Supplementary Information

Table S1 Mechanisms and Pros and Cons of Soil Remediation Techniques for As and Cd Co-Contaminated Farmland

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Remediation technology	Technical mechanism	Technical advantage	Technical defect
Water management	By dynamically adjusting the soil pH and Eh through alternate drying and wetting of rice fields, precise decisions regarding irrigation timing and quantity can be made. Controlling the pH to 6.2 and the Eh to -73 mV minimizes the activity of both arsenic (As) and cadmium (Cd).	This technology is mature, relatively low-cost, and minimally disturbs the soil's physical and chemical properties. It is optimal for controlling single heavy metals but requires precise regulation for addressing composite pollution.	In field management, maintaining constant pH and Eh levels is nearly impossible, and achieving precise water management is challenging for ordinary farmers.
mixing of soil	Deep plowing can be used to turn the top 30 cm of soil contaminated with heavy metals to the lower layers, thereby reducing the heavy metal content in the cultivated soil	This method is simple to implement and suitable for large-scale application.	This method cannot fundamentally solve the problem of soil contamination, and deep plowing may lead to groundwater pollution.
Soil washing	Chemical reagents and surfactants can be used to leach heavy metals from soil aggregates, directly reducing the heavy metal content in the soil.	This method can quickly reduce the heavy metal content in soil with high removal efficiency and is currently widely used in industrial site remediation.	It is challenging to obtain a chemical leaching agent capable of simultaneously removing both As and Cd. The leaching method can damage the soil's physical and chemical properties and microbial

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			communities. Furthermore, the chemical leaching solution may infiltrate and contaminate groundwater and surface water, causing secondary pollution.
Electrochemistry	By applying an external electric field to create a localized electromagnetic field in the soil, electrophoresis and electroosmosis techniques can be used to attract or drive heavy metals away from plant roots.	By utilizing the anode and cathode to attract As and Cd directionally, these heavy metals can be rapidly removed. This method is particularly effective for soils with severe contamination over a localized area.	This technology is energy-intensive and generates significant amounts of acidic and alkaline by-products near the electrodes, which can damage them. There are few reports of its application in large-scale, low-concentration As and Cd composite contamination in farmland.
Heavy metal super accumulator plants	Hyperaccumulating plants can selectively absorb and transport As and Cd, thereby reducing the total concentration of these heavy metals in the soil	This approach can fundamentally reduce the concentrations of As and Cd in the soil with minimal impact on its physical and chemical properties. Recent reports indicate that hyperaccumulating plants offer significant remediation effects and	This method involves a lengthy cycle, particularly due to the extended breeding period for hyperaccumulating crops. Cultivating these plants in different locations can make it challenging for them to become dominant species locally. Additionally, it is difficult to reconcile

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		provide an environmentally friendly solution for heavy metal contamination in soil.	with the concept of simultaneous production and remediation.
In-Situ Soil Passivates	Soil heavy metal passivation technology is a remediation method aimed at mitigating heavy metal contamination. The core objective of this technology is to modify the speciation of heavy metals in the soil by introducing specific substances or treatment methods, thereby reducing their bioavailability and minimizing their adverse impacts on the environment and ecosystem. The implementation of this technology aims to decrease the toxicity of heavy metals in the soil, prevent their uptake by plants, and avoid contamination of water bodies and the food chain, ultimately enhancing soil safety and sustainability.	This method contributes to maintaining ecological balance by altering the chemical forms of heavy metals in the soil, which reduces their bioavailability and mitigates their toxic effects on ecosystems and crops. It is relatively low-cost, making it economically feasible for large-scale applications. The method is broadly applicable and highly flexible, supporting the development of integrated remediation strategies and	This method does not fundamentally reduce the total concentration of heavy metals in the soil. Its effectiveness can vary depending on different soil environments and types of heavy metals. The passivation process may alter soil pH, potentially affecting the soil ecosystem. Additionally, there is a risk of diminishing remediation effectiveness over time. Simultaneous passivation of both As and Cd requires the development of new, cost-intensive synergistic passivation agents. Moreover, there is a risk of secondary release of passivated

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	Common passivation techniques include the addition of specialized remediation agents and adjustments to soil pH to improve soil quality and reduce heavy metal mobility and accumulation.	improving overall remediation effectiveness.	materials as time progresses.
Foliar Spraying Agents	Leaf surface passivation technology is a remediation method for addressing heavy metal contamination. It involves applying physiological antagonistic elements, humic acids, and other physiologically active substances to plant leaves. This approach regulates and restricts the transport and distribution of heavy metals within the plant, thereby reducing their accumulation in edible parts and enhancing the safety and quality of agricultural products.	This technology is easy to implement, environmentally friendly, and relatively cost-effective. It demonstrates significant passivation effects and can also enhance crop yields when applied appropriately. In the context of escalating environmental pollution, leaf surface passivation technology has emerged as a crucial method for the safe utilization of heavy metal-	The efficiency of this method is limited. High concentrations of inorganic foliar passivation agents can cause leaf burn, negatively impacting photosynthetic efficiency, while low concentrations of foliar fertilizers may not provide effective passivation. Furthermore, the effectiveness of this method varies depending on the crop and soil type.

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		contaminated farmland. The rapid advancement of drone technology has further reduced the cost of leaf spraying techniques, leading to their widespread adoption in agricultural production.	