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Soil organic matter from pioneer species and its implications to phytostabilization of mined sites in the Sierra de Cartagena (Spain)

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Abstract

Pioneer plant species were observed growing on mined areas despite unfavourable conditions such as extreme pH, high salinity and phytotoxic levels of several elements. This study evaluated the contribution of pioneer species to the accumulation of soil organic matter (SOM). We collected 51 samples from 17 non-vegetated, natural and pioneer-vegetated sites in five highly saline mined areas in the Sierra de Cartagena (Spain). The composition of SOM was determined using total C, N and S elemental anlayzer, pyrolysis and solid state ^{13}C NMR spectroscopy. Results showed that pioneer species like *Lygeum spartum* had contributed ~11 kg SOM kg^{-1} soil into the Balsa Rosa sites since 1991; it will take ~120 years of continuous growth for this plant to increase the SOM level comparable to natural site. In the Portman Bay area, *Sarconia ramosissima* and *Phragmites australis* can contribute SOM equivalent to present day SOM in natural sites in the next 30 years. Low quality SOM (C/N > 20) deposited by pioneer plants was dominated by lignin-derived organic compounds such as phenols, guaiacols, syringols and aromatics while polyssacharides and alkyls were the major components in high quality SOM (C/N < 20). The addition of SOM to mine wastes is similar to early stages of soil formation and with time, we expect the formation of well-developed Ah horizon on the surface of mine wastes. The presence of *P. australis* on several sites makes it a very good candidate for successful revegetation of hostile conditions found in many mined sites.

Keywords: Mine wastes; Reclamation; Trace elements; Soluble salts; Soil organic matter

1. Introduction

The Sierra de Cartagena in southeast of Spain had been exploited for >2500 years to extract iron, lead and zinc (Martínez Orozco et al., 1993; Conesa et al., 2006, 2007). Majors iron ores extracted in the area were iron oxides/hydroxides, sulfides, sulfates, carbonates and silicates; lead and zinc ores were galena, sphalerite, carbonates, sulfates and lead- and zinc-bearing oxides (Oen et al., 1975). Mining activities came to an end in early 1990s leaving behind legacies of industrially derelict areas.

Recently, the use of plants to stabilize mine wastes including tailings has been increasing because of its multiple benefits; successful revegetation of the mine wastes is proven one of the best reclamation techniques available to date. Vegetation cover provides physical protection to prevent wind erosion and surface runoff of soil materials (Norland and Veith, 1995). Although revegetation is desirable, many challenges including high amounts of metals,

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high salinity and extreme pH confront vigorous plant growth in problem soils in mined sites (Tordoff et al., 2000). Pioneer plant community is tolerant to unfavourable soil conditions and plays a major role in reclamation of degraded mine soils (Freitas et al., 2003). Field observations in the Sierra de Cartagena showed that ecological succession on mining wastes has been taking place since the cessation of mining activities in the early 1990. For example, *Hyparrhenia hirta* and *Zygophyllum fabago* had colonized areas of low salinity in selected mine wastes in the Sierra de Cartagena (Conesa et al., 2007). In highly saline areas, the dominant plant colonizers are *Phragmites australis*, *Salicornia ramosissima*, *Limonium carthaginens*, *Tamarix canariensis*; *Lygeum spartum* is a minor species found in some saline areas.

In addition to physical protection, vegetation cover contributes organic matter to the soil. A healthy soil in properly-functioning ecosystem is often characterized by good quality SOM where essential nutrients such as N, P, S, K, Ca, Na, and Mg are readily available to support growth of plants and organisms. Soil organic matter increases water holding capacity and aeration, regulates temperature, contributes to cation exchange capacity and promotes soil structure favourable to plants and organisms (Stevenson, 1994; Sollins et al., 2006). SOM is an important pool in the global carbon cycle due to its abundance (~2.4 billion tonnes of organic + inorganic C) and sensitivity to changing conditions (Amundson, 2001; Lal, 2004). In the literature (e.g., Wong, 2003; Alverenga et al., 2004; Conesa et al., 2006, 2007), studies on phytoremedition of mined sites were focused on physical protection, bioextraction and phytostabilization of metals and often overlooked the importance of SOM as a requisite to establish a healthy and functioning ecosystem towards a long-term solution to problem soils in mined areas. We believe that the long-term success of any phytoremediation of mined sites should consider the role of SOM addition from plant species especially from pioneer community because of the significant influence of SOM in many soil biogeochemical processes in a healthy ecosystem.

The objectives of this study were to determine (1) the composition of SOM under pioneer plant species and (2) the likely influence of these native plants in the availability of selected essential water-extractable plant nutrients such as ammonium (NH_4^+), potassium (K), sodium (Na), calcium (Ca) and magnesium (Mg) in surface (0–20 cm) layer of soils on selected mined areas in the Sierra de Cartagena (Spain). The results will provide useful information to understand key ecosystem processes for successful revegetation of mined sites in southeast Spain and other similar environments in semiarid places in the world. In addition, it will help us understand some management questions such as: (1) What are the plant species that will likely survive in extreme conditions to stabilize soils in mined areas? and (2) Will the nature of SOM deposition from pioneering plant species help establish a healthy ecosystem in problem soil environment in mined sites?

2. Materials and methods

2.1. Study area

The Sierra de Cartagena is situated in SE Iberian Peninsula, in the province of Murcia (Spain) (Fig. 1). The mining district is located on eastern side of the Cordillera Bética, and is part of a wide volcano-tectonic and metallogenetic belt that extends from Cabo de Gata to the Sierra de Cartagena. The climate is a typical Mediterranean with average monthly temperature ranges from 9.3 °C in January to 24.4 °C in July. Mean annual precipitation is ~275 mm, mostly in autumn and spring. The potential evapotranspiration reaches 900 mm year^{-1}.

2.2. Sample collection

In September and October 2003, soil samples were collected from 17 different locations in five representative mined areas in the Sierra de Cartagena (Table 1). Three replicate soil samples were collected from 0 to 20 cm in each of four non-vegetated, four natural or reference and nine pioneer-vegetated (*P. australis*, *P. lentiscus*, *L. carthaginens*, *T. canariensis*, *S. ramosissima*, *L. spartum*) sites for a total of 51 samples. Non-vegetated sites were characterized by the presence of soils developed/developing on mine wastes. Natural sites were developed on local parent materials, vegetated either naturally (*S. tenacissima*) or reforested (*P. halepensis*) with a recognizable A-horizon and lacks surficial deposits of mine wastes within 0–20 cm depth. In vegetated sites, soil samples were collected as much as possible within the rooting area of plant (Bird et al., 2002). Classification of soils (FAO, 2006) in the study areas ranged from Fluvisol, Regosol, Arenosol in mine wastes to Calcisols, Kastanazems, Cambisols and Solonchaks in natural sites. Gypsum content (%) in study areas varied from nil to 88% (w/w) (Ottenhoff, 2005). The

Fig. 1. Location of the study area (denoted by the enclosure – □) in the Sierra de Cartagena (Spain).