The Potential Consequences of the Hungarian Red Mud Disaster for Soil

S. Ruyters, J. Mertens and E. Smolders

Department of Earth and Environmental Sciences, Division of Soil and Water Management, K.U.Leuven, Arenberg Kasteelpark 20, 3001 Heverlee, Belgium; stefan.ruyters@ees.kuleuven.be; Tel. +32 16321630

Key Words: Hungary; Plant Toxicity; Red mud; Trace metal bioavailability

Abstract

In October 2010 a dam of a waste reservoir of the Hungarian Aluminium Cooperation broke resulting in a red mud (pH=12) spill across the Torna river flooding the cities of Devecser and Kolontar in Hungary. Approximately 800 ha of land have been contaminated with red mud. Red mud was characterized and its toxicity for plants was measured to evaluate the soil contamination risks. Increasing red mud doses were mixed into the soil up to a 16.5% dry weight fraction resulting in a maximal soil pH increase of 1.7 units. Plant toxicity and trace metal availability were determined and a reference experiment was set up with NaOH dose soil to reach the same pH. Trace element concentrations in plant shoots (Cu, Cr, Ni, B and Fe) increased significantly with increasing red mud dose, but were well below phytotoxicity thresholds. Nevertheless, plant growth was significantly decreased at the two highest doses due to increased Na uptake. Plant growth was also impaired in leached soil mixtures and in NaOH amended soils due to Na stress. It is concluded that the salinity of the red mud, not trace metals, is the main ecological concern regarding the Hungarian red mud disaster.

Introduction

On October 4, 2010, the western dam of the sludge reservoir of an alumina plant in Ajka (Hungary) collapsed flooding the valley of the Torna river. Along with the human tragedy, rivers and land (800 ha) have been contaminated with red mud. Incorporating the remaining of the red mud after removal of the largest deposits at the surface into the soil is a considered remediation method. Via the Bayer process aluminium is extracted from bauxite ores resulting in red mud as waste-product. Red mud has an alkaline pH (9-12), contains residual minerals such as hematite (Fe_2O_3), goethite (α-FeOOH), boehmite (γ-AlOOH) or quartz (SiO_2) and has a fine particle size distribution (mostly <10 µm). The concentrations of residual minerals and trace elements (e.g. As, Cr, Cd, Ni, Pb, Zn) depend on the composition of the bauxite ore (Wang et al., 2008).

It is predictable that the adverse effect of red mud in soil relates to (i) its high sodium (Na) content and its fine structure, both deteriorating soil structure and (ii) plant toxicity due to salinity, alkalinity and high soluble Al concentrations. In addition, red mud may contain trace metals at concentrations above regulatory soil limits. However, several studies have shown positive effects of (pretreated) red mud application in soil (typically 5% w w^{-1}) for remediation of trace metal contaminated soil due to adsorption on Fe and Al oxyhydroxides and soil (e.g. Lombi et al., 2002).

This study was setup to monitor the short and potential long-term ecological effects of the Hungarian red mud disaster by analyzing the plant growth and plant composition in red mud contaminated soil.

Materials and Methods

An uncontaminated soil near the red mud contaminated area was mixed with increasing red mud doses (0.1-16.5 dry weight%) with or without leaching the mixtures with artificial rain water. This corresponds to incorporating a red mud layer of maximum 10 cm in the first 30 cm soil. Leaching simulates on a short term the effect of rain fall on the red mud toxicity. Additionally, a NaOH reference series was created by amending soil with increasing concentrations NaOH 1M.

Real total (concentrated HNO_3, $HClO_4$ and HF followed by dissolution in HCl 2.5 M) and *aqua regia* soluble (concentrated HCl and HNO_3) metal concentrations in red mud and soil were determined by ICP-OES. $CaCl_2$ 0.01M extractable metal concentrations were determined in red mud dosed soils. The standard test ISO 11269-1 and ISO 11269-2 used summer barley (*Hordeum vulgare* L.) as test species for the root elongation and plant growth test. Plants were *aqua regia* digested to determine the plant composition.

