility. The use of sustainable agricultural practices, efficient water management, soil conservation practices, and the use of environmentally friendly technology are examples of efforts to prevent and restore soil problems. Additionally, monitoring and scientific research also help in understanding and solving problems related to soil. Collaboration between governments, farmers, scientists and communities is key to carrying out these efforts, and the goal is to ensure that soil remains healthy and functions well to support human life and ecosystems around the world. The biochar composite demonstrates effective performance in capturing chlortetracycline from water solutions, attributed to the presence of zeolite, silica, and nano-zerovalent iron. This technology holds the potential for application in wastewater management and water quality improvement by reducing the concentration of environmentally detrimental chlortetracycline.

Research on biochar is important because biochar has great potential to be used in various fields, bioremediation, agriculture, energy and climate change mitigation. Bioremediation is the process of using living organisms to clean or restore a polluted environment. Biochar is a material made from biomass that is heated without oxygen. Biochar has several properties that make it important for bioremediation, namely the ability to absorb pollutants, the ability to bind microorganisms, the ability to increase soil fertility.

Method

This research was conducted with a descriptive analysis method referring to previous research to find out a general description of a phenomenon or event. This method is done by collecting data, then analyzing and describing the data systematically and objectively. The article review research flow begins with the first step of clearly defining the topic and objectives, focusing on a specific research area. The purpose of this article review is to provide a summary of the research. After that, the second step involves searching and selecting relevant articles from various sources such as academic databases, scholarly journals, and online sources. It is important to select quality articles that match the research topic. The third step involves reading and critically analyzing the articles, focusing on the validity of the methodology, research findings, conclusions, and limitations of the study. Finally, the fourth step involves synthesizing the findings and writing a review article that includes an introduction, literature review, review methodology, review results, discussion, and conclusion.

Result and Discussion

Quality of ex-sand mining soil

Soil quality in former sand mines often experiences a significant decline due to mining activities. The sand mining process often involves the removal of fertile soil layers, resulting in the exposition of subgrade soil or rock that has properties that are less supportive of plant growth. Soil drainage can be poor, and drought conditions and stagnant water often occur on hard soil surfaces. In addition, soil pH can become unstable and unsuitable for plant growth. Soil contamination with harmful pollutants, such as heavy metals or toxic chemical compounds, can also damage the quality of the soil and make it unfit for agriculture or ecosystem purposes. As a result, sand mined land often requires serious rehabilitation and remediation efforts to restore its quality to support plant growth and healthy ecosystem function.

Good quality soil is soil that has characteristics that support the growth of healthy and diverse plants, as well as maintaining environmental sustainability. Good soil has a good structure with sufficient aggregates and pores, allowing smooth movement of water, air and plant roots. Sufficient organic matter content increases the soil's ability to store water, increases fertility, and supports the life of soil microorganisms. The availability of essential nutrients such as nitrogen, phosphorus, and potassium ensure plants have the resources necessary for optimal growth. Proper pH balance in the soil is key to good nutrient availability. Good drainage and low levels of soil compaction protect the soil from waterlogging problems which can damage plant growth. Good soil also has biological diversity that reflects the life of microorganisms and soil fauna that support nutrient cycles. Lastly, good soil is free from harmful pollutants, and has high productivity, providing good agricultural and environmentally sustainable results. By protecting and maintaining good soil quality, we can create a strong foundation for sustainable agriculture and environmental sustainability.

Good soil quality for agriculture is soil that has characteristics that support healthy and productive plant growth. The soil has a good structure with aggregates that allow plant roots to penetrate the soil easily, and facilitate the movement of water and air in the soil. Sufficient organic matter content in the soil provides nutritional resources for plants, increases water retention, and increases soil fertility. A proper pH balance in the soil ensures optimal nutrient availability for plants. The ability of soil to store water and release it evenly maintains appropriate humidity for plants. Good drainage is key to preventing waterlogging which can damage plant roots. In addition, the soil must be free from harmful pollutants that can damage plants and agricultural products. The presence of biological diversity in soil indicates a healthy ecosystem and supports vital nutrient cycles. Good agricultural land also has the ability to produce high agricultural yields, thus supporting productive and sustainable agriculture. By maintaining and improving soil quality, farmers can ensure successful and sustainable farming.

