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Comparison of compost and humic fertiliser effects on growth and trace elements accumulation of native plant species in a mine soil phytorestoration experiment

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ABSTRACT

During the phytorestoration of a soil contaminated by trace elements (TEs), the most appropriate combination of plant species and soil amendments has to be evaluated in order to increase the biomass production of plants and thus, the efficacy of the process. The response of three native species (*Dittrichia viscosa*,*Nicotiana glauca* and *Silybum marianum*), and the applicability of a compost made from pig slurry and a humic fertiliser (HF) prepared from it, were assessed in a mesocosm pot-experiment through the plant growth and composition. The compost reduced the TEs concentrations in the plants to a greater extent than the HF and increased plant biomass of the three studied species, whereas HF increased the TEs concentrations in the leaves of *N. glauca* and limited its growth. *S. marianum* showed a high biomass response and was able to regulate the uptake of As and Zn from the soil solution and their transport to the harvestable parts. Similarly, *D. viscosa* restricted the transfer of As from the soil to the leaves. Therefore, the use of compost and *D. viscosa* or *S. marianum* can be considered a good combination for the remediation by phytostabilisation of TEs contaminated soils under semiarid conditions.

1. Introduction

The mining area of La Unión-Cartagena (Murcia, SE Spain) was, for centuries, one of the main mining districts in Spain, until its final closure in 1991 (Martínez-Sánchez et al., 2008). As a result, more than 40 km^2 of the area have been severely affected by mineral extraction and processing activities. This area holds numerous abandoned mine spoil accumulation ponds, and waste and foundry residues piles that have drastically modified the landscape (García-Lorenzo et al., 2012). These soils have high levels of trace elements (TEs), low organic matter (OM) and nutrients contents and poor physical structure, which hinder plant growth and leave soils exposed to wind and rain water erosion (Marqués et al., 2005; Mendez et al., 2007; Conesa et al., 2009). In addition, soil erosion facilitates the transport of toxic elements like As, Cd, Cu, Mn, Fe, Pb and Zn, which represents an important source of pollution for the surrounding areas (Conesa and Schulin 2010; García-Lorenzo et al., 2012), with the consequent risk for human health and for the entire ecosystem (Torres and Johnson, 2001; Álvarez-Rogel et al., 2004; Navarro et al., 2006). The restoration of these soils is therefore needed to reduce the dissemination of the contaminants.

Plant-based strategies for the large scale remediation of abandoned mining areas require prolonged periods of time and the use of plant species tolerant to soil pollution and to the environmental conditions of the area to be restored. Consequently, the plants used may remain in the soil for enough time to show their ability for expansion, reproduction, competition with nearby plants and colonisation of the surrounding areas. This is of vital importance, especially for soils close to areas of faunistic and floristic interest, where the use of exogenous species may alter the natural habitat. This is the case of the mining area of La Unión-Cartagena, which surrounds the Natural Park of "Calblanque, Monte de las Cenizas y Peña del Águila" that has one of the most important heritages of the Iberian Peninsula in terms of plant and animal species (Dirección General de Patrimonio Natural y Biodiversidad, 2008). The use of native species for the restoration of this type of soils is of special interest in order to maintain the ecosystem equilibrium. Additionally, native plants are adapted to specific climate and soil conditions, providing the basis for natural ecological succession (Mendez et al., 2007), with a greater chance

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of survival, growth and reproduction in environmental stress conditions than plants introduced from other environments (Adriano, 2001; Antonsiewicz et al., 2008).

Phytorestoration can be defined as the type of phytostabilisation that specifically uses native plants for the establishment of a vegetation cover to physically stabilise the soils and minimise soil erosion and dissemination of the contaminants in polluted sites (Mench et al., 2007; Mendez and Maier, 2008). The process may also prevent excessive percolation of rain water, thus decreasing the concentrations of soluble TEs entering both superficial water courses and groundwater (Tordoff et al., 2000).

Soil organic amendments are often necessary for the improvement of soil properties before the establishment of the vegetation (Tordoff et al., 2000 Walker et al., 2004 Clemente et al., 2012). These materials not only provide essential nutrients and OM and improve soil structure, but also modify the solubility and phytotoxicity of TEs (Bernal et al., 2007). Compost made from pig slurry can be a cheap source of OM and nutrients in soil remediation, this being a viable option for the recycling of this residue, which is produced in very high amounts in Spain (23 Mt of pig slurry per year). Also, the humic substances present in highly mature composts can reduce the solubility of TEs in soils, forming insoluble complexes (Clemente and Bernal, 2006; Bernal et al., 2009). Humic extracts are often used as liquid fertilisers, and their use in phytoremediation would mean a direct source of humic substances that may potentially immobilise the contaminants in the soil (Bernal et al., 2007). However, as the solubilisation of As after the addition of organic amendments has been previously reported (Clemente et al., 2010; Pardo et al., 2011), this undesired effect must be carefully assessed when using this type of restoration technology (Clemente et al., 2012).

The objective of this work was to study the usefulness of different combinations of native species and organic amendments for the restoration of a TEs-contaminated soil of the La Unión-Cartagena mining district. The effectiveness of two different organic amendments, a compost prepared from pig slurry and a humic fertiliser obtained from the compost, with regard to soil TEs solubility and the TEs accumulation and growth of three different native plant species were evaluated in a pot experiment.

