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Biochar in Carbon Sequestration: A Sustainable Solution for Climate Change Mitigation

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Greenhouse gases (GHGs) like carbon dioxide (**CO_2**), methane (**CH_4**), and nitrous oxide (**N_2O**) are primary drivers of global climate change. Agriculture is a major contributor, responsible for significant global emissions through direct practices and land-use changes. Carbon sequestration—the process of capturing and storing atmospheric **CO_2** in stable pools—is a vital mitigation strategy. Biochar, a stable, carbon-rich solid produced via pyrolysis, offers a "double-win" by storing carbon for centuries while simultaneously improving soil health and crop productivity. This article integrates field data from the Indian Institute of Soil Science (IISS) and ResearchGate to compare biochar with traditional amendments. Results indicate that biochar enhances soil organic carbon by over 60% and increases crop yields by up to 25% compared to traditional compost. However, critical reviews suggest that biochar implementation must be adjusted to soil types to avoid humus depletion.

Introduction

The global atmospheric concentration of **CO_2** has surpassed 415 ppm. Agricultural systems are uniquely positioned in this crisis; they are highly vulnerable to climate shifts but also possess the biological capacity to act as a "carbon pump." Conventional organic amendments, such as Farmyard Manure (FYM) or raw crop residues, undergo rapid mineralization, returning most of their carbon to the atmosphere as **CO_2** within a few seasons. In contrast, Biochar is a recalcitrant form of carbon that mimics the ancient "Terra Preta" of the Amazon. By heating agricultural waste in an oxygen-limited environment the process known as pyrolysis in which the carbon is "locked" into aromatic structures that resist microbial decay.

Methodology: The Mechanics Of Biochar

1. Production and Pyrolysis Dynamics

Biochar quality is dictated by the temperature of the pyrolysis unit. The transformation of biomass involves the thermal degradation of three primary components:

- **Hemicellulose (250–300°C):** Undergoes initial carbonization.
- **Cellulose (300–450°C):** Transforms into stable aromatic structures.
- **Lignin (300–750°C):** Provides the rigid, recalcitrant skeleton of the biochar.

2. Structural Analysis

Scanning Electron Microscopy (SEM) reveals that biochar is highly porous. These pores act as microscopic "shelters" for beneficial microbes and "reservoirs" for water and nutrients.

