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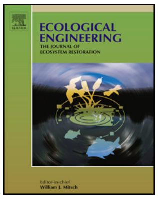

Assessment of the employment of halophyte plant species for the phytomanagement of mine tailings in semiarid areas

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ABSTRACT

Plant selection is a critical issue for the long-term success of phytomanagement projects. The presence of "microenvironments" related to salinity in mine tailings under semiarid climates make halophytes a suitable alternative for phytostabilisation. The goal of this work was to assess the criteria for plant species selection for the phytostabilisation of mining wastes in semiarid areas, focusing on the suitability of the employment of spontaneous halophyte plant species. For this purpose, a comprehensive soil below-plant and plant survey including spontaneous halophyte and non-halophyte plant species were performed in an extensive area covered by mining wastes in SE Spain. The soil samples collected below halophyte plants showed higher electrical conductivity, organic carbon and water extractable salts concentrations than the non-halophyte ones. *Zygophyllum fabago* and *Limonium cossonianum* were the most suitable species to colonize the salty micro niches at the tailings while *Tamarix canariensis* and *Atriplex halimus* showed the best soil fertility indicators under moderate electrical conductivity values. In general, the halophyte species showed lower metal(loid) concentrations in leaves or shoots than the non-halophyte ones (*e.g. Cistus monspeliensis*, *Dittrichia viscosa* and *Helichrysum decumbens*). Oppositely, the leaves of halophyte plant species, specially *A. halimus* and *Z. fabago*, showed higher accumulation of Na and Cl which may be of interest to effect the long term desalination of the tailings. The interest of employing halophytes is not only focused on metal(loid)s tolerance but also in the high potential for soil improvement (organic matter accumulation, desalination). The positive effects of combining halophyte with non-halophyte plant species may enhance the long-term sustainability of the plant community.

1. Introduction

Plant selection is a critical issue for the long-term success of phytomanagement projects (employment of plants to restore degraded ecosystems). In the particular case of the phytomanagement by phytostabilisation of mining wastes in semiarid areas, apart from showing tolerance to extreme pHs, high metal(loid) concentrations or low fertility, plants must deal with additional soil stresses such as salinity or drought (Mendez and Maier, 2008).

Plants which spontaneously colonise mining wastes are suited for phytostabilisation purposes due to their adaptation to contamination but also to local climate conditions (Martínez-Sánchez et al., 2012). However, these polluted areas are normally characterised by low biodiversity, and therefore, abiotic factors (*e.g.* drought) may risk their long-term sustainability (Parraga-Aguado et al., 2013a). For this reason, current approaches have highlighted the need of favouring the employment of several plant species with different ecological functions instead of monospecific plantations or few plant species combinations (Parraga-Aguado et al., 2014).

The Cartagena-La Unión mining district, a former mining area located in semiarid south-east Spain (Fig. 1) and with more than 200 ha of tailings, has been proposed as a suitable scenario for applying phytostabilisation techniques (Conesa and Schulin, 2010; Martínez-Sánchez et al., 2012). A recent study performed by Parraga-Aguado et al. (2013a) in this mining area showed that soil pH and salinity were the main factors driving plant distribution at mine tailings. These authors suggested that high evaporation rates, typical of this semiarid area, might have favoured the existence of high salinity patches inside the tailings in which plants must cope with a combination of stresses (*e.g.* salinity, metals, low fertility). In

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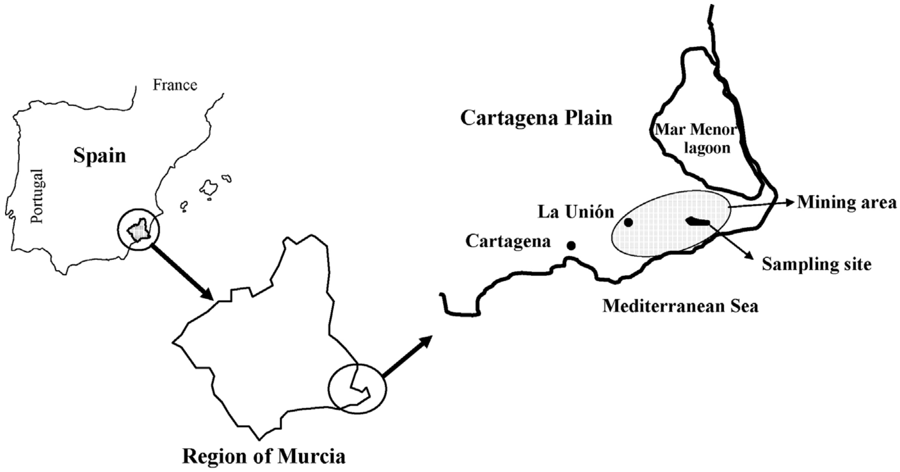

Fig. 1. Location of the study area.

order to overcome this problems, salt tolerant plant species (halophytes) may result a good alternative. Several authors have shown the connection between salt and metal(loid) tolerance mechanisms in halophytes (*e.g.* Otte, 2001). For instance, halophytes have a better system for the compartmentalisation of salts, well developed antioxidant system and osmoprotectants that may also act under metal(loid) stress situations (Manousaki and Kalogerakis, 2011).

