

Role of Biochar in Soil Improvement

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INTRODUCTION

Biochar is a stable, carbon-rich material produced through the pyrolysis of biomass under limited or no oxygen conditions. Agricultural residues such as rice husk, wheat straw, corn cobs, coconut shells, and forestry wastes are commonly used as feedstocks. Unlike ordinary charcoal used as fuel, biochar is specifically produced for soil application with the aim of improving soil quality and environmental sustainability. Due to its porous structure, high surface area, and chemical stability, biochar has gained global recognition as an important amendment for soil restoration and climate-smart agriculture. The incorporation of biochar into soil provides both agronomic and ecological benefits. It enhances nutrient retention, improves soil physical structure, supports microbial activity, and plays a significant role in long-term carbon storage. These properties make biochar an effective tool in addressing soil degradation, declining fertility, and environmental pollution.

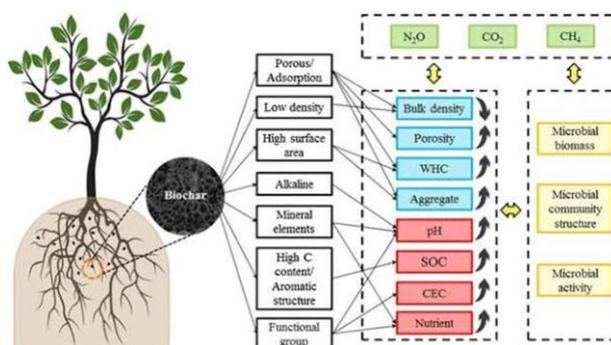


Figure 1: Biochar Effects on Soil Properties and Microbial Activity

2 Production and Characteristics of Biochar

Biochar is produced through thermal decomposition of organic biomass at temperatures ranging from 300°C to 700°C in the absence of oxygen. The quality and effectiveness of biochar depend on several factors:

- **Feedstock Type:** Crop residues, wood chips, manure, and husks produce different nutrient compositions and ash contents.
- **Pyrolysis Temperature:** Higher temperatures increase surface area and stability but may reduce nutrient content.
- **Residence Time:** Longer heating periods improve carbonization but may decrease yield.

Key characteristics of biochar include:

- High porosity and surface area
- Alkaline pH in most cases
- High cation exchange capacity (CEC)
- Resistance to microbial decomposition
- Ability to adsorb nutrients and pollutants

These properties enable biochar to act as both a soil conditioner and a carbon sink.

3 Biochar and Carbon Sequestration

One of the most significant environmental benefits of biochar is its role in carbon sequestration. During pyrolysis, a portion of the carbon present in biomass is converted into stable aromatic carbon structures that resist decomposition for hundreds to thousands of years. When applied to soil, this stable carbon remains locked in the soil matrix instead of returning to the atmosphere as carbon dioxide.

Mechanisms of Carbon Sequestration:

- Conversion of labile biomass carbon into recalcitrant carbon forms
- Protection of soil organic carbon through aggregate formation

- Reduction in greenhouse gas emissions such as methane (CH₄) and nitrous oxide (N₂O)
- Enhanced plant growth leading to greater biomass input into soil

Biochar application therefore contributes to climate change mitigation by lowering atmospheric CO₂ concentrations and improving long-term soil carbon storage. Agricultural systems that integrate biochar with residue management and conservation practices show higher carbon retention compared to conventional systems.

4 Biochar and Soil pH Regulation

Soil acidity is a major constraint in many tropical and subtropical regions. Biochar generally exhibits alkaline properties due to the presence of ash, calcium, magnesium, potassium, and carbonates formed during pyrolysis. When incorporated into acidic soils, biochar acts similarly to liming materials by neutralizing excess hydrogen and aluminum ions.

Benefits of pH Regulation:

- Increased availability of phosphorus and molybdenum
- Reduced aluminum and manganese toxicity
- Improved root growth and nutrient uptake
- Enhanced microbial diversity and enzymatic activity
- Better performance of nitrogen-fixing bacteria

Unlike conventional lime, biochar also adds organic carbon and improves soil structure, making it a multifunctional amendment. However, in alkaline soils, excessive application may raise pH further; therefore, soil testing and dosage control are essential.