Soil remediation

Soil remediation is the process of restoring or improving the quality of soil that is polluted or contaminated by dangerous substances or pollutants. Soil contamination can occur due to chemical spills, industrial waste, livestock waste, excessive use of pesticides, and various other human activities. The remediation process aims to reduce, eliminate, or isolate pollutants from the soil, so that the land can be safely reused for agriculture, plantations, development, or other purposes.

Some commonly used methods and strategies in soil remediation include, the quest for cleaner lands has brought forth a suite of techniques to combat soil contamination. Among these, bioremediation leverages the power of microscopic allies - bacteria, fungi, and algae - to decompose or transform harmful pollutants into less potent forms. Imagine these tiny organisms diligently munching on oil, pesticides, and hydrocarbons, leaving behind a safer soil profile. Next up is phytoremediation, where nature's dedicated chemists - plants specially chosen for their pollutant-handling abilities - step into the spotlight. These marvels of botany absorb, accumulate, or even metabolize heavy metals and specific organic compounds within their tissues. It's like they're miniature factories dedicated to cleaning up the soil from the inside out. For situations with high levels of contamination, physical removal takes center stage. Picture this: contaminated soil is scooped out, transported elsewhere, and either treated or safely disposed of. It's a straightforward approach, best suited for heavily polluted areas. In some cases, a chemical approach, chemical oxidation, comes into play. Here, specific chemicals are introduced to oxidize, or essentially change the chemical composition of contaminants, reducing their harmful effects. Think of it as giving the pollutants a molecular makeover to render them less toxic. For situations where complete removal or transformation isn't feasible, stabilization and solidification offer an alternative. By adding specific chemicals to the soil, pollutants are either bound or encased, preventing them from spreading and minimizing the risk of exposure. It's like building a tiny cage for the harmful molecules, keeping them from causing further trouble. Sometimes, the best solution is to simply close off the contaminated zone or physically separate it from the clean area. This effectively creates a barrier, preventing the pollutants from mingling with the surrounding environment. Think of it as drawing a line in the sand and ensuring the clean soil stays that way. Finally, no soil remediation effort is complete without thorough monitoring. After the chosen technique is implemented, regular checks are essential to ensure the effectiveness of the treatment and confirm that pollutant levels have been reduced to acceptable levels. Think of it as keeping a watchful eye on the progress, making sure the soil is healing and, on its way, back to health. These diverse techniques, from the microscopic work of bioremediation to the physical separation of closure, offer a powerful arsenal in the fight for cleaner soil. Choosing the right approach depends on the specific contaminants, the level of pollution, and the desired outcome. With careful planning and diligent execution, we can ensure that contaminated lands regain their vitality and contribute once again to a healthy and flourishing environment.

The remediation method selected will depend on the type and extent of contamination, the type of pollutant involved, and local soil and environmental conditions. The soil remediation process is often complex and requires careful assessment, careful planning, and close monitoring. The aim is to restore soil quality and maintain environmental health and prevent negative impacts on humans and animals.

Research related to the removal of tetracyclines and sulfonamides using biochar already exists, but information regarding the adsorption mechanism is still limited (Peiris et al., 2017). The adsorption process is very important to understand the behavior of antibiotic compounds in terrestrial and aquatic environments (Qin et al., 2019). Biochar has been shown to be effective in absorbing various organic contaminants, including drugs and antibiotics, which tend to bind to soil (Jung et al., 2015). The presence of functional groups on the surface of biochar, dominant negative charge, varied surface structure, large surface area, and micro porosity make biochar a strong adsorption agent for various types of antibiotic contaminants (Ahmad et al., 2019).

Research has shown that biochar produced via pyrolysis at temperatures higher than 500 °C is able to absorb antibiotics such as ceftiofur and florfenicol more efficiently compared to biochar pyrolyzed at low temperatures (Mitchell et al., 2009; Spender et al., 2019). Likewise, other studies noted that activated carbon biochar has efficient adsorption capabilities against compounds such as diclofenac, sulfamethoxazole, and carbamazepine under limited conditions (Wu et al., 2020). Factors such as the ionic strength of the solution and pH can influence the capacity of biochar to adsorb tetracycline (Hu et al., 2013).