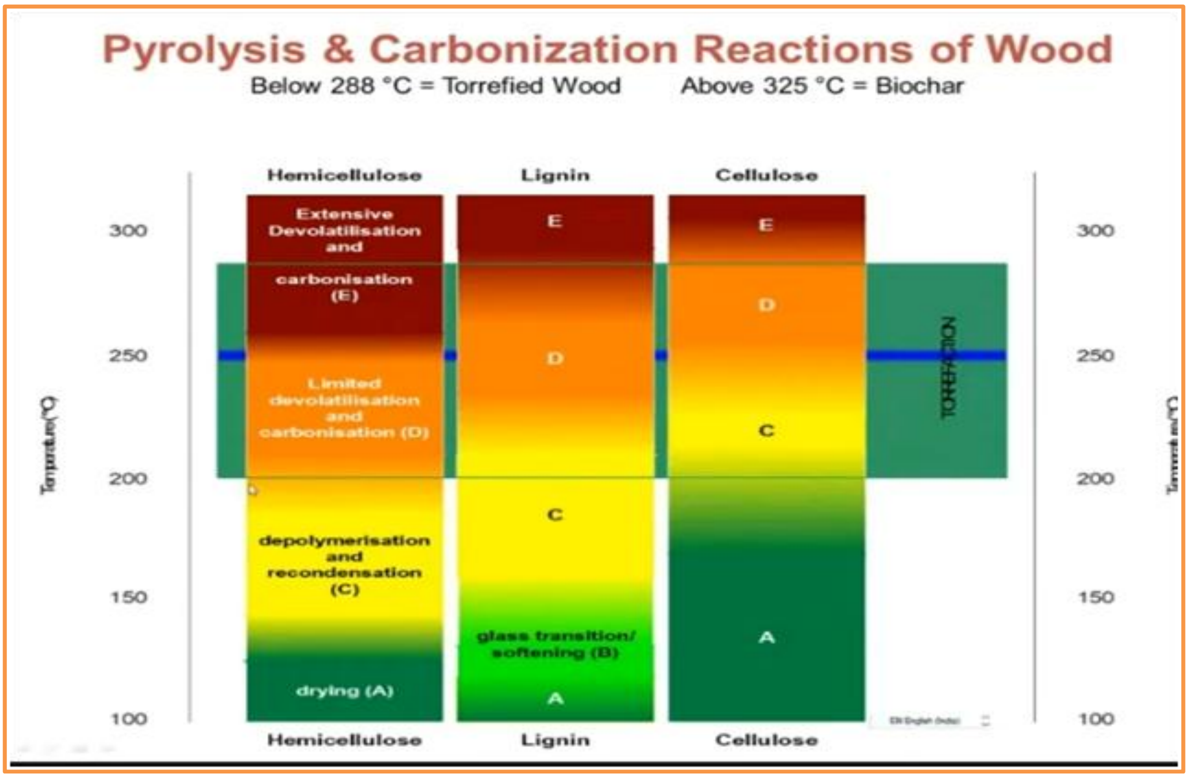


Figure: Scanning Electron Micrograph showing the porous structure of biochar (Source: Skjemstad *et al.*, 2002).

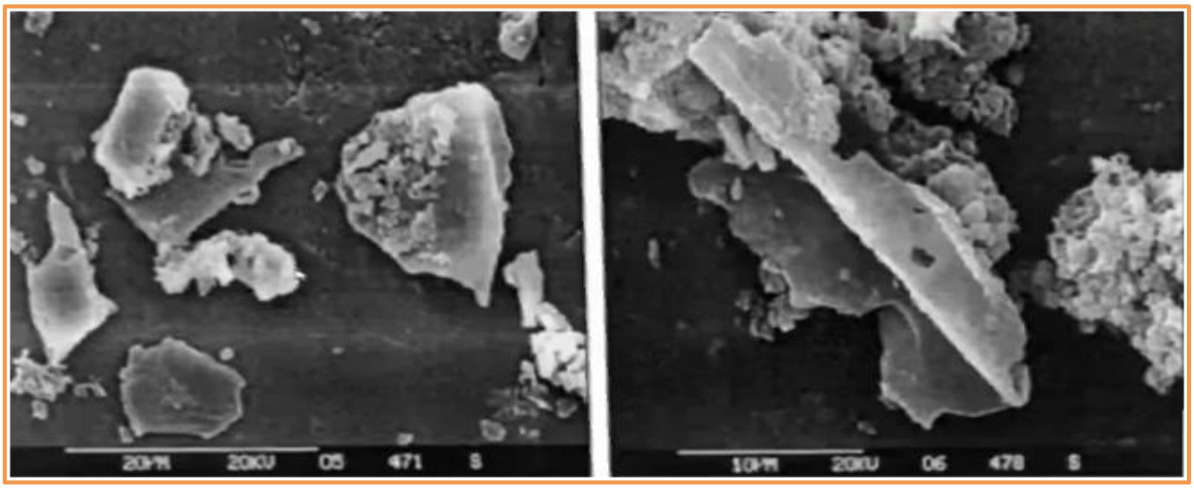
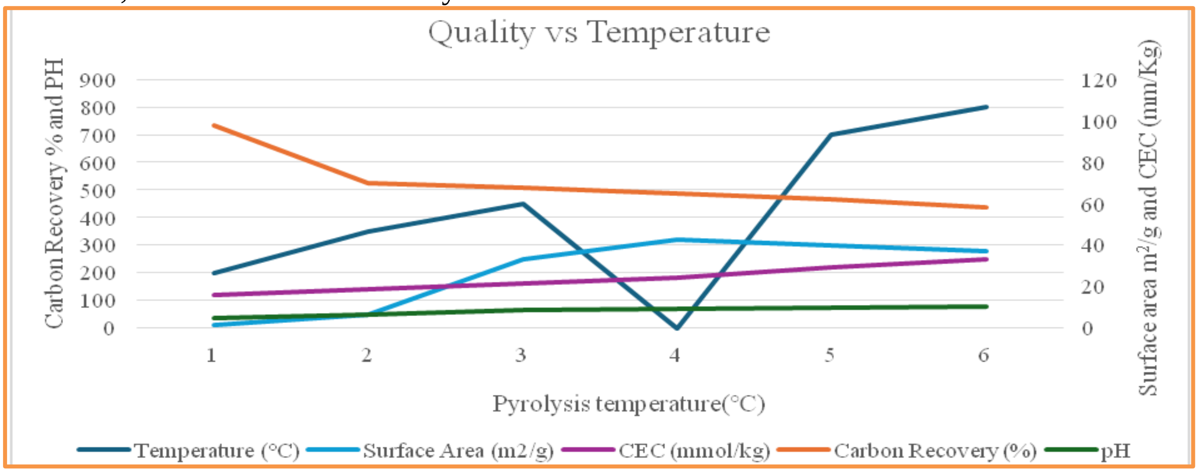


