



Biochar for Improving Sustainable Soils Health

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Biochar improves sustainable soil health by increasing porosity, water retention, and nutrient availability, while also sequestering carbon. This is achieved by heating organic materials like wood or crop waste in a low-oxygen environment (pyrolysis), which creates a stable, carbon-rich substance that can improve soil structure, fertility, and aggregate stability over the long term. Biochar is a type of charcoal produced through the process of pyrolysis, involving the controlled heating of organic biomass in the absence of oxygen. This process transforms the biomass into a stable carbon-rich material, highly porous and capable of retaining essential nutrients and moisture. Biochar has the ability to enhance soil fertility and nutrient retention, improve water management, and promote beneficial microbial activity. Its porous structure facilitates the retention of essential nutrients, reducing nutrient leaching and runoff. By improving soil water-holding capacity, biochar aids in drought resilience and mitigates the risk of soil erosion during heavy rainfall events. Furthermore, biochar serves as a habitat for beneficial microorganisms, contributing to the overall health and resilience of the soil ecosystem. In addition to its positive impact on soil health, biochar plays a crucial role in mitigating climate change. It serves as a carbon sink, removing carbon dioxide from the air and permanently depositing it in the soil. This carbon sequestration potential makes biochar a valuable tool for reducing greenhouse gas emissions and achieving carbon neutrality in agricultural systems. Furthermore, biochar production can also generate bioenergy, displacing fossil fuel-based energy sources and further reducing greenhouse gas emissions.

Biochar improves sustainable soil health by enhancing soil structure, water retention, and nutrient availability, while also sequestering carbon. Its porous structure acts like a reservoir for water and nutrients, preventing nutrient loss and providing a stable habitat for beneficial microbes. Additionally, biochar can remediate contaminated soils by binding heavy metals and reducing greenhouse gas emissions.

Crop residue management is a significant challenge in India, with millions of tons of agricultural waste generated annually. Traditionally, farmers have resorted to burning crop residues, leading to severe air pollution and loss of soil nutrients. However, biochar—a carbon-rich product obtained from the pyrolysis of organic materials, offers a sustainable solution by enhancing soil health and reducing carbon emissions. The extensive utilisation of chemical fertilisers has resulted in the deterioration of ecosystems and various related problems, such as diminished nutritional value of crops and the long-term reduction of soil fertility. Alongside fertilisers, pesticides provide a significant concern within the field of agriculture due to their noteworthy environmental consequences, which exert a major influence on the microbiological characteristics of soil. The overuse of fertilisers and pesticides, as well as their persistent presence in the soil, has negative consequences for soil health, leading to a significant decrease in the biomass of bacteria and fungus. The utilization

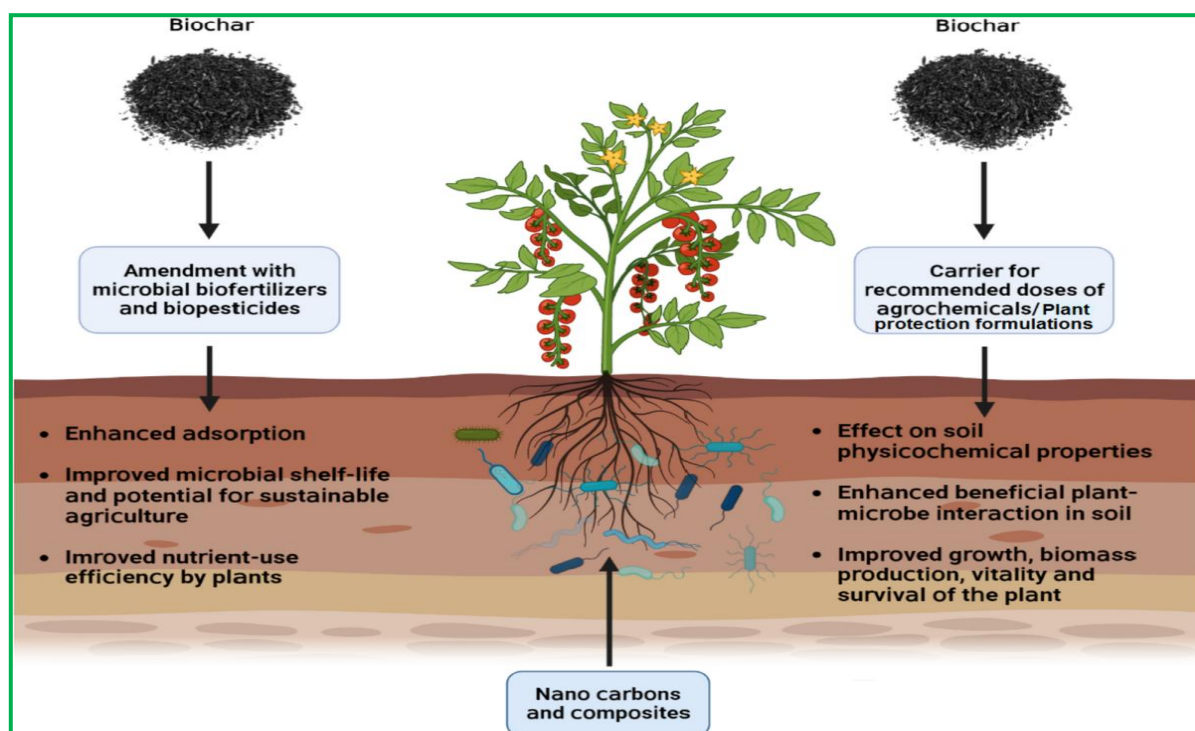
of biochar has been recognised as a sustainable approach and a potentially effective technique for enhancing soil quality and mitigating the problem of heavy metal contamination in soil.