Another study involved the use of a two-stage adsorption system involving the use of magnetic chicken bone biochar to remove tetracycline. The results of this study indicate that 75% tetracycline remediation in a one-stage system requires 63.0 g of magnetic chicken bone biochar within 12 hours. However, in a two-stage adsorption system, 33.2 g and 22.2 g of magnetic chicken bone biochar were able to remove 96% of tetracycline from waste solution with a concentration of 100 mg L^{-1} within 180 minutes (Xu et al., 2012). Magnetically derived biochar has been used effectively to extract various antibiotics such as tetracycline, sulfamethoxazole, and other hormones, with adsorption capacities varying between (3.46–169.70 mg g^{-1}), (5.19–212.80 mg g^{-1}), and (33.10–297.61 mg g^{-1}), respectively (Qin et al., 2019; Yi et al., 2019). However, most biochar production techniques tend to be complex and expensive, and approaches that consider only one or two antibiotics are not always adequate (Y. Chen et al., 2019; Yu et al., 2016). Therefore, it is necessary to develop an economical and simple technique to modify biochar so that it has a higher adsorption capacity and is able to induce hydrophobic interactions. In addition, a deeper understanding of the movement of antibiotics in the environment will provide important insights into the persistence and potential mobility of these compounds in soil and irrigation water. This will be an important basis for the development of effective modified biochar to reduce antibiotic pollutants, especially in the context of sustainable agriculture.

Bioremediation

Bioremediation is an important method of environmental management that involves the use of living organisms, such as microorganisms and plants, to clean or reduce pollutants in soil, water, or air. A biological process called "bioremediation" is mediated by microbes or other organisms. It is a sustainable method for environmental pollutant degradation and detoxification (Sarkar et al., 2019). The goal is to reduce or eliminate harmful pollutants from the environment naturally through biological processes. In the context of polluted soil remediation, microorganisms can decompose or convert pollutants into safer or less dangerous forms. Bioremediation is often considered a more environmentally friendly and sustainable approach than physical or chemical methods for cleaning up contaminated environments. It has been used in the remediation of a variety of contaminants, including petroleum, heavy metals, organic compounds, and many other pollutants. In research and practice, bioremediation continues to be a growing area for maintaining environmental quality and supporting sustainability.

Biochar applications can include bioremediation in some contexts. However, it should be understood that biochar is generally used as a soil amendment to increase soil fertility, water retention and nutrient availability for plants. Although biochar has the ability to bind some pollutants and reduce the risk of contamination, the primary use of biochar is not always directly related to traditional bioremediation efforts. The use of biochar in environmental remediation is more often related to the remediation of polluted soil or soil contamination with dangerous chemicals. In this case, biochar can be used to bind and reduce the mobility of certain pollutants in the soil, thereby helping to clean polluted soil.

It is important to understand that the use of biochar in bioremediation is not the primary method and is often used in conjunction with other methods such as microbial bioremediation or plant phytoremediation. So, while biochar can be used in a bioremediation context, that is not the most common primary use associated with biochar. The choice of remediation method will depend on the type of pollutant, soil conditions, and the goals to be achieved in cleaning the polluted environment. The indiscriminate use of pesticides can lead to serious issues related to food safety and toxicity, posing a threat to the environment and biodiversity. Pseudomonas nitroreducens AR-3, isolated from pesticide-contaminated agricultural soil, can remove 97% of chlorpyrifos (CP) in just 8 hours. This occurs in a mineral salt medium (MSM) containing glucose (1.0 g/L) and yeast extract (0.5 g/L) at a temperature of 30°C with a 2% (v/v) inoculum when challenged with 100 mg/L CP. The degradation product of CP, 3,5,6-trichloro 2-pyridinol (TCP), was detected only in low levels, indicating further degradation.

Mechanisms of remediation

A remediation mechanism is a series of processes or steps used to reduce, remove, or isolate pollutants from contaminated soil, water, or air. The main goal of the remediation mechanism is to return environmental quality to a better and safer condition for humans, animals and ecosystems. Selection of the most appropriate remediation mechanism will depend on the type and extent of contamination, the type of pollutant involved, and the condition of the contaminated soil, water, or air. The remediation process is often complex and requires careful assessment, careful planning, and close monitoring to achieve the desired results.

