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Biochar: The Eco-Friendly Boost for Soil Health

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Soil is fundamental to productive agriculture, and improving its quality is key to increasing crop yields and fertility. A promising approach to achieve this is the use of biochar—a carbon-rich material created by pyrolyzing organic waste, crop residues, or wood under limited oxygen. Biochar helps in carbon sequestration, enhances nutrient retention, recycles farm waste, and lowers greenhouse gas emissions. These benefits make it a sustainable tool for soil improvement. This chapter provides an in-depth overview of biochar's properties, methods of production, and its positive impact on agriculture, making it a useful guide for researchers, farmers, and agricultural professionals.

Introduction

As the effects of climate change become more severe, global agriculture is facing immense pressure. Among the many challenges is the deterioration of soil health, which directly threatens food security. Soil organic matter—the foundation of healthy soils—is rapidly depleting due to unsustainable farming practices and environmental stresses. Scientists stress the importance of restoring soil's physical, chemical, and biological functions. One promising solution gaining attention is biochar—a carbon-rich, porous substance produced through pyrolysis (the heating of organic materials in the absence of oxygen). This ancient technique, now revived with modern science, offers a powerful tool for improving soil health, capturing carbon, and enhancing crop productivity. Importantly, it addresses a serious global imbalance: land ecosystems cannot absorb the 9.5 peta-grams of carbon emitted annually. Biochar offers a tangible path toward climate mitigation and sustainable agriculture.

What is Biochar?

Biochar is not simply burned biomass. It is a stable, carbon-rich product created when organic material like wood, crop residues, or manure is thermally decomposed at temperatures between 350°C and 600°C under oxygen-limited conditions. Unlike ash or charcoal, biochar retains the essential elements of carbon, hydrogen, oxygen, nitrogen, and sulphur—along with trace minerals—making it uniquely suited to enhance soil health.

Its strength lies in its porous structure, large surface area, and chemical stability, enabling it to persist in soil for hundreds of years. These features make it ideal for sequestering carbon, reducing greenhouse gas emissions, and restoring degraded lands.

Biochar Production

Modern biochar is often derived from agricultural and agro-industrial residues (fig. 1) such as straw, husks, nutshells, or algae. Instead of allowing this biomass to rot or burn—releasing greenhouse gases—pyrolysis locks much of the carbon into a solid form. Several methods exist for producing biochar: Slow pyrolysis (≤500°C) yields more solid biochar. Fast pyrolysis and gasification focus on liquid and gaseous fuels. Hydrothermal carbonization (HTC) can process wet feedstocks. Biochar production is efficient: for example, high-quality biochar contains 70% fixed carbon, has a calorific value of 30–33 MJ/kg, and only 1–3% ash content. Yield depends on the feedstock and process used, with open burning wasting over 50% of carbon—whereas pyrolysis minimizes such losses.