Figure: Scanning Electron Micrograph showing the porous structure of biochar (Source: Skjemstad *et al.*, 2002).

Results and Discussion

1. Biochar Quality vs. Pyrolysis Temperature

The interaction between heat and quality is non-linear. As temperature rises, surface area increases, but total carbon recovery decreases.



Source: Lakaria (2024). Biochar for Carbon Sequestration and Climate Change Mitigation

2. Biochar vs. Traditional Farmyard Manure (FYM)

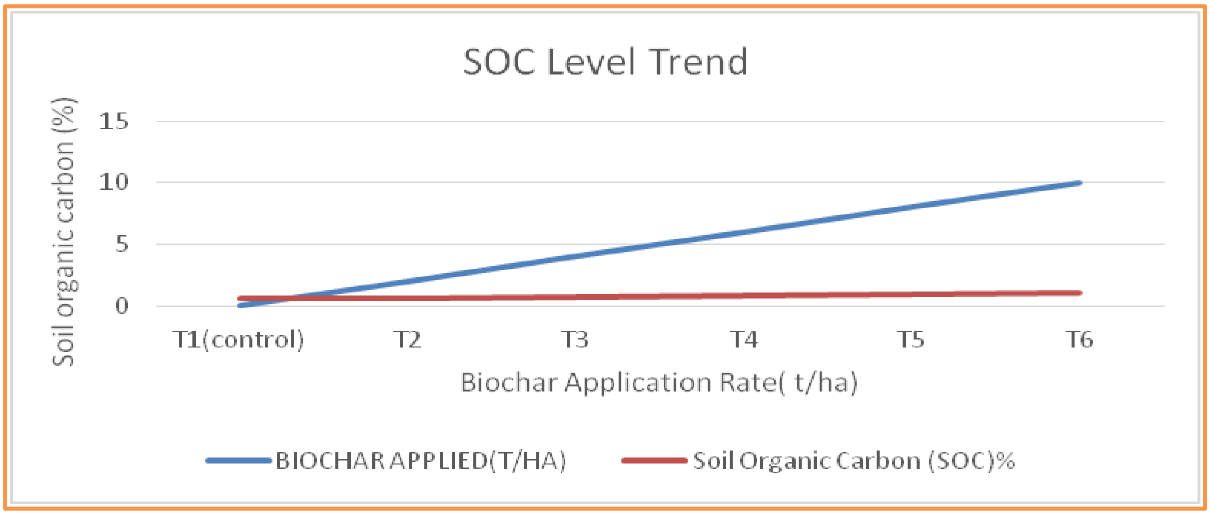
Field research on Black Gram (*Vigna mungo*) demonstrates that while FYM is an excellent source of quick-release nutrients, biochar creates a more efficient, long-term "nutrient bank."

PARAMETER	BIOCHAR (10 tonnes/ha)	TRADITIONAL COMPOST(FYM)
Pod yield(kg/ha)	1250	1000
Plant height(cm)	48	40
Nutrient retention (Index)	95	78
Weed Occurrence (Count)	14	20
Carbon half-life (Years)	1400	2

SOURCE: Bharathi, et al., (2024). Comparison of Soil Amendments using Biochar and Traditional Compost in Enhancing Soil Quality.

