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Biochar-amended soils for heavy metal immobilization in contaminated agricultural lands.

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Introduction

The contamination of agricultural soils with heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) has become a serious global concern. These toxic elements, often originating from industrial activities, mining, wastewater irrigation, and excessive agrochemical use, pose a threat to food safety, soil health, and ecosystem sustainability. Among various remediation strategies, biochar amendment has emerged as a promising, lows-cost, and sustainable approach for the immobilization of heavy metals in contaminated soils [1].

Biochar is a carbon-rich material produced by pyrolyzing organic biomass (such as crop residues, wood chips, or manure) under limited oxygen conditions. It has a highly porous structure, large surface area, and abundant functional groups, which make it effective in adsorbing a wide range of contaminants. Its chemical and physical properties can be tailored depending on feedstock type and pyrolysis conditions, making it a versatile tool for environmental remediation [2].

Biochar immobilizes heavy metals through several mechanisms: adsorption, ion exchange, complexation, precipitation, and surface electrostatic attraction. The negatively charged surface of biochar interacts with positively charged metal ions, reducing their mobility and bioavailability. Additionally, the high pH of most biochars promotes the precipitation of metals as insoluble hydroxides or carbonates. Functional groups such as carboxyl, hydroxyl, and phenolic moieties further enhance metal binding through complexation reactions [3].

Beyond metal immobilization, biochar offers agronomic benefits that improve soil quality. It enhances soil structure, water retention, cation exchange capacity (CEC), and microbial activity, which are often compromised in contaminated soils. These improvements support better plant growth and help restore the productivity of degraded agricultural lands. In particular, biochar's ability to increase soil pH can mitigate the toxicity of acidic soils where heavy metal solubility tends to be higher [4].

Numerous laboratory and field studies have demonstrated the effectiveness of biochar in reducing heavy metal availability. For example, biochar derived from rice husk and poultry litter has been shown to significantly reduce cadmium uptake in rice and leafy vegetables. In a long-term field trial in China, biochar application to lead-contaminated soil decreased Pb concentrations in maize grains by over 50%. These results underline the potential of biochar as both a soil amendment and a remediation agent [5].

Conclusion

Biochar-amended soils offer a practical and sustainable solution to the problem of heavy metal contamination in agricultural lands. By immobilizing toxic metals and improving soil health, biochar helps restore productivity and safeguard food security. While ongoing research continues to optimize its use, the integration of biochar into broader soil remediation strategies holds great potential for advancing environmental restoration and sustainable agriculture.

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