How biochar improves soil health

- **Improves water retention:** Biochar's porous nature acts like a sponge, absorbing and holding water for plants and reducing leaching.
- **Increases nutrient availability:** It increases the soil's cation exchange capacity (CEC), allowing it to hold onto essential nutrients and release them to plants over time. This reduces the need for frequent fertilizer applications.
- **Promotes microbial activity:** The pores provide a habitat for beneficial microbes, which improves soil structure, nutrient cycling, and plant growth.
- **Enhances soil structure:** Biochar can improve soil aeration and aggregation, leading to better drainage and a more stable soil structure.
- **Sequesters carbon:** It provides a stable, long-term source of carbon in the soil, which helps to mitigate climate change.
- **Remediates contaminated soils:** Biochar can bind to heavy metals and other pollutants, reducing their toxicity to plants and the environment.
- **Reduces greenhouse gas emissions:** Biochar application can significantly reduce emissions of gases like carbon dioxide, methane, and nitrous oxide from the soil.

Considerations for use

- **Application rates:** The optimal application rate varies depending on soil type and other conditions, with rates ranging from 5 to 30 tons per hectare being common. Excessive application can negatively impact soil.
- **Biochar and compost synergy:** Combining biochar with compost or manure often provides greater benefits than using either amendment alone. The compost can "charge" the biochar with nutrients, and the mixture can lead to better soil health and higher crop yields.
- **Optimal use:** It is best to mix biochar with compost or manure before applying it to the soil to prevent direct contact with seeds, which can hinder germination.



Biochar improves soil health and crop production by enhancing soil structure, increasing water and nutrient retention, and promoting beneficial microbial activity. Produced through the pyrolysis of organic waste, it also acts as a carbon sink, helping to mitigate

climate change. The specific effects and benefits depend on the feedstock used and the production conditions, and while it holds great promise, more research is needed to fully understand its long-term impacts across various ecosystems. Biochar enhances crop production by improving soil health, nutrient retention, and water-holding capacity through its porous structure. It acts as a slow-release reservoir for nutrients, reduces leaching, and stimulates beneficial soil microbes, which can increase crop yields and resilience while reducing the need for synthetic fertilizers and helping with carbon sequestration.

How biochar improves soil and crop production

- **Improves soil structure:** Its high porosity increases the soil's surface area, which improves aeration, water infiltration, and water-holding capacity, making it more resilient to drought.
- **Enhances nutrient availability:** Biochar acts as a "slow-release" reservoir for nutrients, preventing them from leaching out of the soil and making them more accessible to plant roots.
- **Supports beneficial microbes:** It promotes the growth of soil microbes that are crucial for nutrient cycling and overall soil health.
- **Reduces fertilizer needs:** By improving nutrient retention and availability, biochar can reduce the amount of synthetic fertilizers required for a healthy crop.
- **Boosts crop yield:** Studies have shown that biochar can significantly increase crop yields, especially when combined with organic matter or fertilizers.
- **Increases resilience:** It can make crops more resilient to environmental pressures, such as climate change-related stressors, and may even activate plant defenses against pathogens.

