THE ROLE OF BIOCHAR IN CARBON SEQUESTRATION FOR SUSTAINABLE AGRICULTURE

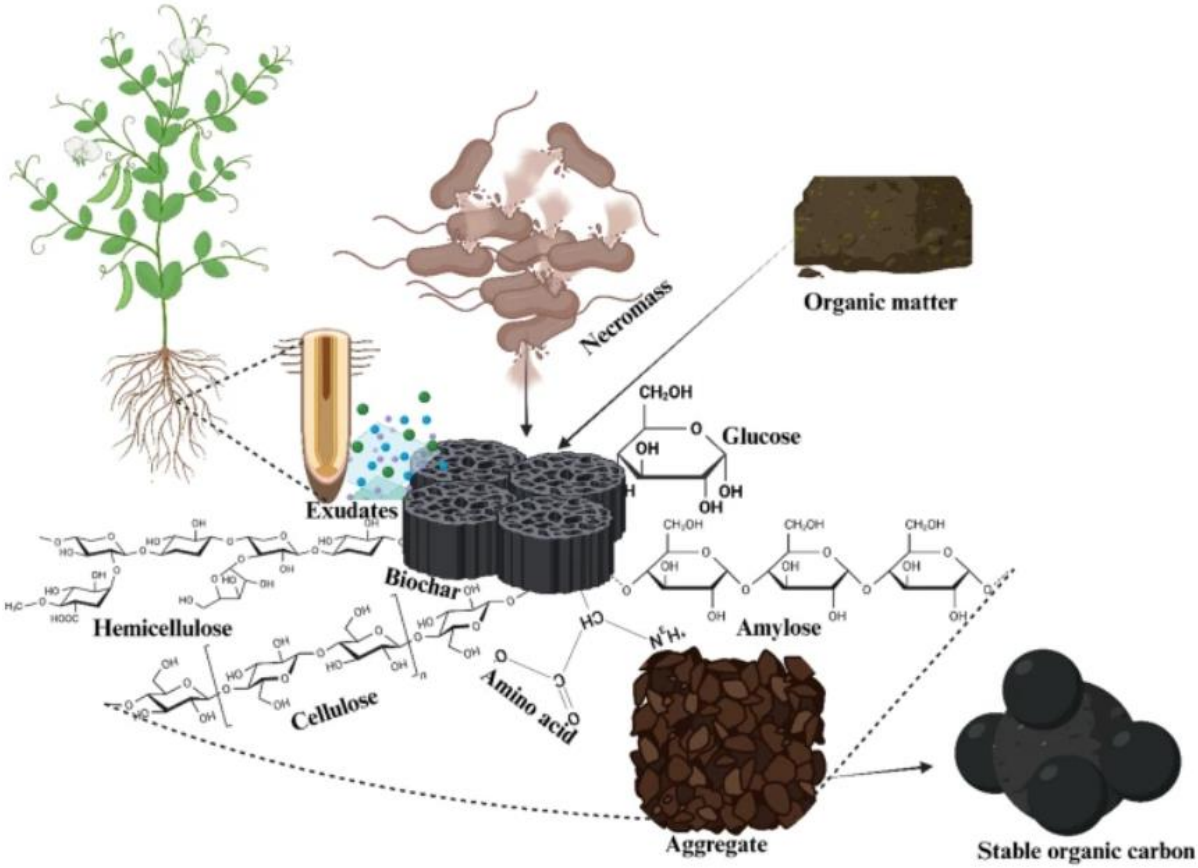
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Biochar is a carbon-rich material produced through biomass pyrolysis and is recognized as an effective tool for long-term carbon sequestration in agricultural soils. Its stable carbon structure reduces CO_2 emissions by storing carbon in soil for extended periods while improving soil organic carbon, water retention, and nutrient availability. Recent studies have shown that biochar application enhances soil fertility, supports microbial activity, and contributes to sustainable agricultural production. Therefore, biochar represents a promising climate-smart technology for improving soil health and mitigating climate change.

Rising atmospheric temperatures and climate change have increased the need to reduce greenhouse gas emissions and ensure environmental sustainability. Soil is one of the largest carbon reservoirs in the biosphere, storing substantial amounts of organic carbon derived mainly from plants. Approximately 50% of the carbon fixed during photosynthesis is transferred to the soil through root exudates and plant residues. These organic compounds are decomposed by soil microorganisms through carbon mineralization, respiration, and methanogenesis, resulting in the release of carbon dioxide (CO_2) and methane (CH_4). Consequently, soil organic carbon stocks decline, contributing to climate change. In this context, biochar has gained significant attention as a sustainable technology due to its ability to sequester carbon in soils for extended periods, reduce greenhouse gas emissions, and improve soil quality, thereby supporting sustainable agricultural production [1].

