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Influences of wetland plants on weathered acidic mine tailings

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Wetland plant establishment on acidic mine tailings may contribute to a reduced metal release and a stabilisation of pH.

Abstract

Establishment of *Carex rostrata*, *Eriophorum angustifolium* and *Phragmites australis* on weathered, acidic mine tailings (pH ~3) and their effect on pH in tailings were investigated in a field experiment. The amendments, sewage sludge and an ashes–sewage sludge mixture, were used as plant nutrition and their influence on the metal and As concentrations of plant shoots was analysed. An additional experiment was performed in greenhouse with *E. angustifolium* and sewage sludge as amendments in both weathered and unweathered tailings. After one year, plants grew better in amendments containing ashes in the field, also in those plants the metal and As shoot concentrations were generally lower than in other treatments. After two years, the only surviving plants were found in sewage sludge mixed with ashes. No effect on pH by plants was found in weathered acidic mine tailings in either field- or greenhouse experiment.
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Keywords: *Carex rostrata*; *Eriophorum angustifolium*; *Phragmites australis*; Weathered mine tailings

1. Introduction

Wetland plants have been found to be able to grow on unweathered water-covered mine tailings rich in sulphides (Wilkinson et al., 1999; Wright and Otte, 1999; Stoltz and Greger, 2002a). A vegetation cover on top of the tailings makes the impoundment more aesthetic and, in addition, may reduce the production of acid mine drainage (AMD) by elemental uptake and prevention of pH reduction (Stoltz and Greger, 2002a). The effects of a vegetation cover on weathered, acidic tailings have not been investigated so far.

Impoundments with old, weathered, sulphide-rich tailings create a more hostile environment for plants compared with unweathered tailings, since they are already acidic and their water has high concentrations of metals and As (Jung, 2001) due to oxidation of sulphides (Lowson, 1982; Holmström, 2000). However, plant establishment on weathered tailings might be possible by using a suitable amendment together with plant species that can cope with low pH and high metal and As concentrations. Some amendments that have been used to improve plant growth are sewage sludge and mixtures of sewage sludge and ashes (Borgegård and Rydin, 1989; Stoltz and Greger, 2002a). These types of amendments have been suggested since they are less expensive compared to other nutrient sources. The type of amendment added may have an impact on the uptake and translocation of elements, e.g. metals and As, in plants because the organic material in sewage sludge can bind metals and reduce their availability to plants (Stoltz and Greger, 2002a; Düring et al., 2003; Zhu et al., 2004). Amendments like ashes may reduce plant metal uptake even more, since ashes increase the pH of weathered tailings (Greger et al., 1998), which make metals even less mobile (Schnoor, 1996).

As a result of plants showing a buffering influence on pH in unweathered tailings (Stoltz and Greger, 2002a), it might be possible that plants could increase the pH in weathered tailings also. The mechanism behind the plant's ability to buffer the

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pH in Stoltz and Greger (2002a) was not found, but might have been due to release of buffering exudates by the roots, such as HCO_3^- and OH^- (Nye, 1981; Marschner and Römheld, 1983). Wetland plants that can survive in acidic environments are *Carex rostrata*, *Eriophorum angustifolium, Phragmites australis* and *Typha latifolia* (Nixdorf et al., 2001). All these species usually have lower element concentrations in the shoot than in the root when growing in metal-contaminated soil (Zhang et al., 1990; Stoltz and Greger, 2002a; Ye et al., 2003). For effective management of pollutants, plants established on mine tailings ought to have low translocation of metals and As to the shoot, otherwise the elements may be spread into the environment through grazing animals or at senescence.

The aim of this investigation was to determine if plant establishment by human intervention for remediation purposes is possible on weathered mine tailings with low pH. Furthermore, to determine if plant growth has an impact on the pH of the tailings, and to investigate the effect of the addition of different amendments on the pH as well as on the metal and As concentrations in shoots of the plants.

The first hypothesis was that plant establishment by human intervention on acidic weathered tailings is possible. The second hypothesis was that plants would have a similar buffering effect in weathered tailings as previously found in unweathered tailings; thus, plants would increase the pH of the weathered tailings. The third hypothesis was that the treatments with amendments containing ashes would additionally have a pH raising effect and thereby make the metals less mobile which would result in lower shoot metal uptake of the plants.

A field experiment at an old tailings impoundment with weathered, acidic tailings (pH ~3) was set up. Sewage sludge and a mixture of sewage sludge and ashes were used as amendments, since plant establishment in these treatments had been found successful previously (Stoltz and Greger, 2002a). Three wetland plant species that were common in the area were tested. Tailings were collected at two different depths at the field site, both above and below the weathering zone, in order to compare the effects of plants on the pH of weathered and unweathered tailings. The influence of the growth of one of the plant species was therefore studied on the two different tailings in a greenhouse experiment.

