Lessons from long-term field phytostabilisation studies

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Abstract
Smelter waste deposits or soils near smelters that are heavily polluted pose a threat to environment and human health worldwide. There is limited availability of long-term phytostabilization field studies evaluating and documenting persistence of tested remediation methods. The paper combines experience from greenhouse testing of most effective soil amendments and long-term field experiments aimed at optimizing phytostabilisation of toxic smelter waste deposits. We compared the impact of novel soil amendments and their combinations with traditional materials on metal solubility and the response of plants, soil organisms and microbial activity. Field evaluations involved long-term smelter wasteland site reclaimed with biosolids and by-product limestone combined with implementation of resistant grass species. The data on metal extractability and bioavailability, plant cover, microbial activity, abundance and biodiversity is presented.
Keywords: gentle remediation, smelter wasteland, soil amendments, trace elements

1. Introduction

High content of trace elements (TE) in soils and wastelands can lead to serious risks for human health and ecosystems through root exposure, plant uptake and accumulation and leaching from soil. Since these risks are not only related to the total TE concentrations in soil but also to the labile ("bioavailable") fraction several management strategies or gentle remediation options (GRO) have been developed with the aim of decreasing TE mobility, bioavailability and bioaccessibility in the soil, thus avoiding their entrance in excess into plants or further spread through the environment (Mench et al., 2010). A well-developed plant cover protects the contaminated soil from wind and water erosion, also reducing water percolation through the soil and leaching of TE. TE can be stabilized in soil by amendments increasing metal adsorption or altering their chemical form. Few experiments compare different amendments under similar environmental conditions, or consider whether all soil properties or functions (microbes, soil fauna, plant growth, retention, colloid stability, etc.) are similarly protected.

2. Materials and Methods

2.1. Greenhouse pot studies

One-year greenhouse pot experiment was established on toxic soil contaminated through smelter dust spill (pH 6.8). Amendments were tested individually and in novel combinations in planted and unplanted soils: compost (GWDA), drinking water residue (DWR), iron grit (IG), Ca-phosphate (PO4), LD slag (LD), Thomas basic slag (TBS), gravel sludge and siderite (GS/SID) and cyclonic ash (CA). Soil was planted with tall fescue. Soil metal extractability and bioaccessibility, pH, EC and enzymatic activity were measured. Soil pore waters were analysed for trace element/nutrient concentrations.

Parallel tests evaluated earthworm behaviour and metal accumulation. Earthworms *Eisenia veneta* were put into jars – five earthworms (previously weighed to record the initial weight) to each jar. Earthworms were removed from the soil after 4 weeks, weighted and analysed for metals content with inductively coupled plasma mass spectrometry (ICP-MS, AGILENT 7500CE) after dissolving in concentrated nitric acid.

2.2. Long-term field experiment

In order to test the effectiveness of various rates of biosolids and by-product lime in the reclamation of Zn and Pb smelter wasteland a field experiment was established in 1996 at the site located in Piekary Slaskie, Poland. The waste was still very high in Zn, Pb (several % content of both metals) and Cd. The site was barren of vegetation constituting a substantial environmental hazard through wind-blown metal dust, metal leaching to ground and surface waters.

Six different treatments of the top layer were applied in the plot experiment and compared with the untreated control: LB - lower biosolids (150 t ha^{-1}), HB – higher biosolids rate (300 t ha^{-1}), LB-LL - lower biosolids (150 t ha^{-1}) and lower lime (100 t ha^{-1}) rates, HB-LL - higher biosolids rate (300 t ha^{-1}) and lower lime (100 t ha^{-1}) rates, LB-HL - lower biosolids (150 t ha^{-1}) and higher lime (1000 t ha^{-1}) rates, HB-HL - higher biosolids (300 t ha^{-1}) and higher lime (1000 t ha^{-1}) rates.

The surface layer was sampled in 2016 for measuring chemical and biochemical parameters. Microbial processes were characterised by enzyme activities, abundance of specific groups of microorganisms and identification of N fixing bacteria. Plant communities of the area were characterised by a percent coverage of the surface and by a composition of plant species and plant diversity.

3. Results

3.1. Comparison of soil amendments

Soil was phytotoxic when untreated. Similarly liming as separate amendment did not allow for establishment of any significant grass growth. The highest yield was produced in pots amended with combinations of compost: GWDA/ IG/LD and GWDA/PO4/DWR (1st harvest) or GS/SID/GWDA (2nd harvest). None of tested materials was fully effective as single amendment. Limited effectiveness of compost applied separately was partly related to pH drop due to acidification. All amendments reduced Zn and Cd solubility, measured by NH_4-nitrate extraction, comparing to control soil. Most effective in limiting their solubility were combinations based on DWR and GWDA. Combinations of iron grit and compost were most successful in limiting Zn accumulation in tall fescue shoots whereas combinations of DWR and compost reduced Cd translocation most effectively. Cd accumulation in earthworm tissues was reduced in soil amended with combination of IG or DWR and GWDA. Biochemical activity of contaminated soils was generally significantly improved by amendments involving iron grit and GWDA compost.

3.2. Persistence of remediation at field conditions

The long-term field experiment proved that the incorporation of high rates of biosolids and by-product lime enables the establishment of a persistent plant cover that exhibits high diversity 20 years after reclamation (Fig. 1). The plant cover consisted of original grass species, such as *F. rubra, P. pratensis, F. arundinacea, F. ovina* and *A. capillaris* and numerous spontaneous species, mainly dicot plants.

The functioning of the phytostabilized system is supported by overall microbial activity and an abundance of various groups of microorganisms - highest number when combinations of biosolids and lime were applied. Nitrogen cycling in the top layer of the wasteland, which has not been fertilised since the original treatment in 1996, is sustained by the activity of ammonification and non-symbiotic N fixing bacteria. They were highly abundant in the plots treated with both biosolids and by-product lime (Siebielec et al., 2018)

Figure 1. Revegetated smelter wasteland 20 years after the reclamation

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