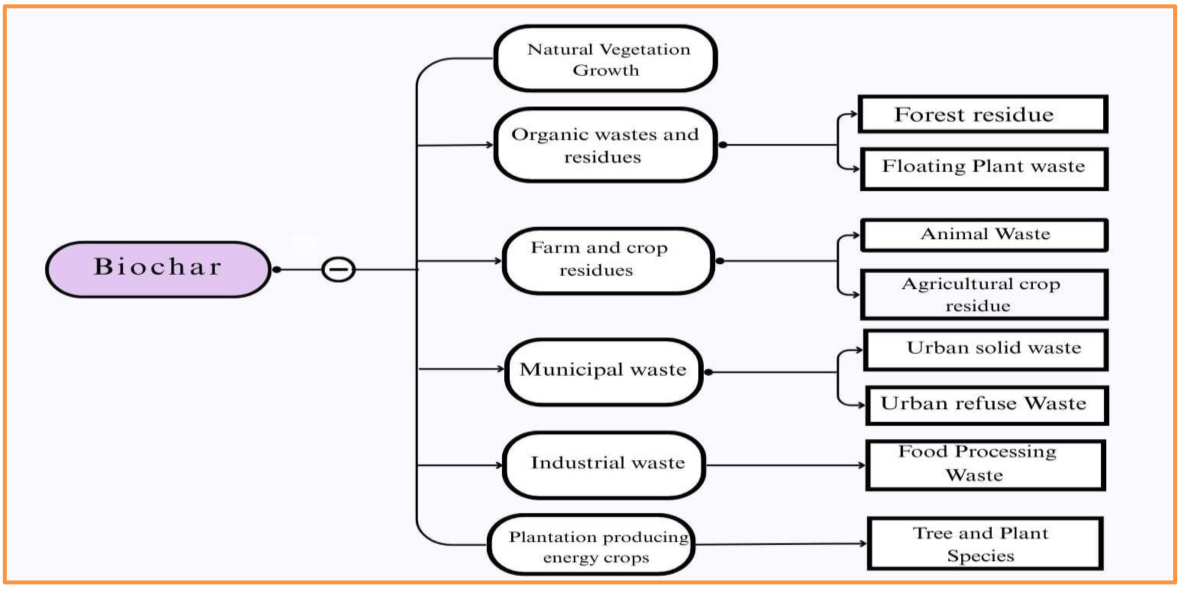

Fig 1: Categorization of different types of biomasses for biochar production

Method of application of biochar

The method of applying biochar matters. Researchers have identified three key strategies:

1. **Topsoil Incorporation:** Mixed with compost or manure and ploughed into the top 15–30 cm of soil. This is the most common method in traditional tillage systems.
2. **Deep Placement (Deep Banding):** Biochar is placed closer to root zones via trenches or furrows, enhancing plant uptake and minimizing surface runoff.
3. **Top-Dressing:** Biochar is spread on the soil surface, suitable for no-till farming or forested areas. While simple, it risks wind and water erosion and may not integrate well without tillage.

The chosen method depends on soil type, climate, land use, and farming systems.

Biochar's Impact on Soil Properties

Biochar influences (fig. 2) soil in three major ways—physically, chemically, and biologically.

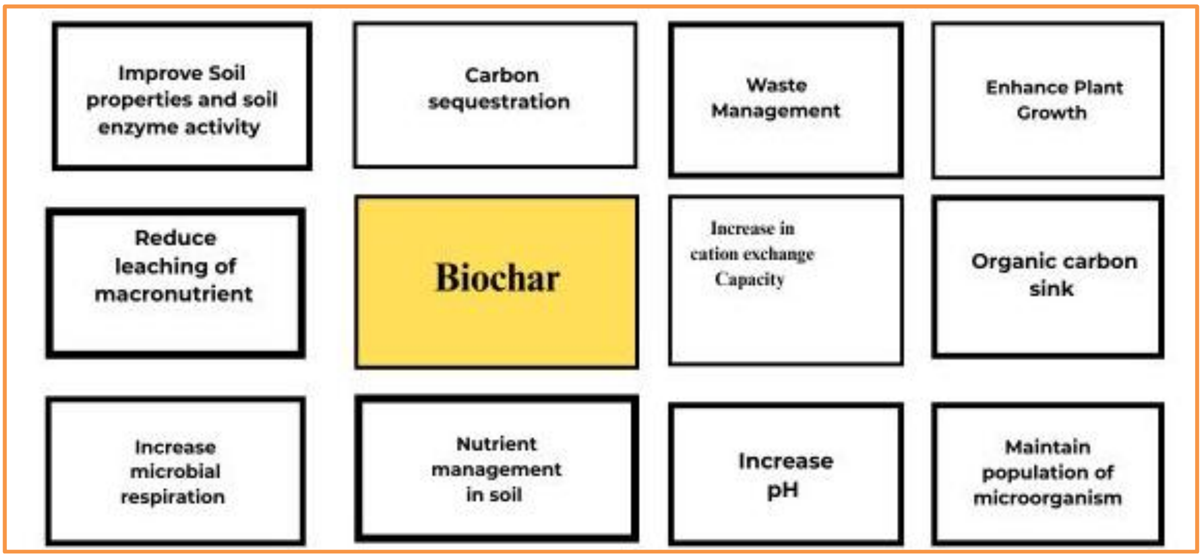

Fig. 2. Advantages of adding biochar to soils with poor physicochemical characteristics

Physical Improvements

- ✓ **Soil Moisture Retention:** Biochar's porosity allows it to store water effectively. Applied at 5 t/ha, it increased soil moisture to 11.2% at 35 cm depth.