3. Impact on Soil Organic Carbon (SOC)

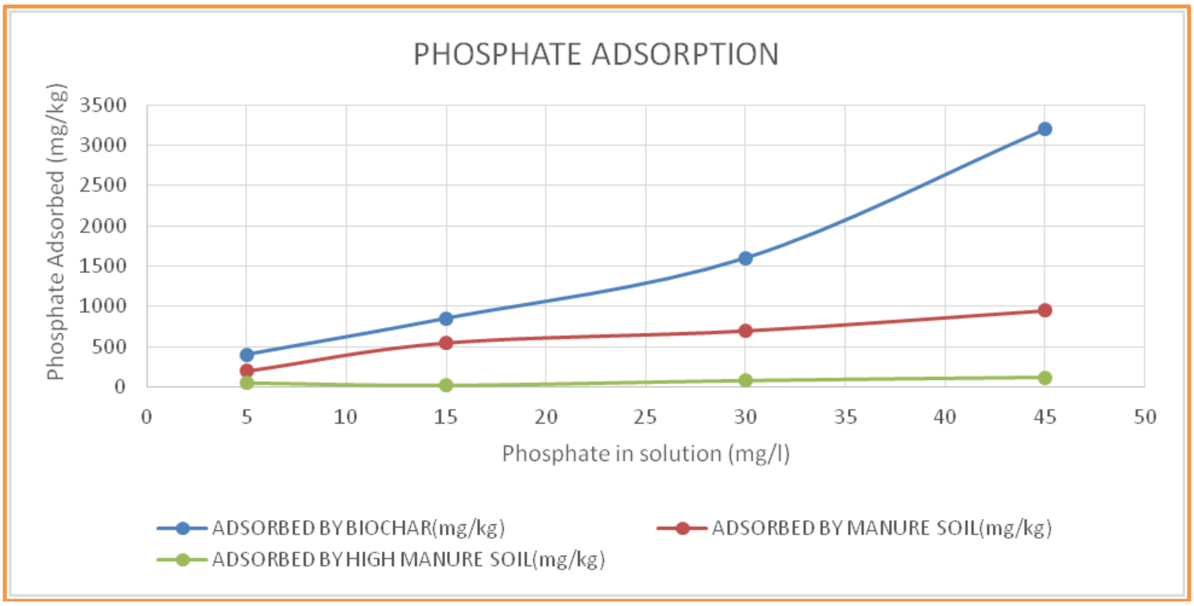
Data from ICAR-IISS Bhopal (2021–2023) confirms that biochar application leads to a direct increase in stable carbon within the soil profile.



Source: Lakaria, (2024). Biochar for Carbon Sequestration and Climate Change Mitigation

4. Nutrient Retention and Adsorption

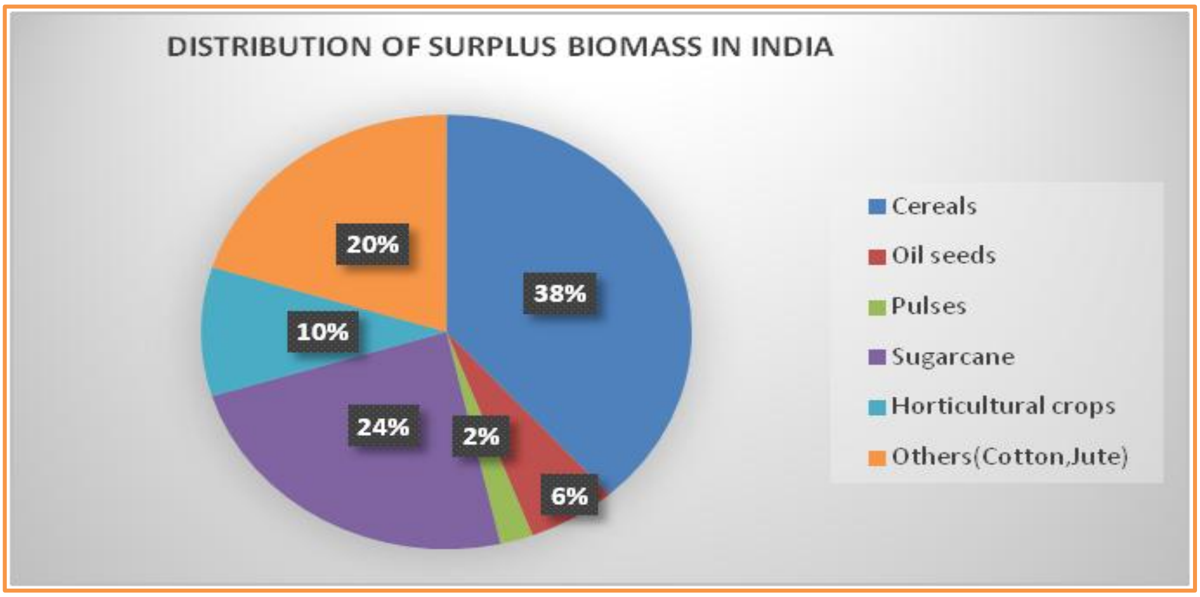
Biochar has high surface area that allows it to adsorb essential nutrients like Phosphate (**PO_4**). This provides a slow-release mechanism and prevents water pollution.



