

Biochar-Driven Enhancements in Soil Fertility and Agricultural Sustainability

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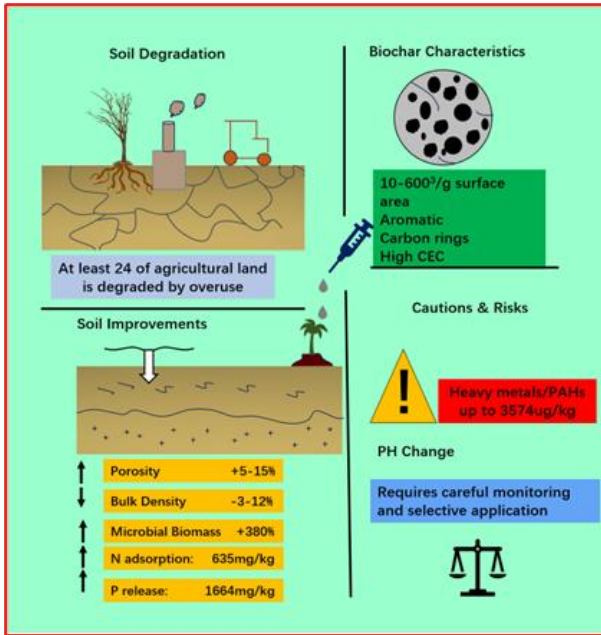
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Abstract

Soil degradation driven by climate change, deforestation, and unsustainable agriculture threatens global ecological resilience and food security. Current estimates suggest that at least 24% of the world's agricultural land is degraded by overuse, and this proportion is expected to increase in the coming years. This review presents advances in biochar as a soil amendment, emphasizing its structural, chemical, and biological impacts on soil fertility. Biochar possesses a highly porous structure with a specific surface area ranging from 10 to 800 m² per gram, featuring resilient aromatic carbon frameworks and effective nutrient-holding capabilities. Empirical studies reveal that biochar amendments enhance soil porosity by 5–15%, reduce bulk density by 3–12%, and elevate microbial biomass by up to 380% in soils amended with *Miscanthus* straw biochar. Nutrient dynamics are markedly improved, with nitrogen adsorption capacities reaching 635 mg kg⁻¹ and phosphorus release rates as high as 1664 mg kg⁻¹, depending on feedstock and pyrolysis conditions. However, potential risks, including heavy metal retention (*e.g.*, PAH concentrations up to 3574 µg kg⁻¹ in amended soils) and pH alterations, necessitate judicious management. Collectively, this review positions biochar as a transformative tool for sustainable soil management, contingent upon context-specific application strategies and rigorous monitoring of long-term environmental impacts.

Table of Contents



Innovative Description: Biochar-engineered soil revival: Porous carbon unlocks fertility, microbes, and risk-aware sustainability.