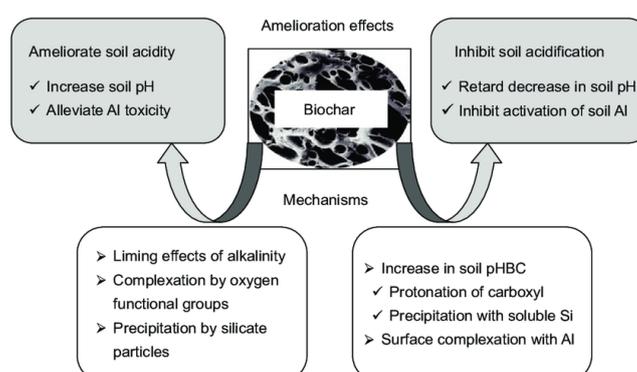


Figure 2: Biochar for Soil Acidity Amelioration

5 Biochar and Heavy Metal Adsorption

Biochar has strong adsorption capacity due to its porous structure and surface functional groups such as hydroxyl, carboxyl, and phenolic groups. This makes it effective in immobilizing heavy metals and reducing their bioavailability in contaminated soils.

Heavy Metals Commonly Adsorbed:

- Lead (Pb)
- Cadmium (Cd)
- Chromium (Cr)
- Nickel (Ni)
- Zinc (Zn)
- Copper (Cu)

Mechanisms of Adsorption:

- Ion exchange
- Surface complexation
- Precipitation reactions
- Physical entrapment within pores

By binding heavy metals, biochar reduces their uptake by crops and prevents entry into the food chain. This property is particularly useful in rehabilitating polluted agricultural lands, mining areas, and industrially contaminated soils.

6 Effects on Soil Physical Properties

Biochar significantly influences soil physical conditions:

- **Improved Porosity:** Enhances aeration and root penetration.
- **Reduced Bulk Density:** Makes soil lighter and easier to cultivate.
- **Increased Water Holding Capacity:** Especially beneficial in sandy soils and drought-prone regions.
- **Enhanced Aggregate Stability:** Reduces erosion and compaction.

These improvements collectively contribute to better plant establishment and resilience under water stress conditions.

7 Effects on Soil Chemical Properties

Biochar acts as a nutrient reservoir and chemical stabilizer:

- Increases Cation Exchange Capacity (CEC)
- Reduces nutrient leaching losses
- Improves nitrogen use efficiency

- Enhances phosphorus availability
- Supplies potassium, calcium, and magnesium depending on feedstock

It also interacts with fertilizers, often allowing reduced chemical fertilizer requirements without compromising yield.

8 Effects on Soil Biological Properties

Biochar provides a favorable habitat for soil microorganisms due to its porous structure and stable carbon source. Microbial populations such as bacteria, fungi, and actinomycetes often increase after biochar application. Benefits include:

- Enhanced enzyme activity
- Improved nutrient mineralization
- Promotion of mycorrhizal associations
- Suppression of certain soil-borne pathogens

However, extremely high doses may temporarily immobilize nitrogen; hence balanced application is necessary.

9 Limitations and Challenges

Despite its advantages, biochar adoption faces several constraints:

- High initial production cost
- Lack of standardized quality guidelines
- Variable performance across soil types
- Risk of contamination if feedstock is polluted
- Limited farmer awareness and technical knowledge

Long-term field trials and policy support are required for large-scale implementation.

CONCLUSION

Biochar serves as a multifunctional soil amendment that enhances physical, chemical, and biological soil properties while simultaneously addressing global environmental challenges. Its roles in carbon sequestration, pH regulation, and heavy metal adsorption make it particularly valuable for restoring degraded soils and mitigating climate change. When applied judiciously and combined with organic and integrated nutrient management practices, biochar can significantly improve soil health, crop productivity, and long-term agricultural sustainability.

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