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# Heavy metal contamination in agricultural soils: Strategies, Challenges

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**Introduction:**

Soil heavy metal pollution is a global environmental challenge, posing significant threats to eco-environment, agricultural development, and human health. In recent years, advanced and effective remediation strategies for heavy metal-contaminated soils have developed rapidly, and a systematical summarization of this progress is important. In this, the anthropogenic sources of heavy metals in agricultural soils, including atmospheric deposition, animal manure, mineral fertilizers, and pesticides, are summarized. Second, the accumulation of heavy metals in crops as influenced by the plant characteristics and soil factors is analyzed. Then, the reducing strategies, including low-metal cultivar selection/breeding, physiological blocking, water management, and soil amendment are evaluated. Finally, the phytoremediation in terms of remediation efficiency and applicability is discussed. Therefore, this review provides helpful guidance for better selection and development of the control/remediation technologies for heavy metal-contaminated agricultural soils (Rai *et al.*, 2019).

**Sources of Heavy Metal in Agricultural Soils**

Heavy metals enter the soil in two ways: Natural activities and anthropogenic activities.


**Fig 1 Main sources of heavy metals in agricultural soils**

Natural activities include pedogenic processes (high background) and volcanoes and forest fires; anthropogenic sources

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include mining, smelting, transportation, and agricultural activities, which are considered the major causes of heavy metal contamination in soil.

Besides high background regions, the main inputs of heavy metals to agricultural lands are atmospheric deposition, sewage irrigation, sewage sludge, animal manure, mineral fertilizers, and pesticides (Figure 1), among which, atmospheric deposition is considered the predominant contributor to agricultural soils, especially in more industrial countries such as China and the UK (Nicholson *et al.*, 2013).

**Factors Affecting Heavy Metal Accumulation in Crops**

The uptake and accumulation of heavy metals in plants depend both on plant physiological features and soil components, including soil pH, redox potential (Eh), organic matter content (OM), clay content, and cation exchange capacity (CEC) (Figure 2). Great differences in metal absorption, translocation, and distribution among and within plant species have been observed, even when planted in the same contaminated site. Generally, leafy, stem, and bulb vegetables accumulate higher contents of heavy metals (such as Cd, Cu, and Pb) in their edible parts than melon, fruit, and bean vegetables (Alexander *et al.*, 2006).

Heavy metals in the soil exist in various forms, and not all of them are available for plants. Soil pH is considered the key factor controlling the solubility and mobility of heavy metals in soil, and thereby their uptake by plants. In several studies, the availability of cationic metals in plants was

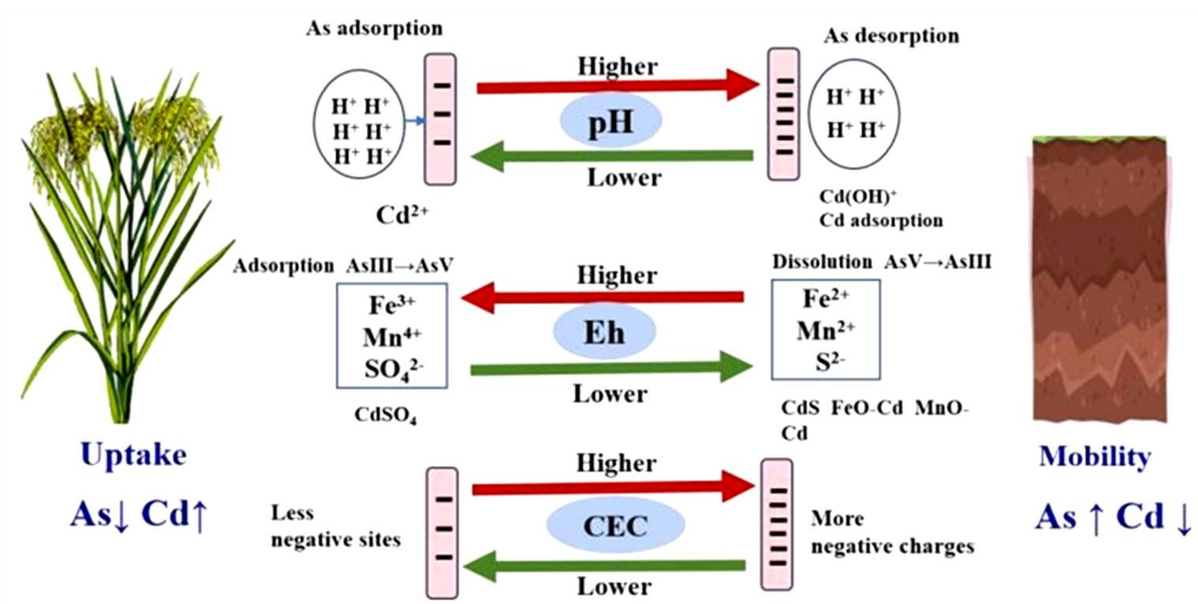



**Fig 2 Mechanisms of heavy metal mobility in the soil are affected by soil factors**

negatively correlated with soil pH (Mu *et al.*, 2023).