Degradation is the process of breaking down organic contaminants into chemical compounds that are harmless and stable in the environment (Aswathi et al., 2019). Organic contaminants can undergo degradation in soil or wastewater through various mechanisms, including biodegradation, photolysis, hydrolysis and oxidation, both through biotic and abiotic processes (Varjani et al., 2019). The physicochemical properties of biochar play an important role in its ability to adsorb or release organic contaminants, including chemical structure and composition, porosity, surface area, pH, elemental ratios, and surface functional groups (Khalid et al., 2020). All these physicochemical properties may vary depending on the type of raw materials used and the production conditions. Adsorption of organic contaminants by biochar is influenced by a number of mechanisms, including partitioning, electrostatic interactions, interactions between electron acceptors and donors, pore filling, and hydrophobic interactions (Madadi & Bester, 2021).

Biochar's potential as a material for improving soil quality

Biochar is a carbon material produced from the pyrolysis process (thermal decomposition) of biomass such as wood, straw, sawdust, or other organic materials in conditions without oxygen. Biochar has shown significant potential to improve soil quality through various mechanisms, such as increased water retention, increased soil fertility, and reduced greenhouse gas emissions. Here are some of the benefits of biochar in improving soil quality. Biochar, a charcoal-like substance created from burning organic matter, acts as a potent soil superhero, wielding a multitude of powers to enhance the land's health and productivity. Its spongy structure boosts water retention, a shield against drought and a life-giving spring for thirsty plants. Packed with nutrients and beneficial microbes, it fuels soil fertility, reducing the need for chemical fertilizers and keeping harmful toxins locked away. Biochar sculpts the soil itself, forming sturdy aggregates that airate the earth and let roots explore freely. But its environmental superpowers extend far beyond the ground. By trapping carbon within its depths, biochar becomes a champion against climate change, holding fast to greenhouse gases that would otherwise escape into the atmosphere. Not only does it curb carbon dioxide, but also tames methane and nitric oxide, potent greenhouse gasses emitted from the soil. And to top it all off, biochar strengthens the land's armor against erosion, standing firm against wind and water that would steal away precious topsoil. The result? Plants thrive in this revitalized environment, bursting with productivity and yielding bountiful harvests. Biochar, a simple product with extraordinary powers, holds the key to unlocking a future of healthy soils, abundant crops, and a thriving planet.

It is important to remember that the effects of biochar on soil quality can vary depending on the type of biochar used, biomass source, and existing soil conditions. Therefore, it is important to assess soil characteristics and consider recommendations appropriate to local situations before applying biochar in agricultural or plantation practices.

The use of biochar in soil has beneficial long-term effects in various aspects of agriculture and the environment. Over a long period of time, biochar can increase soil fertility by increasing the availability of nutrients to plants. This contributes to increased agricultural productivity and reduced dependence on chemical fertilizers. Additionally, biochar helps soil to retain water better, reduces soil erosion, and improves soil structure. A significant long-term effect is biochar's ability to store carbon in the soil, reduce greenhouse gas emissions, and contribute to climate change mitigation. Improved soil quality can also support stronger plant growth and drought tolerance. Overall, the use of biochar has the potential to restore, improve and maintain soil quality and have a positive impact on sustainable agriculture and environmental protection in the long term.

Biochar is carbon produced from the pyrolysis of organic materials, such as plant residues, and can be used as an additive in brick production or as a soil amendment. Biochar can help reduce CO_2 emissions by locking organic carbon in the soil for a longer period, contributing to addressing the issue of global warming. In the context of brick production, adding biochar to the brick formula can be a strategy to mitigate environmental impact. Biochar can enhance the physical and chemical properties of bricks, such as compressive strength, and reduce the need for fuel in the brick firing process, thereby lowering CO_2 emissions. Additionally, the use of biochar in brick manufacturing can contribute to organic waste management, reduce reliance on conventional raw materials, and create more environmentally friendly products. Therefore, biochar can be integrated into building material innovations to achieve sustainable development goals and minimize negative environmental impacts.

Nutrients in biochar

Biochar contains a number of nutrients that can be beneficial for soil and plants. Some of the nutrients generally contained in biochar and their benefits are as follows biochar, the earthy magician, wields not only magical structures but also a potent potion brimming with essential nutrients. Carbon, its primary ingredient, forms the sturdy foundation, enriching the soil and enhancing its water-holding capacity. Nitrogen, though subtle in its presence, acts as a loyal retainer, safeguarding the precious resource and preventing its escape. Phosphorus, sometimes organic, sometimes inorganic, dances a delicate balance, unlocking its benefits for thirsty plants while keeping them snugly bound within the soil. Potassium, a regal visitor in some biochars, adds a flourish of vitality, while calcium and magnesium, the sturdy companions, lend their strength to improve soil structure. Finally, a sprinkle of trace elements, like iron, copper, and zinc, provides the finishing touch, ensuring no plant suffers from micronutrient woes. With every element playing its part, biochar's alchemy creates a thriving soil kingdom, ready to nourish and sustain bountiful life.