How to use biochar

- **Mix it with soil:** A general guideline is to mix 5% to 10% biochar into the soil.
- **"Charge" it with nutrients:** To maximize its benefits, "charge" biochar before use by soaking it in liquid fertilizers, compost teas, or compost for about 24 hours to allow it to absorb nutrients.
- **Combine with other amendments:** The combination of biochar with organic fertilizers, like manure, can be particularly effective in improving both soil health and crop yield.
- **Top-dress and mulch:** You can spread a layer of nutrient-loaded biochar on the soil surface and cover it with mulch to keep it moist and help it integrate with the soil over time.

To make biochar from crop residues, dry the residues, then heat them in a low-oxygen environment through a process called pyrolysis. Several methods exist, including simple pyrolysis kilns, brick kilns like the Holy Mother kiln, and more advanced technologies like microwave pyrolysis. The temperature and heating rate determine the quality and yield of the biochar.

Effects of biochar on soil chemical properties

Improved soil properties are commonly reported benefits of adding biochar to agriculture soils. To investigate the range of biochar's effects on soil chemical properties (e.g., soil pH, electrical conductivity (EC), cation exchange capacity (CEC), soil organic carbon (SOC), soil total carbon (TC), and soil carbon-nitrogen ratio (C:N ratio)) in response to varied experimental conditions, a meta-analysis was conducted on previously published results. The results showed that the effect of biochar on soil chemical properties varied depending on management conditions, soil properties, biochar pyrolysis conditions, and biochar properties. The effect size (Hedges'd) of the biochar was greatest for SOC (0.50), the C:N ratio of soil (0.44), soil pH (0.39), TC (0.35), EC (0.21), and CEC (0.20). Among the various factors examined by aggregated boosted tree analysis, the effects of biochar on soil chemical properties were largely explained by the biochar application rate, initial soil pH, and soil sand content. In conclusion, our study suggests that improving soil chemical properties by adding

biochar not only requires consideration of biochar application rates and chemical properties but also the local soil environmental factors, especially soil initial pH and sand content of the soil, should be considered.

Challenges and Considerations

While biochar shows great potential for climate change mitigation and improving soil health, several factors must be considered. The sustainable sourcing of biomass for biochar production is crucial to ensure that it does not contribute to deforestation or compete with food production. Additionally, the optimal application rates and methods of biochar vary depending on soil conditions, crop types, and regional factors. Continuous research, monitoring, and knowledge-sharing are essential for maximizing the benefits of biochar while minimizing potential drawbacks.

Summary and Conclusions

Biochar is carbon-rich material obtained by the thermal decomposition of organic material in the absence of air. Biochar can provide a good solution to agricultural issues such as cropland deterioration due to acidity, salinity, and nutrient shortages. Adding biochar to the soil significantly reduces nutrient leaching and increases yields and nutrient use efficiency. However, the agricultural advantages of biochar are solely dependent on using specific biochar at the optimal field application rate under suitable soil types and parameters. It has been recommended that co-composting biochar made from various alternative feedstocks can be used to improve soil health, rehabilitate land resources, and reduce carbon output related to agriculture. Biochar can replace soil as a growing medium to meet the ever-increasing food demand and generate additional income by improving crop productivity and providing other revenue opportunities, leading to economic and agricultural benefits. Biochar is a carbon-rich material with potential applications in agriculture, industry, and the energy sector. It has significant application in agriculture to enhance crop production, soil condition, nutrient uptake, and carbon sequestration due to its unique characteristics like high surface area and pore volume. This review focuses on biochar as an agricultural additive to enhance crop productivity and improve soil health and the potential benefits as a material for growth media and composting. Cocomposting of biochar produced from various organic sources can stabilize the soil, repair degraded land, and reduce carbon emissions associated with agriculture. In conclusion, it was found that biochar is also used as growing media for a hydroponic system, which enhances the growth of high-value food crops to meet the increased food demand. Furthermore, the biochar-based soilless alternative to traditional farming may provide a more environmentally-friendly system for growing food and reduce the demand for chemical fertilizers, significantly reducing greenhouse gas emissions. Biochar presents a viable solution for crop residue management in India, offering numerous environmental and agricultural benefits. By improving soil health, enhancing water retention, and reducing pollution, biochar can play a crucial role in promoting sustainable agriculture. With appropriate support and adoption, biochar can help transform Indian agriculture, making it more resilient and eco-friendlier.