Although there is an extensive research in grasses, weeds and trees in relation to metal tolerance, studies on halophytes are restricted to metal(loid) pollution in salt marshes (Conesa et al., 2011; González-Alcaraz et al., 2011). Therefore, the goal of this study was to assess the criteria for plant species selection in the phytostabilisation of mining wastes in semiarid areas, focusing on the suitability of spontaneous halophyte plant species. To achieve this goal, a comprehensive survey including aerial parts of selected plant species and the soil below-plants was performed in an extensive area covered by mining wastes at the Cartagena-La Unión Mining District.

2. Materials and methods

2.1. Site description

The Cartagena-La Union Mining District (0–392 m.a.s.l.; 50 km^2) was one of the most important mining areas in Spain during the last centuries. Metal(loid) contamination in this area has been recently reviewed by Conesa and Schulin (2010). The semiarid Mediterranean climate of the zone is characterised by an annual precipitation of 250–300 mm, average temperature of 18 °C and evapotranspiration rate of 850 mm. The natural vegetation is mainly based on small formations of *Pinus halepensis* and thicket plant species with xerophitic characteristics.

A former tailings disposal area, covering approximately 18,000 m^2 and located at the *Huerta de la Calesa* site (37°60′40″N, 0°83′42″W) was selected for the sampling (Fig. 1). This site has been selected due to the long term existence of mining wastes together with the occurrence of pioneer vegetation adapted to the local climatic conditions (Parraga-Aguado et al., 2013a).

2.2. Plant and soil sampling and analyses

Twelve plant species were chosen (Table 1) based on the species abundance found by Parraga-Aguado et al. (2013a) when describing the spontaneous vegetation growing at the selected tailings. The plants species were classified into halophytes and non-halophytes following the classification proposed by Menzel and Lieth (2003). Depending on plant morphology, leaves or shoots were collected. In all the cases, four replicates were taken at least.

Plant samples were carefully washed with distilled water and dried at 65 °C for 72 h. For each sample, an aliquot of 0.1–0.5 g was incinerated (550 °C, 3 h) prior to ashes redissolution with concentrated nitric acid. The resulting extracts were diluted to 25 ml with distilled water and filtered through a CHM 2041 ashless filter paper (20–25 μm pore diameter). Then, metal(loid)s (As, Cd, Cu, Mn, Pb, Sb and Zn) were analysed using an ICP-MS (Agilent 7500A), Cl and S (calculated from SO_4^{2-} concentrations) were analysed using an Ion Chromatographer (Metrohm), and Ca, Mg, Na and K were measured using a flame atomic absorption spectrometer (UNICAM 969 AA). Plant analyses were referenced using a CTA-VTL-2 certified material (Virginia tobacco leaves). The recovery percentages were between 90% and 110%.

Additionally, the corresponding soil-below plants was collected, completing 32 soil samples for the halophyte species and 28 for the non-halophyte ones. Soil samples were air dried, sieved through a 2 mm mesh, homogenised and stored in plastic bags prior to laboratory analysis. Soil pH and Electrical Conductivity (EC) were determined in a 1:5 soil to water mixture after 2 h shaking using a Crison Basic 20 pH-meter and a Crison Basic 30 conductivity meter, respectively. The resulting extracts were filtered through nylon membrane 0.45 μm syringe filters (Wicom), and then, analysed for major ions (K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}) and dissolved organic carbon (DOC) using an Ion Chromatographer (Metrohm) and a TOC-automatic analyser (TOC-VCSH Shimadzu), respectively. Equivalent calcium carbonate ($CaCO_3$) was estimated using the Bernard calcimeter method. Particle size distribution was determined following the method of Bouyoucos densimeter (Gee and Bauder, 1986). Total nitrogen (TN) was determined using the Kjeldahl method (USDA (United States Department of Agriculture), 1996). Organic carbon (OC) was determined by oxidation of the organic matter using potassium dichromate (Duchaufour, 1970). Total element composition was measured by X-Ray Fluorescence (Bruker S4 Pioneer).

Extractable (0.01 M $CaCl_2$) metal(loid) concentrations were employed to assess their bioavailability for plants (Gonzalez et al., 2011). For this purpose, a 1:10 soil to 0.01 M $CaCl_2$ solution was shaken for 2 h. The resulting extracts were filtered through nylon membrane 0.45 μm syringe filters (Wicom) and analysed for metal(loid) concentrations (As, Cd, Cu, Mn, Pb, Sb,Zn) using an ICP-MS (Agilent 7500A).