2. Materials and methods

2.1. Field experiment

The experiment was performed at a 50-year-old mine tailings impoundment with weathered tailings (pH 3), at the Boliden mine area in Northern Sweden (64° 52′ N, 20° 22′ E). The tailings were water-saturated and some parts were covered with a shallow (ca 0.1 m) water table. The weathered zone of the tailings was approximately 10–15 cm deep and was distinguished by the orange colour from oxidised iron, below that zone there were unweathered, dark grey tailings. The tailings were collected at different sites of the area and then mixed. Six samples of the mixed tailings were taken, dried at 80 °C, for 30 min in 7 mol L^{-1} HNO_3 at 120 °C to obtain the "total" fraction of As, Cd, Cu, Fe, Pb and Zn. Also one sample of each tailings was analysed with ICP-AES (inductively coupled plasma atomic emission spectroscopy) by SGAB Analytica, Sweden. The results of the tailings chemical characteristics, both weathered and unweathered, are shown in Table 1. The impoundment had some 'islands' of vegetation of *E. angustifolium* and *P. australis*, and these were avoided when the test plots (1 × 1 m) were laid out in rows over the area. The experiment set up was a randomised complete blocks design. The different treatments were randomly distributed among the plots. There were three different amendment treatments: controls (no amendments), addition of sewage sludge and the addition of sewage sludge mixed with ashes (1:2 v/v). On each amendment treatment 12 plants of either *C. rostrata* Stokes, *E. angustifolium* Honck. or *P. australis* (Cav) Steud. were planted, in addition there were plots without plants. There were five replicates of each treatment. The plants were collected from a tailings impoundment containing unweathered sulphidic tailings with natural plant establishment, close to the site of the experiment in the middle of the summer (July). The plants were inserted in the weathered zone of the tailings, approximately 5–10 cm below the surface. One month after the start of the experiment any dead plants were replaced with new ones.

One year after the start of the experiment, in the middle of the summer, pH (TRIODE™ pH electrode connected to a portable meter model 290A, Orion), dissolved O_2 (oxi-196, WTW), and redox potential were measured in the different plots. The electrodes were pushed down into the soft tailings (±amendments) in the centre of each plot and allowed to stabilise. For pH and O_2 measurements, the electrodes were slowly kept in motion during the measurement. The O_2 readings were taken after about 30 s. For redox potential, measurements were made at two depths (10 and 15 cm from the surface) with a Pt-electrode made according to Hagris and Twilley (1994), connected to a saturated Ag/AgCl double junction reference electrode (model 90-02, Thermo Orion) in a portable meter (model 290A, Orion). The electrodes were tested in quinhydrone and pH buffers according to Bohn (1971).

When the pH, O_2 and redox potential had been measured, the shoots of the plants in the plots were harvested, however, about 10 cm of the lower part of the shoots was left to ensure that the plants would survive and could be studied the next season; thus, the total biomass was not collected. The shoots were dried at 80 °C and thereafter weighed, wet digested in HNO_3:$HClO_4$ (7:3, v/v) and analysed for Fe, Cd, Zn, Cu and Pb with an atomic absorption spectrophotometer (Varian SpectrAA-100) using the flame technique. For As, the hydride vapour generation technique (VGA-77) was used. As plant reference material, energy grass (*Phalaris arundinaceae* L., reference material NJV 94-4, Swedish University of Agricultural Sciences) was used.

Two years after the start of the experiment, in the middle of the summer, pH and redox potential were measured in the plots in the same manner as done

Table 1
Chemical composition of weathered and unweathered mine tailings used in the experiment

	Weathered tailings [a](%DW)	Unweathered tailings [a](%DW)
SiO_2	41.5	39.1
Al_2O_3	8.89	11.1
CaO	3.6	3.88
Fe_2O_3	18.4	7.61
K_2O	2.08	1.69
MgO	5.42	6.79
MnO	0.0443	0.117
Na_2O	0.688	0.409
P_2O_5	0.106	0.345
TiO_2	0.392	0.307
S	5.0	7.9
	Weathered tailings [b](mg kg^{-1})	Unweathered tailings [b](mg kg^{-1})
As	2126 ± 314	1841 ± 257
Cd	3.9 ± 0.1	58.9 ± 1.9
Cu	233 ± 12	1414 ± 95
Fe × 10^3	171 ± 12	144 ± 10
Pb	1783 ± 186	2002 ± 73
Zn	355 ± 43	18 332 ± 1271

[a] ICP-AES, SGAB Analytica, $n = 1$.
[b] AAS, $n = 6$, ±SE.

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