Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.35833

Environmental Reliability of Phytostabilization on Sulfidic Mine Tailings: Informed by a Greenhouse Study

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Sulfidic mine tailings contain sulfide minerals that has the potential to undergo acid rock drainage and metal leaching (ARD/ML) and releasing toxic elements, such as As, Cu, Pb and Zn, to the soil and groundwater environment. Thus, reclamation of sulfidic mine tailings is important to prevent toxic elements from being released to the surrounding environment. While phytostabilization, one technique of phytoreclamation, is proposed as a cost-effective alternative to engineered cover systems, its regulatory acceptance depends on demonstrable long-term environmental reliability. This study evaluates the efficiency and reliability of phytostabilization by analysing plant metal uptake, metal stabilization, substrate geochemical evolution, and drainage quality over a complete growth cycle of grass species by a greenhouse experiment. The greenhouse experiment, using sulfidic tailings amended with combinations of bauxite residue (BR), lime (L), and compost (C), demonstrates that initial immobilization of As, Cu, and Pb was highly effective, with over 97% of these metals successfully stabilized within the rhizosphere which is an extremely active zone of soil-roots interactions including inorganic geochemical reactions and microbial activities. However, data revealed a geochemical threshold at approximately 6th–8th week during the experiment, where alkalinity depletion triggered a resurgence in metal mobility, particularly for Zn. Notably, compost amendment enhanced Zn leachability to 9%–15% in drainage, highlighting a specific geochemical risk for phytostabilization application at zinc-rich legacy sites. This research reveals the geochemical mechanism that can enhance the metal stabilization and environmental reliability of phytostabilization on sulfidic mine tailings in the short-term, and further suggests that source-control measures should be applied dynamically to mitigate metal release over the long-term within a broader closure strategy. This study provides insights for care and maintenance and adaptive management plans when considering phytostabilization for tailings reclamation, integrating scheduled maintenance and monitoring of geochemical triggers to ensure long-term geochemical stability, and regulatory compliance in complex mine closure projects.