Results

The pH of the red mud was 12. Mixing the red mud into the soil resulted in a maximum pH increase in soil of 1.7 units (from 6.8 to 8.5). Selected trace metal concentrations in the red mud are given in Table 1 and are well above Hungarian soil limits for some elements. In addition, red mud consisted of 20% Fe, 7.5% Al, 6% Ca and 4.3% Na. Mixing in soil resulted in up to 70 times higher Na concentrations in $CaCl_2$ soil extracts. Root elongation showed no decrease with increasing red mud dose. In contrast, plant growth was significantly lower in the soils amended with the two highest red mud doses (Figure 1 A). Similar results were observed in the series leached with artificial rain water (Figure 1 B), however, root elongation was inhibited at the largest dose, probably due to loss of soil structure. Trace element concentrations in plant shoots (Cu, Cr, Ni, B and Fe) increased significantly with increasing red mud dose. Shoot Cd, Zn, Mn and Pb concentrations did not increase with increasing red mud dose. Plant growth was similarly impaired in the NaOH reference series suggesting that red mud application decreased plant growth through increased Na concentrations or pH, rather than increased trace metal concentrations.

Discussion

Large red mud concentrations impaired plant growth and rain water application did not remove toxicity. Even though increasing with increasing red mud dose trace metal concentrations in plant shoots were low. Plant toxicity is due to increased Na uptake, since concentrations in affected plants exceeded reported Na toxicity thresholds (0.8%). Therefore, remediation of the Hungarian land area contaminated by the red mud disaster should focus on removing salinity. Incorporating red mud into the soil may be accompanied by gypsum application (Courtney and Timpson, 2004), since it will restore soil structure, resulting in increased Na leaching due to rain fall on the long term.

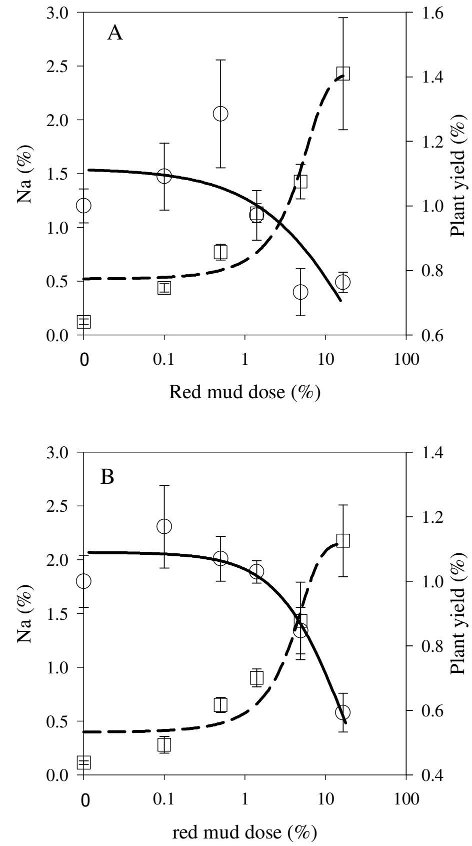

Figure 1: Plant yield (% relative to control) (circles) and Na concentration in plants (%) (squares) with increasing red mud dose in soil without leaching (A) or with leaching (B) the mixtures with artificial rain water (error bars denote standard deviation, n=4).

Table 2: Concentration of selected trace metals in the red mud as determined by real total and aqua regia digestion.

mg kg^{-1}	As	Cd	Co	Cr	Cr(VI)*	Cu	Hg	Ni	Pb	Zn
Real total	140	3.3	98	620	<0.1	52	1.7	290	160	130
Aqua Regia	5	1.3	64	560	nd	52	nd	268	158	105
Soil limits	15	1	30	75	nd	75	0.5	40	100	200

nd: not determined

References

R.G., Courtney, J.P., Timpson. 2004 Nutrient status of vegetation grown in alkaline bauxite processing residue amended with gypsum and thermally dried sewage sludge - A two year field study. Plant Soil 266, 187-194.

E. Lombi, F.J., Zhao, G.Y., Zhang, B., Sun W., Fitz, H., Zhang, S.P., McGrath. 2002 In situ fixation of metals in soils using bauxite residue: chemical assessment. Environ. Pollut. 118, 435-443.

S.B., Wang, H.M., Ang, M.O., Tade. 2008. Novel applications of red mud as coagulant, adsorbent and catalyst for environmentally benign processes. *Chemosphere 72*, 1621-1635.