2. Materials and methods

2.1. Soil and amendments

The soil used in this study consisted of a composite sample taken from an abandoned mine tailings accumulation pond situated by the El Gorguel gully (37°35′ 29.51″, −0°52′ 44.04″), within the former mining area of La Unión-Cartagena (Murcia, Spain) (Fig. 1). This soil can be considered a sterile deposit with no edaphic development and almost bare of vegetation. The soil was air-dried, sieved through a 2 mm sieve and homogenised for its initial characterisation (pH 7.5, EC 2.31 dS m^{-1}, OM 1.1%, TOC 5.97 g kg^{-1}, TN 0.28 g kg^{-1}, sand 73%, silt 22% and clay 5%; Supplementary data, Table A.1), which was carried out using the methods described in Walker et al. (2003, 2007),). Pseudo-total (aqua regia MW digestion) concentrations of trace elements in this soil were very high: As 529, Cd 31, Cu 142, Pb 6130, Zn 12,506, all mg kg^{-1}; Fe 153 g kg^{-1} and Mn 4.07 g kg^{-1}, clearly above the reference values reported for the soils of this area (Martínez-Sánchez and Pérez-Sirvent, 2007).

The compost was elaborated using the solid fraction of anaerobically digested pig slurry, obtained after mechanical solid–liquid separation and composted by turning for 173 days in an industrial composting plant. The main characteristics of the compost were: pH 6.4, EC 7.34 dS m^{-1}, OM 49.3%, TOC 242 g kg^{-1}, TN 26.3 g kg–1, Total-P 16.2 g kg^{-1} and Total-K 7.5 g kg^{-1}. This material is rich in humified OM (NaOH extractable-C (C_{ext}) 39.7, humic acids-C 21.7, fulvic acids-C 1.8, all g kg^{-1}), whereas it has a small soluble OM fraction (water soluble-C 8.7 g kg^{-1}; Table A.1). The humic fertiliser (HF) was obtained from the compost by alkaline extraction of humic substances (1.5 M KOH at 70 °C for 24 h) – that were mixed with 1 M phosphoric acid (ratio 1:3) to prepare a liquid PK organo-mineral fertiliser. The characteristics of the HF were: pH 13.5, TOC 44.1, TN 4.9, Total-P 9.0, Total-K 43 (all in g kg^{-1}), giving a 0.5:2:5 N:P:K fertiliser, expressed as P_2O_5 and K_2O equivalents (Table A.1). The HF was diluted with distilled water to a final concentration of 17%, and supplemented with HNO_3 (1:10) in order to add an amount of available N (0.105 g N kg^{-1}) to the soil equivalent to that added with the compost, while neutralising the alkaline pH of the humic extract.

The following treatments were studied: a control soil without any treatment; compost (20.3 g DW compost kg^{-1} soil); and HF (19.5 ml kg^{-1} soil). The doses of compost and HF were chosen in order to add the same amount of C_{ext} (0.81 g C kg^{-1}soil), with the intention of increasing by 1% the OM content of the soil and reach appropriate values for plant growth. The soil:compost mixtures were left to stabilise for one month in the pots (1.5 l) before sowing, whereas the HF was added gradually to the soil after sowing, during 70 days, by drip irrigation. Plants were also grown in a commercial, non-polluted substrate under the same experimental conditions, in order to determine the normal plant growth.

2.2. Plant species

Three plant species were studied for all the soil treatments: *Dittrichia viscosa* (L.) Greuter (syn. *Inula viscosa* (L.) Aiton) (Asteraceae), *Nicotiana glauca* R.C. (Graham) (Solanaceae) and *Silybum marianum* (L.) Gaertner (Asteraceae), all native species of the area. They were pre-selected from an assortment of plant species previously sampled in the area, based on their tolerance to

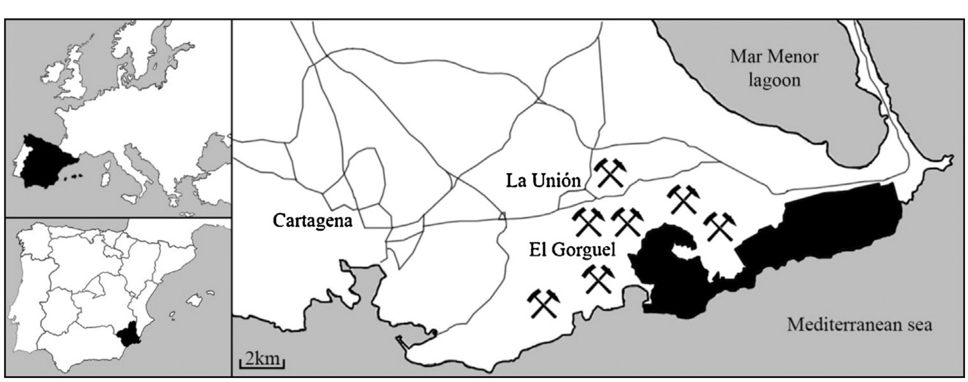

Fig. 1. Localisation of the former mining area and of the Natural Park of "Calblanque, Monte de las Cenizas y Peña del Águila" (in black), in the Region of Murcia (Spain).