The benefits of the nutrients contained in biochar are increasing soil fertility, availability of nutrients for plants, increasing water retention and soil drainage, and reducing soil erosion. Using biochar in soil can help optimize plant growth and reduce the need for chemical fertilizers, which can reduce environmental impacts and agricultural production costs. It is important to remember that the chemical composition of biochar can vary depending on the raw material and production method. Therefore, it is important to assess the composition of the biochar to be used and consider plant needs and soil conditions before applying biochar in agricultural or plantation practices.

Nutrients are chemical elements that are very important for plant growth and health. Soil rich in nutrients is needed because these nutrients act as a source of essential nutrients for plants. The main nutrients include nitrogen (N), phosphorus (P), and potassium (K), but also include secondary and micro nutrients such as calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), and boron (B).

Nitrogen is needed for the growth of plant leaves and stems, phosphorus supports the formation of strong roots and plays a role in flowering and fruiting, while potassium influences the overall growth process and increases plant tolerance to disease and environmental stress. Secondary nutrients such as calcium and magnesium are important for the formation of cell walls and plant structure, while microelements such as iron, copper and boron are required in small amounts, but are essential for various biochemical reactions in plants.

Soil rich in nutrients supports plants in achieving maximum growth, increases crop yields, and improves plant quality. Without sufficient nutrients, plants can experience delayed growth, pale leaf color, and reduced productivity. Therefore, fertilization and wise soil management are very important to ensure the availability of sufficient nutrients for plants, as well as to support productive and sustainable agriculture. Soil amendments and NPK fertilizer doses individually affect the growth, including the height and leaf number, of shallot plants. The best treatment for bulb yield was obtained with the combination of applying 20 tons/ha of manure and 450 kg/ha of NPK fertilizer.

Biochar production technology from biomass waste

The main reserves of biochar come from biomass pyrolysis. Before mass production, the pyrolysis mechanism, structure, and compositional characterization of biochar must be determined. The pyrolysis process depends on the operating parameters specified below. In general, pyrolysis is defined as "the burning or decomposition of biomass in an oxygen-free environment at moderate temperatures (400–700 ◦C)" (Mishra and Mohanty, 2018b). Pyrolysis is a thermal chemical process that involves the breakdown of organic materials under high temperatures, in the absence of oxygen or with very limited amounts of oxygen. This process can be used to convert biomass, such as wood, straw, rice husks, or other organic materials, into valuable products such as biochar.

The following are the general steps in the pyrolysis process to produce biochar, biochar's journey from humble biomass to potent soil superhero begins with a grind, crushing raw materials like wood chips into bite-sized pieces for smooth pyrolysis. Next, a careful dehydration dance ensues, coaxing out excess moisture from thirsty materials through sun-kissed drying or a hot air dryer's gentle breeze. Then comes the fiery heart of the process - pyrolysis. In reactors heated above 300°C, organic magic unfolds, transforming the materials into biochar, gas whispers like methane and hydrogen, and liquid whispers like bio-oil. A swift cool-down bath, a gentle filtering waltz, and voilà - biochar stands ready, a porous haven for nutrients and water. For an extra dose of power, an activation ritual with steam or gasses can be performed, enhancing its ability to bind pollutants and organic treasures. Finally, this versatile earth hero goes forth, nourishing fields as a soil amendment, taming waste in management systems, or even powering flames as an alternative fuel. From raw beginnings to a multitude of noble uses, biochar's journey exemplifies the potential hidden within nature's humble offerings.

Biochar is a pyrolysis product consisting of stabilized carbon that has unique properties that can help improve soil quality and store carbon in the soil, thereby reducing carbon dioxide emissions into the atmosphere.

