

# Screening amendment performance for diffuse metal immobilization and soil quality recovery in micro-plots with *Lolium perenne*

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Diffuse accumulation of heavy metals in soils has become an increasingly relevant environmental issue, particularly in agricultural and peri-urban landscapes affected by long-term, low-intensity inputs from fertilizers, atmospheric deposition, irrigation water, and organic residues. Unlike point-source contamination, diffuse metal accumulation is often difficult to detect and manage, yet it poses significant risks due to the persistence, toxicity, and potential bioaccumulation of metals such as cadmium, cobalt, manganese, lithium, and boron (Angon et al., 2024). These elements can impair soil biological activity, reduce crop productivity, and ultimately threaten food safety through gradual entry into the food chain. Addressing this challenge requires remediation strategies that are not only effective in reducing metal mobility but also compatible with soil fertility restoration and sustainable land management (Serrano et al., 2023).

Traditional remediation approaches, including soil excavation, washing, or chemical stabilization, are often economically prohibitive and environmentally disruptive, particularly when applied to large areas with diffuse contamination. In response, nature-based and low-impact strategies such as phytoremediation have gained increasing attention (Acosta-Luque et al., 2022). However, classical phytoextraction may enhance metal uptake and translocation to shoots, potentially increasing risks if biomass is not properly managed. As an alternative, assisted phytoremediation and phytostabilization strategies, which combine tolerant plant species with soil amendments, aim to immobilize metals in situ while simultaneously improving soil physicochemical properties and biological functioning (Becerra-Agudelo et al., 2022). Organic soil amendments have been widely proposed as tools to enhance metal immobilization through mechanisms such as pH adjustment, complexation, sorption, and increased cation exchange capacity. Nevertheless, the performance of different amendments is highly context-dependent and metal-specific, and comparative experimental evidence under low-fertility soil conditions remains limited (López & Saldarriaga, 2023).

There is a need to better understand how different organic amendments influence metal bioavailability, soil fertility indicators, and plant uptake patterns when applied under controlled yet realistic conditions. The present study addresses this knowledge gap by evaluating the effectiveness of amendment-assisted phytoremediation using *Lolium perenne* as a model grass species combined with five organic amendments: biochar, compost, humus, poultry manure, and vermicompost. The primary objective was to identify which amendment or group of amendments most effectively promotes diffuse metal immobilization while contributing to soil fertility recovery in degraded, low-fertility soils. By adopting a comparative micro-plot approach, the study aims to provide practical insights for site-specific amendment selection in sustainable soil management frameworks.

A factorial experiment was conducted under controlled environmental conditions over a period of 45 days. Micro-plots were prepared using a low-fertility soil and amended with the selected organic materials at predefined application rates. *Lolium perenne* was established in all treatments to evaluate plant–soil–amendment interactions. Throughout the experimental period, key soil physicochemical parameters were monitored, including pH, electrical conductivity, organic matter content, and cation exchange capacity. Metal bioavailability in soil was assessed to determine changes in mobility induced by the amendments. In parallel, plant growth parameters were measured, and metal concentrations were quantified separately in roots and shoots to assess accumulation patterns and translocation behaviour.

The results revealed that organic amendments exerted differentiated and metal-specific effects on both soil properties and metal immobilization. Biochar exhibited the highest immobilization efficiency for cadmium and lithium, likely due to its alkaline nature, high surface area, and strong sorption capacity. In contrast, compost and humus showed superior performance in retaining boron and cobalt, highlighting the role of organic functional groups and complexation mechanisms. Poultry manure and vermicompost contributed to improvements in soil fertility indicators but displayed more variable effects on metal immobilization, emphasizing the importance of amendment composition and maturity. Across treatments, most amendments induced increases in soil pH, organic matter content, and cation exchange capacity, reflecting an overall enhancement of soil fertility conditions.

However, not all observed changes were statistically significant, underscoring the short experimental duration and the inherent variability of biological systems. Electrical conductivity increased notably in biochar-amended soils, indicating a potential risk of salinity-related effects if application rates are not carefully managed.

This finding highlights the need for dosage optimization when biochar is used in fertility recovery strategies. Plant tissue analysis showed that cadmium, cobalt, and manganese accumulated predominantly in root systems rather than in aboveground biomass.

This root retention pattern suggests a phytostabilization mechanism that limits metal translocation to shoots and reduces the risk of entry into the food chain. Such behaviour is particularly desirable in agricultural contexts, where minimizing metal concentrations in edible plant parts is a critical concern. The combination of *Lolium perenne* with selected organic amendments therefore appears to support a defensive retention strategy rather than active phytoextraction. Taken together, the findings demonstrate that amendment-assisted phytoremediation represents a promising and environmentally sound approach for managing soils affected by diffuse metal accumulation while simultaneously restoring fertility. The effectiveness of this strategy is strongly influenced by amendment type and metal-specific interactions, reinforcing the need for tailored, site-adapted solutions rather than generic remediation prescriptions. This study contributes experimental evidence supporting the targeted use of organic amendments within integrated soil restoration frameworks and provides a basis for developing sustainable management strategies that balance productivity, environmental protection, and long-term soil health.

## References

- Acosta-Luque, M., López, J., Henao, N., Zapata, D., Giraldo, J., & Saldarriaga, J. (2022). Remediation of Pb-contaminated soil using Biochar-Based Slow-Release P Fertilizer and biomonitoring employing bioindicators. *Scientific Reports*. <https://doi.org/10.21203/RS.3.RS-2289314/V1>
- Angon, P. B., Islam, M. S., KC, S., Das, A., Anjum, N., Poudel, A., & Suchi, S. A. (2024). Sources, effects and present perspectives of heavy metals contamination: Soil, plants and human food chain. *Heliyon*, *10*(7), e28357. <https://doi.org/10.1016/J.HELIYON.2024.E28357>
- Becerra-Agudelo, E., López, J. E., Betancur-García, H., Carbal-Guerra, J., Torres-Hernández, M., & Saldarriaga, J. F. (2022). Assessment of the application of two amendments (lime and biochar) on the acidification and bioavailability of Ni in a Ni-contaminated agricultural soils of northern Colombia. *Heliyon*, *8*(8), e10221. <https://doi.org/10.1016/J.HELIYON.2022.E10221>
- López, J. E., & Saldarriaga, J. F. (2023). Surface Co-application of Dolomitic Lime with Either Biochar or Compost Changes the Fractionation of Cd in the Soil and Its Uptake by Cacao Seedlings. *Journal of Soil Science and Plant Nutrition*, *1*, 1–11. <https://doi.org/10.1007/S42729-023-01469-Z/FIGURES/5>
- Serrano, M. F., López, J. E., Henao, N., & Saldarriaga, J. F. (2023). Phosphorus-Loaded Biochar-Assisted Phytoremediation to Immobilize Cadmium, Chromium, and Lead in Soils. *ACS Omega*. [https://doi.org/10.1021/ACSOMEGA.3C07433/ASSET/IMAGES/LARGE/AO3C07433\\_0012.JPEG](https://doi.org/10.1021/ACSOMEGA.3C07433/ASSET/IMAGES/LARGE/AO3C07433_0012.JPEG)