Source: Lakaria, (2024). Biochar for Carbon Sequestration and Climate Change Mitigation

Biochar Potential in the Indian Landscape

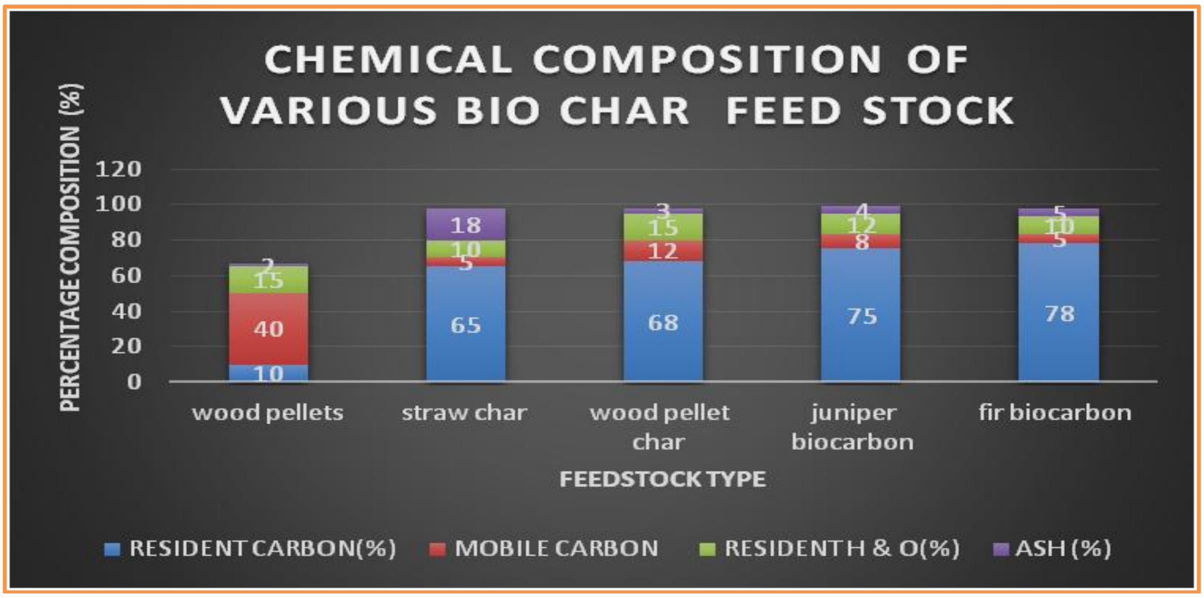
India produces over 686 million tonnes of gross biomass annually. Converting the surplus into biochar presents a massive sequestration opportunity.



Source: Lakaria, (2024). Biochar for Carbon Sequestration and Climate Change Mitigation

Critical Perspectives: Climate Mitigation Strategy

According to recent 2023 frameworks, biochar is a vital Carbon Dioxide Removal (CDR) technology. It fits the "Climate-Smart Agriculture" (CSA) framework by increasing productivity, enhancing adaptation to droughts, and ensuring long-term mitigation. However, reports from the Convention on Biological Diversity (CBD) highlight risks. Stripping all agricultural residues for biochar may reduce natural humus formation. Furthermore, if biochar is not tilled deeply, it could release airborne "black carbon," which is a warming agent.



Source: Lakaria, (2024). Biochar for Carbon Sequestration and Climate Change Mitigation

Conclusion

Biochar is a transformative tool for sustainable agriculture. It transforms agricultural waste into a stable carbon sink, preventing the pollution caused by field burning. Results show that biochar can enhance soil organic carbon by over 60% and increase crop yields by 25%. While it is superior to traditional FYM for long-term sequestration, its application must be site-specific to avoid ecological trade-offs. Moving forward, "slash and char" practices could be a cornerstone of India's climate-resilient future.

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