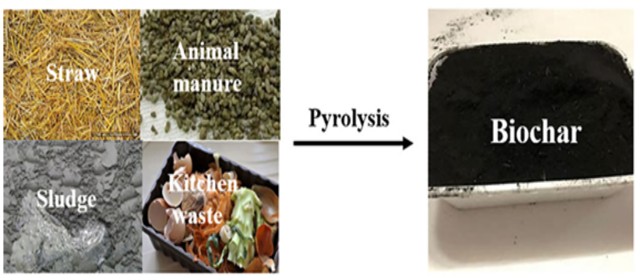

Figure 1. Biochar Production

Biochar is a product produced through the pyrolysis process of organic materials. Various types of organic materials can be used as raw materials in biochar production. This includes sawdust, plant residues such as leaves, twigs, and straw, agricultural waste such as rice husks and corn cobs, agricultural and forestry industry residues such as empty palm oil bunches or sawdust, as well as recycled organic materials such as coffee husks. Even organic materials that are usually thrown away, such as wood litter from the lumber industry, can be converted into biochar. Choosing the right raw material is important because it will affect the properties and quality of the biochar produced. Using organic materials that are produced sustainably and are waste or production residue also supports a more environmentally friendly approach to biochar production.

The materials used for biochar production have a number of advantages that make them very valuable in a variety of applications. First, the raw materials used for biochar are often waste or production residue from various sectors, such as agriculture, forestry and the wood industry. By converting this waste into biochar, we can reduce the amount of waste thrown into the environment and at the same time produce value-added products. Another advantage is that biochar can improve soil structure, increase water retention, and provide a habitat for soil microorganisms, all of which support better soil health and plant growth. In addition, biochar has the ability to reduce greenhouse gas emissions and store carbon in the soil in the long term, thereby contributing to climate change mitigation. By using sustainable and potentially organic materials as a resource without disturbing limited natural resources, biochar production can be a sustainable and environmentally friendly approach to managing resources and improving soil quality.

Application dosage of functional biochar

Methane production and reactor efficiency do not always increase with increasing biochar dosage. For example, in research conducted by Li et al. (2019a), it was found that methane production increased significantly by 71.1–122.0% when biochar (MBC) doses were used in the range of 0.75–4.0 g. However, methane production decreased by 30.7% in the reactor with 5.0 g MBC. A similar thing happened in the research of (Zhang et al., 2021), where the dosage of $MnFe_2O_4$ modified biochar influenced cumulative methane production. Increasing the dosage of biochar from $MnFe_2O_4$ modified corn straw from 1.5 g to 5 g caused a decrease in methane production and methane production rate by 52.4% and 70.8% respectively. The use of high doses of biochar from $MnFe_2O_4$ modified corn straw resulted in reduced methanogenic activity and VFA accumulation. The addition of excessive amounts of metal-modified biochar can poison anaerobic microorganisms and cause low methane production. Likewise, the addition of high doses of HNO3-modified biochar can lower the pH in the anaerobic digestive system, which significantly inhibits the activity of methanogenic archaea (Liang et al., 2021; Mulyati et al., 2022).

Biochar application doses vary depending on several factors, including soil type, plant type, intended use, source of biomass used to make biochar, and characteristics of the biochar itself. Some general guidelines that can help determine the application dose of biochar are as follows Biochar, the soil's potent alchemist, thrives on a delicate balance. The ideal dose of its magic brew hinges on several whispers: the whispered texture and structure of the soil, the murmured needs of the plants yearning for life, the hushed purpose of the application, whether fertility shall bloom, emissions wane, or contamination yield. Even the biochar itself whispers - its surface area, nutrients, and pH, all influencing the potion's strength. To find the perfect harmony, listen to the land's language: conduct tests, seek local wisdom, and observe the plant's dance with the soil. Only then can biochar's transformative power truly resonate, whispering a symphony of health and abundance.

In most cases, the application dose of biochar ranges from 1 to 10 percent by weight of biochar to soil weight. However, exact dosages may vary, and more research is being done to understand the effects of biochar dosage on various soil and plant conditions. A recent study conducted by Li et al. (2022a) showed that the effect of functional biochar on methane production, methane content, and VFA conversion efficiency was not significantly different from that of native biochar at low concentrations. The optimal dosage of metal-modified biochar is also related to the type of metal in the biochar. For example (Y. Chen et al., 2019) reported that the optimal doses for Co/C, CoO/C, and Co3O4/C were 15 mg/L, 60 mg/L, and 60 mg/L respectively in anaerobic digestion of dairy cow manure. This resulted in increases of 34.2%, 32.1%, and 32.1% in biogas production compared to the control group. High doses of functional biochar may increase costs and reduce methane production, while low doses may have little effect. Therefore, selecting the right dosage for functional biochar is very important to improve anaerobic digestion performance. The effect of functional biochar on anaerobic digestion is highly dependent on the selection of raw materials, correct modification methods, and appropriate dosage. Thus, selecting the right functional biochar can increase methane production and maintain process stability.