- ✓ **Soil Texture and Structure:** It improves soil aeration, reduces compaction, and promotes water infiltration—especially beneficial in sandy or degraded soils.
- ✓ **Bulk Density & Porosity:** It decreases bulk density by up to 5% and increases pore space, enhancing root growth and nutrient availability.

Chemical Enhancements: Biochar affects key chemical indicators of soil health: pH Raised by 0.5–0.6 units in acidic soils. Nutrient Retention Increases nitrogen, phosphorus, potassium availability, CEC (Cation Exchange Capacity) Improved to 6.5 cmol^{+} kg^{-1} in some treatments, Salinity Helps manage EC within crop-safe limits. For instance, red gram stalk biochar (RSB) at 5 t/ha yielded 178 kg/ha of nitrogen and significantly boosted phosphorus and potassium availability (Pandian et al., 2016). Biochar is rich in stable carbon and improves soil organic carbon (SOC). A 3-year study found that, SOC increased from 3.6 to 4.8 g/kg, Water-soluble carbon rose by 73% and Biomass carbon improved by 37%. The carbon-rich environment supports microbial life and encourages root exudation, further enhancing soil vitality.

Microbial and Enzymatic Activities in Biochar-Amended Soils: Soil microbes play a critical role in nutrient cycling. Biochar supports microbial biomass by offering habitat and food. Soil Microbial Biomass Carbon (SMBC), Increased by 12.5% over control. Soil Microbial Biomass Nitrogen (SMBN), Improved in treatments combining biochar with chemical fertilizers. Microbial Populations, Red gram and maize stalk biochars showed the highest bacterial and fungal counts.

Biochar also boosts soil enzymatic activities: Dehydrogenase activity increased by 27%, signalling active microbial respiration. Urease activity crucial for nitrogen cycling, rose by up to 39%. Phosphatase enzymes, involved in phosphorus availability, also increased.

Biochar's Role in Nutrient Management and Soil Fertility: Biochar helps retain key nutrients while reducing nutrient leaching, nitrogen losses minimized due to ammonium adsorption. Phosphorus & potassium released slowly from biochar, ensuring availability over time. Micronutrients enhance uptake of iron, copper, zinc—vital for plant metabolism.

In saline and sodic soils, biochar reduces sodium toxicity and enhances calcium and magnesium availability, improving plant water uptake and resilience.

Biochar for Soil Remediation and Pollution Control: One of biochar's most powerful applications lies in remediation of heavy metal toxicity. Its porous surface binds toxic metals and organic pollutants like: Polychlorinated biphenyls (PCBs), Chlorobenzene, P-nitrophenol, Diethyl phthalate. Its low-cost, eco-friendly nature makes biochar an ideal solution for cleaning contaminated soils affected by industrial or municipal waste.

Constraints and Considerations

Despite its benefits, biochar is not a magic bullet. Key limitations include; it may immobilize herbicides and nutrients. Increased bulk density, in some cases, it affects soil pore continuity. Phytotoxicity, poorly prepared biochar may contain harmful compounds. Dust Issues, fine particles can be lost through wind or water erosion. Permanent soil presence, once applied, it cannot be easily removed. Moreover, not all feedstocks are suitable. Biochar quality depends heavily on raw material and pyrolysis conditions. Some may be poor in nutrients or degrade too quickly in soil.

Conclusion

Biochar stands out as a multi-functional, climate-smart technology. When produced and applied correctly, it improves soil structure and fertility, enhances crop productivity, sequesters carbon, reduces environmental pollution, supports sustainable nutrient cycling. Given its versatility and sustainability, biochar is a powerful ally in the fight against climate change and soil degradation. However, for it to reach its full potential, collaboration is essential—between farmers, researchers, soil scientists, and policymakers. With thoughtful application and ongoing research, biochar can help rewrite the future of agriculture—from degraded soils to thriving, resilient ecosystems.

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