**Strategies to Reduce Heavy Metal Accumulation in Crops**

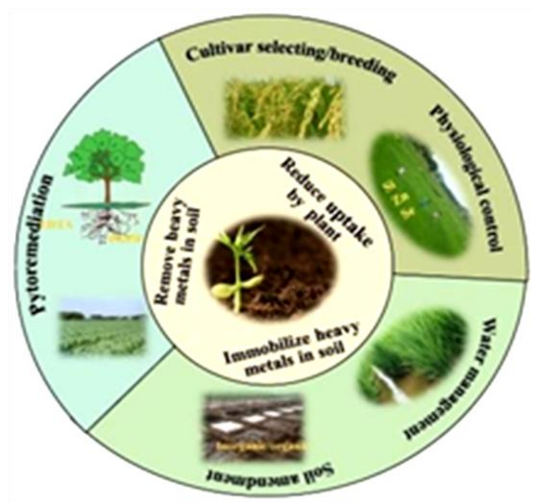
To minimize heavy metal exposure to humans, effective measures should be taken to reduce the uptake of heavy metals by crops and immobilize or remove heavy metals from the soil. These measures mainly include (1) low-metal cultivar selection/breeding; (2) physiological blocking; (3) water management; (4) soil amendment; and (5) phytoremediation.

**1. Low-Metal Cultivars Selecting/Breeding**

To reduce the entry of heavy metals into the food chain, alternative food crops or cash crops with low heavy metal accumulation could be planted. However, alternative planting has not been commonly practiced, especially on large scales, due to the difficult to face in changing their agricultural habits. Nevertheless, low-metal cultivars are proposed as an economical and environmentally friendly approach to address the low-to-medium heavy metal-contaminated farmland (Liu *et al.*, 2020).

2. **Physiological Blocking**

Mineral nutrients are essential in the process of gene expression, photosynthesis, metabolism, and other activities of plants, and the deficiency of macro- or micro-elements could lead to a negative influence on plant growth and development. Meanwhile, mineral elements can also alleviate heavy metal accumulation and toxicity in plants by alleviating oxidative stress, restoring cell membrane integrity, enhancing photosynthesis, balancing the uptake of essential nutrients, and regulating the uptake, translocation, distribution, and speciation of heavy metals in plants (Riaz *et al.*, 2021).




**3. Soil Amendment**

In situ immobilization and stabilization are considered economical and effective techniques to reduce the bioavailability of heavy metals in contaminated soil. In recent decades, inorganic and organic soil amendments, such as lime, phosphate minerals, clay minerals, biochar, and livestock manure, have been widely used for soil control and remediation.

**4. Phytoremediation**

Soil phytoremediation refers to the utilization of certain heavy metal accumulating

| Type | Material | Metal | Mechanism |
| --- | --- | --- | --- |
| Lime | CaO, $CaCO_3$, $Ca(OH)_2$ | Cd, Pb, Zn, Cu | Increase soil pH |
| Phosphate mineral | Phosphate, phosphate rock powder, hydroxyapatite | Cd, Pb, Zn, Cu, Ni, Hg, Cr, As | Electrostatic interaction, ion exchange, surface complexation, precipitation, etc. |
| Clay mineral | Sepiolite, kaolinite attapulgite, bentonite | Cd, Pb, Zn, Cu | Complexation, lattice diffusion, and isomorphic substitution |
| Biochar | Wood/crop residues based biochar | Cd, Pb, Zn, Cu | Increase soil pH, cation-π interaction, electrostatic attraction, ion exchange, complexation, and precipitation |
| Organic fertilizer | Manure, compost | Cd, Pb | Increase soil pH, complexation, adsorption, and precipitation |

plants to reduce the metal content or alleviate the toxic effects in the soils, which is an eco-friendly and sustainable approach to restoring contaminated land. Among various phytoremediation techniques (phytoextraction, rhizofiltration, Phyto stabilization, and phytovolatilization).

**Conclusions**

In this study, current soil control and remediation strategies for heavy metal-contaminated agricultural soils are summarized, including low-metal cultivar selection/breeding, physiological blocking, water management, soil amendment, and phytoremediation. The application of these technologies is relatively mature, but there are some limitations.

**References**

1. Rai, P.K.; Lee, S.S.; Zhang, M.; Tsang, Y.F.; Kim, K.H. Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environ. Int. 2019, 125, 365–385.
2. Nicholson, F.A.; Smith, S.R.; Alloway, B.J.; Carlton-Smith, C.; Chambers, B.J. An inventory of heavy metals inputs to agricultural soils in England and Wales. Sci. Total Environ. 2003, 311, 205–219.
3. Alexander, P.D.; Alloway, B.J.; Dourado, A.M. Genotypic variations in the accumulation of Cd, Cu, Pb and Zn exhibited by six commonly grown vegetables. Environ. Pollut. 2006, 144, 736–745.
4. Mu, D.; Zheng, S.; Lin, D.; Xu, Y.; Dong, R.; Pei, P.; Sun, Y. Derivation and validation of soil cadmium thresholds for the safe farmland production of vegetables in high geological background area. Sci. Total Environ. 2023, 873, 162171.

5. Liu, N.; Huang, X.; Sun, L.; Li, S.; Chen, Y.; Cao, X.; Wang, W.; Dai, J.; Rinnan, R. Screening stably low cadmium and moderately high micronutrients wheat cultivars under three different agricultural environments of China. Chemosphere 2020, 241, 125065.
6. Riaz, M.; Kamran, M.; Rizwan, M.; Ali, S.; Parveen, A.; Malik, Z.; Wang, X. Cadmium uptake and translocation: Synergetic roles of selenium and silicon in Cd detoxification for the production of low Cd crops: A critical review. Chemosphere 2021, 273, 129690.