Prominent features of biochar

Biochar exhibits several prominent features that make it a valuable and versatile substance for various applications. First and foremost, biochar is a carbon-rich material, primarily produced through pyrolysis, and it serves as an effective means of carbon sequestration. Its stable carbon storage properties contribute to mitigating climate change by reducing the release of carbon dioxide into the atmosphere. Additionally, biochar boasts a highly porous structure with a multitude of pores and cavities, resulting in a large surface area that facilitates diverse chemical and biological processes. This porosity enhances soil structure by improving aeration, water retention, and root penetration, thus promoting healthier plant growth. Furthermore, biochar has the capacity to retain essential plant nutrients, preventing their leaching and making them available to plants over an extended period. Its pH-buffering properties can help stabilize soil pH, reducing the likelihood of extreme fluctuations. Biochar also serves as a habitat for beneficial microorganisms, fostering microbial activity and enhancing soil health. Moreover, when used in the soil, biochar can contribute to the reduction of greenhouse gas emissions such as methane and nitrous oxide, which are more potent than carbon dioxide. Lastly, biochar's ability to effectively retain water reduces runoff and helps maintain consistent soil moisture levels. Overall, biochar's diverse features make it a valuable tool in agriculture, environmental restoration, and sustainable land management practices.

The superior features of biochar are its ability to improve soil quality, increase nutrient availability, support microbial life in the soil, reduce the need for irrigation and fertilizer, and increase crop yields (Liu et al., 2016; Nie et al., 2018). Biochar has a high content of inorganic elements, which function as nutrients in the soil to support plant growth (Ding et al., 2016). In addition, biochar helps address the impacts of climate change by sequestering carbon and reducing greenhouse gas emissions, thereby increasing carbon sequestration in agricultural soils (Yang et al., 2010).

Biochar has demonstrated its ability to enhance soil quality, increase the availability of nutrients, promote soil microbial activity, and reduce the need for irrigation and fertilizers, resulting in improved crop yields (Liu et al., 2016; Nie et al., 2018). Additionally, biochar possesses a substantial content of inorganic elements that serve as nutrients in the soil, supporting plant growth (Ding et al., 2016). Moreover, biochar plays a crucial role in addressing climate change by sequestering carbon and reducing greenhouse gas emissions, thereby enhancing carbon storage in agricultural soils (Virk et al., 2020). Consequently, the incorporation of biochar represents an effective approach for augmenting nutrient content and availability. The utilization of biochar leads to an elevation in the concentration of micronutrients such as boron (B) and molybdenum (Mo), along with the facilitation of nitrogen (N) fixation. Biochar particles exhibit lower density and greater porosity compared to soil particles, enabling the soil to retain more water and air while reducing soil density.

Application of biochar results in the reduction of soil erosion, elevation of soil pH, enhancement of overall soil porosity, water-holding capacity, and stability of soil organic matter through the promotion of soil aggregation. Furthermore, the introduction of biochar enhances soil stability by improving soil aggregation. In clay soils, biochar utilization enhances the stability of soil aggregates and mitigates soil particle dispersion. Additionally, the alterations in soil characteristics induced by biochar support erosion control. All these factors have a significant impact on the abundance and composition of soil microbial communities, depending on the taxa and type of raw material, and play an important role in nutrient cycling (Bertschy et al., 2013).

Cost of using biochar

The use of biochar includes cost efficiency because it uses organic materials that are easy to find. The costs of using biochar as a soil remediation material can vary depending on various factors that must be considered. One of the main factors is the cost of purchasing or producing biochar itself, which depends on the raw material source, production method, and pricing policy of the biochar producer. Transportation costs also play an important role, especially if biochar must be transported from production sites to areas requiring remediation. The costs of applying biochar to soil must also be taken into account, including the cost of equipment and labor involved in the application process. In addition, the costs of monitoring and evaluating remediation performance should also be included in the calculation, as this is important to ensure remediation effectiveness. However, it is important to remember that the cost of using biochar as a soil remediation agent can provide long-term benefits, including increased soil productivity, reduced fertilizer costs, and improved soil quality. In many cases, a cost-benefit analysis can help assess whether using biochar is a worthwhile investment to improve overall soil and environmental quality.