Biochar’s contribution to soil carbon sequestration is attributed to its carbon content, which is rich in recalcitrant and aromatic carbon, and to its ability to induce negative priming effects on soil microbial metabolism. Negative priming is a phenomenon where biochar application reduces microbial mineralization of resident or native soil organic carbon by lowering microbial metabolic quotient, limiting microbial accessibility to soil organic carbon, and stimulating carbon use efficiency, thereby facilitating an increase in soil carbon storage and a decrease in soil respiration. It also

increases microbial biomass carbon through promoting carbon use efficiency and supports carbon assimilation into biomass as opposed to respiration. Biochar, also improves microbial habitat through enhanced soil cation exchange capacity, water holding capacity, aggregate formation, and aeration [1].



Chemical mechanisms of biochar contribution to soil carbon sequestration. The exudate carbon released by plants gets adsorbed on the surface of the biochar as well as decomposed organic carbon from organic matter to form biochar-organo interface and organo-mineral interface with soil minerals. Biochar also adsorbs and retains microbial necromass, protecting it from decomposition to form an aggregate and stable organic carbon pool in the soil

A comprehensive review of the literature indicates that the carbon sequestration potential of biochar in soil systems ranges from 0.7 to 1.8 Gt CO_2-equivalent carbon per year. Biochar characterized by high chemical stability and a high carbon-to-nitrogen (C/N) ratio enhances long-term carbon storage in soils, thereby significantly improving carbon sequestration efficiency. Furthermore, the application of biochar at higher rates, particularly in highly porous and alkaline soils (pH > 7.5), further promotes carbon sequestration. Biochar amendment also alters the composition of soil microbial communities. Specifically, the relative abundance of Proteobacteria and Acidobacteria is enriched in biochar-amended soils, while Ascomycota remains the

dominant fungal phylum. The effects of biochar on soil microbial biomass and community structure are largely influenced by its particle size, porosity, and application rate [2].

The modification of feedstocks or pristine biochar can be classified into three different types: activated biochar (AB), engineered biochar (EB), and functionalized biochar, based on the methods used to alter the biochar. AB is produced by exposing biochar to high temperatures in the presence of certain gases (such as CO_2 or steam), which enhance its physicochemical properties while EB is modified by changing the feedstock or adding compounds like metal ions ($MgCl_2$ and $ZnCl_2$). Biochar modified by adding functional groups to enhance its chemical properties is referred to as functionalized biochar. However, the term B generally distinguishes between pristine and altered biochar [3].

Biochar and its derivatives significantly improve soil structure and fertility, potentially increasing porosity by 14–64%, reducing bulk density by 3–31%, and nearly doubling the water-holding capacity in sandy soils at a 20% application rate. Furthermore, biochar can enhance nutrient availability, stimulate microbial biomass, and, on average, increase crop yield by 16% and reduce CO_2 emissions by 8.62%. Additionally, it can reduce CH_4 emissions by 27%, N_2O emissions by 23.9%, and GHG emissions by 12% [4].

Climate-smart agriculture (CSA) seeks to sustainably increase productivity, improve resilience (adaptation), and minimize or eliminate greenhouse gas emissions (mitigation), while also supporting national food security and development goals [5].

Overall, biochar represents a promising approach for sustainable agriculture by improving soil carbon sequestration, enhancing soil quality, and supporting beneficial microbial activities. Its stable carbon structure and porous properties contribute to long-term carbon storage and increased soil fertility. Therefore, the application of biochar can be considered an effective strategy for climate change mitigation and sustainable agricultural development.

REFERENCES

1. Joseph S., Lehmann J., Fawcett D., et al. The Impacts of Biochar on Carbon Sequestration, Soil Processes, and Microbial Communities: A Review // Biochar. – 2025..
2. Mandal S., Sharma P., Singh R., et al. Use of Biomass-Derived Biochar as a Sustainable Material for Carbon Sequestration in Soil: Recent Advancements and Future Perspectives // npj Materials Sustainability. – 2025.
3. Zhang Y., Wang X., Li H., et al. Advancing Modified Biochar for Sustainable Agriculture: A Comprehensive Review on Characterization, Analysis, and Soil Performance // Biochar. – 2025.
4. Ali A., Khan M., Hussain S., et al. Biochar in Agriculture: A Review on Sources, Production, and Composites Related to Soil Fertility, Crop Productivity, and Environmental Sustainability // C. – 2025.
5. Kumar R., Verma P., Singh A., et al. Use of Biochar as a Sustainable Agronomic Tool, Its Limitations and Impact on Environment: A Review // Discover Agriculture. – 2024.