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When liming and revegetation contribute to the mobilisation of metals: Learning lessons for the phytomanagement of metal-polluted wetlands

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ABSTRACT

The aim of this study was to identify the effectiveness of liming in combination with vegetation for the recovery of slightly acidic, saline soils of eutrophic wetlands affected by mine wastes, under fluctuating flooding conditions. Simulated soil profiles were constructed and four treatments were assayed under greenhouse conditions: control, only plant, only liming, and liming and plant. The plant species was the halophyte *Sarcocornia fruticosa*. Three horizons were differentiated: A (never under water), C1 (alternating flooding-drying conditions), and C2 (always under water). The pH, Eh, salinity, and the concentrations of dissolved organic carbon and soluble metals were measured regularly for 18 weeks. Liming favoured the growth of *S. fruticosa*, an increase in pH and a fall in Eh. The amendment was effective for reducing Mn, Zn, and Cd in pore water of bare soils, but not Cu and Pb. In the treatment with liming and plant, the growth of *S. fruticosa* counteracted the effect of the amendment, strongly increasing the concentrations of metals in pore water and distributing them along the soil profile. Hence, the combined use of liming and plants may increase the risk of metals mobilisation.

1. Introduction

The negative effects of mining on soils, waters, and organisms are well known. The persistence of these pollutants and their release into ecosystems in ecotoxicological forms are currently major concerns worldwide (Batty et al., 2008). The consequences of mining also affect areas far away from the mine site, when tailings are eroded and wastes transported and deposited in lowland areas. Wetlands are among those environments most affected due to their location in topographically depressed positions. These environments have the capacity to remove and/or immobilise contaminants and are considered as green filters against pollution and eutrophication (Vega et al., 2009). However, since metals mobility depends on multiple factors, wetlands might also act as sources of hazardous substances (Du Laing et al., 2007; Baldwin and Fraser, 2009; Frohne et al., 2011).

Liming is a common management practice to recover soils polluted by mine wastes, since it promotes a rise in the pH and thus reduces metals mobility (Fernández-Caliani and Barba-Brioso, 2010; Simón et al., 2010). By-products from the marble industry are some of the materials used. In fact, their use is a suitable strategy to reduce waste disposal and revalue the wastes generated during marble processing (Fernández-Caliani and Barba-Brioso, 2010). There is an extensive literature demonstrating the effectiveness of liming with regard to improvement of soil conditions and enhancement of plant growth (e.g. Bolan et al., 2003). Since phytomanagement consists of the engineering or manipulation of soil–plant systems in order to control pollutant fluxes in the environment (Robinson et al., 2009), the combined use of soil amendments and revegetation is a strategy recommended for the remediation of mine soils.

A study conducted in microcosms showed that liming reduced the concentrations of soluble metals and increased the growth of *Sarcocornia fruticosa* (L.) A.J. Scott (a Mediterranean halophyte) in non-flooded salt marsh soils polluted by mine wastes (González-Alcaraz et al., 2011). Nevertheless, several reports have indicated that the plant rhizosphere may contribute to metals mobilisation (Du Laing et al., 2009b; Wenzel, 2009), particularly in waterlogged soils (María-Cervantes et al., 2010). Moreover, as far as we know, the consequences of combining liming and plants in soils polluted by mine wastes and regularly flooded are poorly understood. We hypothesise that the benefits of liming may depend on the

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moisture content and/or soil flooding regime and may be modulated, in turn, by the presence or absence of vegetation. In addition, different depths in the soil profile may behave differently. Hence, if an inadequate management strategy is implemented, the release of metals might be favoured, transforming these systems into sources of contaminants.

The aim of this study was to identify the effectiveness of combining liming and vegetation for the remediation of slightly acidic, saline soils of eutrophic wetlands affected by mine wastes, under fluctuating flooding conditions. The latter shall help to improve the phytomanagement strategies of these polluted systems and to reduce the potential environmental risks. For this purpose, we tested the effects of marble sludge application and the growth of *S. fruticosa* on the dynamics of metals in simulated soil profiles constructed with soil polluted by mine wastes from a saline, eutrophic wetland.

2. Material and methods

2.1. Field soil sampling and initial characterisation

Soil samples were collected from the top 20 cm of a Spolic Technosol (WRB, 2006) in a coastal salt marsh – Marina del Carmolí – (318.6 ha, N37°41′42″, W0°51′31″) of the Mar Menor lagoon, south-eastern Spain (Fig. 1). This marsh is affected by eutrophic water of agricultural and urban origin and by metal-mine wastes carried there by the surface watercourses coming from the nearby mining area of Sierra de Cartagena-La Unión (Conesa and Jiménez-Cárceles, 2007). This area is among those most affected by the impact of mining activities in Europe (Conesa and Schulin, 2010).

Soil material was homogenised mechanically and three subsamples were analysed to perform an initial characterisation (for details see González-Alcaraz et al., 2011). The soil was fine textured (60% silt + clay) and slightly acidic (pH ~6.4), with a low $CaCO_3$ content (~6 g kg^{-1}) and high concentrations of total metals (g kg^{-1}: Cd ~0.016, Cu ~0.18, Mn ~3.51, Pb ~6.75, Zn ~52.3). The major minerals identified (by semi-quantitative estimation of the crystalline fraction, by power X-Ray Diffraction) were quartz (36%), phyllosilicates (22%), gypsum (14%), goethite (3%), and natrojarosite (2%).