Challange

The use of biochar in agricultural and environmental management practices has many potential benefits, but also has a number of challenges that need to be overcome. Some of the main challenges of using biochar include biochar, the rising star of soil science, faces a balancing act between promise and pitfalls. Its effectiveness can differ depending on its recipe, whispers of pyrolysis and chosen ingredients. Sourcing ample feedstock in an eco-friendly way, without stripping ecosystems bare, presents a logistical tango. Setting up the dance floor, with its pyrolytic equipment and infrastructure, can be a costly first step, especially for smaller players. And while biochar's long-term impact remains a whispered secret, its interaction with the environment, like a butterfly wing's flutter, can trigger cascading changes in water flow, land health, and nutrient balances. Local rules and regulations, the environmental waltz of policies and waste management, must be carefully followed to avoid discordant steps. Choosing the right partner for biochar's dance, a sustainable biomass source, ensures it doesn't become a villain in the climate change drama. Finally, spreading the word, educating the audience of farmers, land managers, and the public, is crucial for biochar to truly take center stage and unlock its full potential. With careful consideration and informed practices, biochar can transform from a promising newcomer into a seasoned performer, enriching the soil's symphony and ensuring a harmonious future for our planet.

Despite the challenges of using biochar, research continues to address some of these issues and identify effective solutions. Using biochar wisely and taking into account soil characteristics and plant needs can help maximize its benefits while reducing its negative impacts.

To produce economically effective functional biochar in large-scale applications, there are several steps that need to be taken based on current research and future outlook development of functional biochar preparation technology that is environmentally friendly, economical and practical and optimization of production conditions by modifying the preparation process, including the raw materials used, preparation conditions, and types of modified materials added, which can significantly influence the functional properties of biochar.

Although biochar has many benefits, there are several disadvantages to consider when using it. One of them is that production and application costs may be high, especially if the biochar must be imported or transported long distances. In addition, the effects of biochar on soil and plants can vary depending on the type of soil and specific environmental conditions, requiring appropriate adjustments. During the introduction period, biochar may take time to achieve the desired effect in improving soil quality. Unsustainable or unethical selection of raw material sources in biochar production can also cause environmental and social problems. Furthermore, if biochar is not applied properly, especially in excessive amounts, it can disrupt the balance of the soil and cause problems such as increased soil pH. Therefore, while biochar has great potential in soil remediation and environmental management, its use must be accompanied by a good understanding of its properties as well as appropriate selection and application in order to optimize its benefits and overcome any possible drawbacks.

Conclusion

In this summary, the authors highlight various studies that support the important role of biochar in addressing environmental problems caused by compounds such as dyes, pesticides, antibiotics, and PAHs in wastewater and rhizosphere environments. This research also seeks to explain the mechanisms underlying the role of biochar, especially in the adsorption process. Biochar has a crucial role in reducing the negative impact of compounds such as pesticides, antibiotics, dyes and PAHs by reducing the absorption and bioavailability of these xenobiotic compounds. It is important to note that biochar application in soil affects various aspects, including absorption, biodegradation, and movement of pesticides in soil. The physicochemical properties of biochar have a significant impact on its ability to absorb or release organic contaminants. These include aspects such as structure and chemical composition, porosity, surface area, pH, elemental ratios, and surface functional groups. These properties vary depending on the type of raw material used and the manufacturing conditions. Furthermore, the ability of biochar to absorb organic contaminants also depends on the type of contaminant encountered. Thus, before applying biochar to soil or wastewater, it is important to consider the physicochemical properties of the biochar itself, the condition of the soil or wastewater that will receive the application, and the type of organic contaminants present. Although biochar-based materials offer promising potential in remediation efforts, ecosystem rehabilitation, agricultural land management, wastewater treatment, and organic contamination control, further research is still needed to understand in depth the physicochemical properties that regulate the effectiveness of biochar adsorption.

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Conceptualization, B.Z, A.S and L.C.P; methodology, B.Z, A.S and L.C.P; validation, B.Z and A.S; formal analysis, B.Z, A.S and L.C.P; investigation, B.Z, A.S, and L.C.P; resources, L.C.P; writing—original draft preparation, L.C.P; writing—review and editing, B.Z, A.S, and L.C.P; visualization, L.C.P. All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflict of interest.

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