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Effectiveness and Mechanistic Analysis of Biochar-Based Remediation for Heavy Metal-Contaminated Soils

With the rapid advancement of industrialization and urbanization, heavy metal contamination has become one of the most severe types of soil pollution. The accumulation of heavy metals in soils not only threatens plant growth but also poses serious ecological risks through bioaccumulation in the food chain, ultimately affecting human health. Traditional remediation methods often face challenges such as high costs, low efficiency, and secondary pollution, necessitating the development of green and effective soil remediation materials and technologies.

Biochar, a carbon-rich porous material, has recently attracted significant attention for its excellent adsorption capacity and soil amendment properties in the remediation of heavy metal-contaminated soils. Biochar can effectively immobilize heavy metal ions in soils by physical adsorption, chemical complexation, ion exchange, and surface chelation, thereby reducing their bioavailability and mobility and mitigating environmental risks. Additionally, biochar application can improve soil physicochemical properties, stimulate microbial activity, and enhance soil self-purification capacity.

This study systematically evaluates the remediation efficacy of biochars derived from different feedstocks and preparation methods on typical heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), and chromium (Cr) in contaminated soils. Batch experiments and field trials will quantify biochar adsorption capacities and immobilization efficiencies. By assessing soil physicochemical parameters and plant growth indicators, the study will also investigate the impacts of biochar amendments on soil health and vegetation development. Advanced characterization techniques, including scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and X-ray photoelectron spectroscopy (XPS), will be employed to elucidate the interaction mechanisms between biochar and heavy metals, revealing pathways such as adsorption, complexation, and precipitation.

The findings will provide theoretical insights and technical support for the application of biochar in soil remediation, facilitating its engineering and large-scale deployment, and promoting green restoration and sustainable utilization of polluted soils.