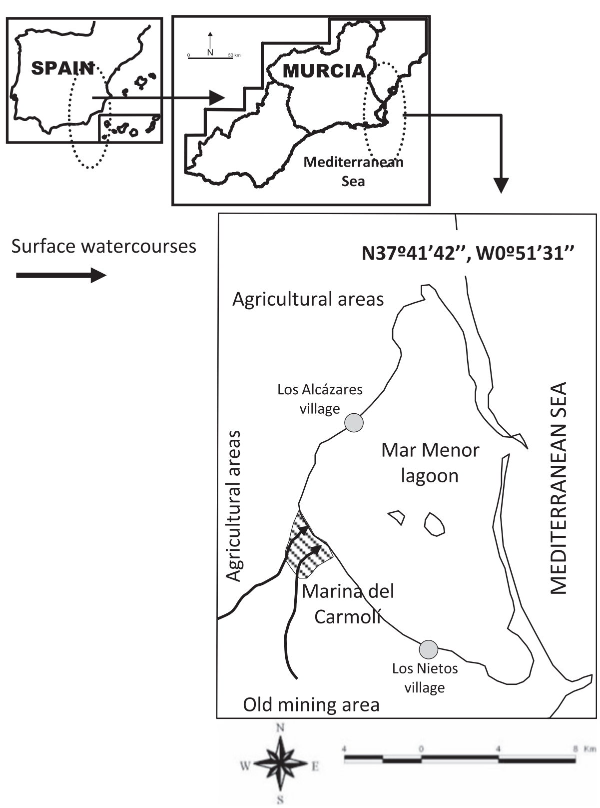

Fig. 1. Location map of the sampling site (SE Spain).

2.2. Experimental set-up

Two soil treatments were prepared: 1) soil without liming and 2) soil with liming. In the liming treatment the soil was amended with a marble sludge (54% magnesium calcite-$(Mg_{0.03}Ca_{0.97})(CO_3)$ and 37% dolomite-$CaMg(CO_3)_2$) of pH 8.9 (1:2.5 water suspension) and particle size <50 μm, at a dose of 20 g kg^{-1} soil. Liming increased the soil pH, from ~6.4 to ~7.3. Plastic pots (13.5 cm in diameter and 14 cm high) and methacrylate cylinders (20 cm in diameter and 60 cm high) were filled with each soil treatment. The cylinders were covered with opaque plastic, to prevent light exposure of the soil profiles.

The experiment was performed in a greenhouse in two phases, both under natural light conditions and with temperatures ranging from 5 to 35 °C. In the first phase of the experiment, cuttings of *S. fruticosa* (collected from non-polluted areas of the Marina del Carmolí) were planted in a number of the pots (one plant per pot) (for details see González-Alcaraz et al., 2011). The pots were watered (but not flooded) 2–3 times per week for 10 months, with eutrophic water from a local stream reaching the salt marsh (pH ~8.1, electrical conductivity ~22 dS m^{-1}, NO_3^- ~370 mg L^{-1}, PO_4^{3-} ~1 mg L^{-1}, dissolved organic carbon ~10 mg L^{-1}). Pots without plants were handled in the same way. In the first phase of the experiment, liming favoured the decrease of soluble metal concentrations and enhanced the growth of *S. fruticosa* (González-Alcaraz et al., 2011).

After 10 months, the second phase of the experiment began and the results of this phase are presented in the present paper. The contents of six pots per soil treatment (three with plants and three without) were transferred to their corresponding cylinders, by mixing and homogenising the root ball (plant roots and soil attached to them) with the soil in the cylinder. Hence, four treatments were assayed: 1) without liming + without plant (control), 2) without liming + with plant (only plant), 3) with liming + without plant (only liming), and 4) with liming + with plant (liming and plant).

In each cylinder (hereafter soil profile), two 10-cm Rhizon® type samplers (pore diameter = 0.1 μm) and Eh and pH electrodes (Crison 50–55 and Crison 50–50, respectively) were installed horizontally at depths of 5, 30, and 55 cm (hereafter A, C1, and C2 horizons). The Rhizon® samplers were connected to 50-mL plastic syringes by means of extension tubes, to extract soil solution. The cylinders were irrigated (but not flooded) for 5 months with the preceding eutrophic water in order to facilitate plant establishment.

After these 5 months, each soil profile was placed inside a larger container filled with synthetic eutrophic water with a pH ~7.5 and an electrical conductivity ~11 dS m^{-1}, enriched in organic carbon (g L^{-1}: 0.31 $Ca(NO_3)_2$, 3.8 NaCl, 3 $MgSO_4$, 0.8 $CaCl_2$, 0.2 KCl, 0.043 H_3PO_4 (85%), 0.15 $C_6H_{12}O_6$ and 0.1 meat extract (46% organic carbon)). The water level (WL) in the containers was maintained at 20 cm below the soil surface for five weeks –weeks 1 to 5 – (1st High WL) and then at 45 cm during the following five weeks – weeks 6 to 10 – (1st Low WL), repeating this cycle once more along the study (2nd High WL – weeks 11 to 15 – and 2nd Low WL – weeks 16 to 18). Hence, the upper 20 cm (A horizons) were never under water, the soil between 20 and 45 cm (C1 horizons)