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Tree vegetation and waste amendments to improve the physical condition of copper mine soils

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HIGHLIGHTS

- ▶ Two copper mine soils were treated by planting trees and amending with wastes.
- ▶ The physical degradation of the untreated soils was considerable.
- ▶ The planted trees increased soil porosity in the mine soils.
- ▶ The added wastes increased MWD, WSA and SI due to their organic C content.
- ▶ To use both treatments is the best to improve the soil physical situation.

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ABSTRACT

Mine soils are often physically degraded, which hinders plants development. The untreated soils at the depleted copper mine in Touro (Galicia, north-west Spain) have no vegetation and are probably physically degraded. These mine soils were reclaimed both by planting trees and amending with waste (sewage sludge and paper mill residues). The purpose was to determine the effect of these treatments on the physical quality of the soils of the Touro mine under field conditions. We evaluated the physical situation of both the settling pond and the mine tailings in Touro, then comparing them with their respective treated areas: vegetated, amended or with both treatments at the same time. We corroborated that the physical degradation of untreated soils was considerable: low porosity, high density and less than 50% of water stable aggregates. The trees that were planted increased porosity, probably due to root activity. The added amendments increased the mean weight diameter (MWD), the percentage of water stable aggregates (WSA) and the stability index (SI) due to the high organic carbon content in the added wastes. We verified that using both treatments at the same time is better than using only one to improve the physical situation of mine soils.

1. Introduction

Reclaiming areas where mining has previously carried out is necessary in order to restore mine soils. Mine tailings occupy huge areas, requiring substantial resources to improve the quality of their soils. Planting vegetation is a common practice to reclaim mine areas (Shrestha and Lal, 2008; Chodak and Niklińska, 2010; de Varennes et al., 2010), although in most cases this is not enough due to the severely degraded condition of these soils (extreme pH, nutrient deficiency, poorly aerated). Amending with organic residues has proven to be a cheap and effective treatment to increase soil quality (Bendfeldt et al., 2001; Brown et al., 2003; Hemmat et al., 2010), as well as being a good way to reuse wastes.

There are three main categories of soil quality indicators: chemical, physical and biological (Carter et al., 1997). This paper focuses on the physical quality of the studied soils.

In 1988, work began on recovering the depleted copper mine in the village of Touro (Galicia, north-west Spain, Fig. 1). The mine soils were partially reclaimed by planting trees at the end of the copper extraction, although another company has been carrying out work to restore the whole area since 2000. This reclamation process involves planting pine trees (*Pinus pinaster* Aiton) and eucalypts (*Eucalyptus globulus* Labill) and amending with organic wastes (mainly sewage sludge and paper mill residue). Mine soils are usually physically degraded (Shukla et al., 2004a; Shrestha and Lal, 2011). They have high bulk density, high percentage of

Abbreviations: EC, electrical conductivity; SOC, soil organic carbon; MWD, mean weight diameter; WSA, water stable aggregates; SI, stability index.

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stoniness, poor structure and low porosity (Shukla et al., 2004b). In order to evaluate the physical quality of soil, bulk density, porosity, aggregate size distribution and percentage of water stable aggregates (WSA) are widely used as indicators (Boix-Fayos et al., 2001; Reynolds et al., 2002; Shukla et al., 2004b; Velasquez et al., 2007; Shrestha and Lal, 2008). The percentage of stoniness was also taken into account in this study, as it is usually an important limiting factor for vegetation in mine soils (Vega et al., 2005). Soil physical characteristics are usually influenced by soil pH or organic carbon concentrations (SOCs). Soil organic carbon is known to be a critical parameter affecting virtually all aspects of physical soil quality (Reynolds et al., 2008).

Numerous studies have already evaluated the effect of waste amendments and/or vegetation on heavy metal-polluted mine soils (Shu et al., 2005; Vega et al., 2005; Conesa et al., 2007a,b; Lottermoser et al., 2008; Nouri et al., 2009; Karami et al., 2011), but only a few of them have focused on physical soil properties (Jordán et al., 2009; Zanuzzi et al., 2009). The added value of this research is that it was carried out under field conditions and with the combined effect of tree vegetation and waste amendments.

The hypothesis of this work was that planting trees and amending with sewage sludge and paper mill residues improves the physical quality of mine soils, especially when both treatments are combined. For this reason, selected physical properties were measured in soils at the Touro mine with different treatments (vegetated, amended or vegetated + amended) applied at different times.

2. Materials and methods

2.1. Soil sampling

The sampling area is located at the mine in Touro (Galicia, north-west Spain) (Lat/Lon (Datum ETRS89): 8°20′12.06″W 42°52′46.18″N) (Fig. 1). The climate of the experimental site is Atlantic (oceanic), with precipitation reaching 1886 mm per year (with an average of 157 mm per month) and a mean daily temperature of 12.6 °C. The average relative humidity is 77% (AEMET, 2012).

Copper was extracted from the Touro mine between 1973 and 1988 (14 years). This activity left behind a settling pond (71 ha) and a huge mine tailing (larger than 700 ha). Nowadays, apart from the extraction of material for road construction, the former mining areas are being reclaimed. Settling ponds are created by the accumulation of waste after the process of metal concentration in flotation banks. Mine tailings are the accumulation of thick material after mining activity. The settling pond in the Touro mine was created with waste from the copper flotation process, but today it is completely emerged and dry. There is an active oxidation zone near the surface where vegetation does not grow. The unvegetated or amended areas in the mine tailing were also completely bare. In order to evaluate the effectiveness of treatments in the settling pond and mine tailing, four areas were selected in each area (Table 1 and Fig. 1). The soil samples are described in greater detail below. Five soil samples were randomly collected in points sufficiently spaced to be representative of each site on 9th March 2010. Samples were stored in polyethylene bags, dried at room temperature and sieved to <2 mm prior to being analysed. All soils had only one horizon, except two of them, where both horizons were sampled (described below). Soils were classified according to the latest version of the FAO (2006).

2.2. Settling pond samples

The control sample from the settling pond (B1) was in an untreated area. B1 is a Spolic Technosol located 336 m above sea level, covering an area of 1.9 ha with an AC horizon 40 cm deep.

The second sampled area (B2) was chosen for its old vegetation. Pine trees (*P. pinaster* Aiton) were planted here in 1989 (21 years ago). B2 is also a Spolic Technosol, with spontaneous vegetation: eucalyptus (*E. globulus* Labill), gorse (*Ulex* sp.), heather (*Erica* sp.), *Agrostis* sp. and bryophytes. The B2 soil covers 6200 m^2 and is 340 m above sea level, with an AC horizon 20 cm deep.

The third sample (B3) was chosen because of its young vegetation, in order to compare it with B2 and to observe the effect of trees over time. The B3 area was vegetated with eucalyptus in 2004, and is also a Spolic Technosol. This area also has spontaneous vegetation: pine trees (*P. pinaster* Aiton), *Agrostis* sp., broom (*Cytisus* sp.), *Acacia* sp. and bryophytes. The B3 soil covers 1.15 ha and is 335 m above sea level, with an AC horizon 20 cm deep.

The fourth sample (B4) was located in a recently amended area. Sewage sludge mixed with paper mill residue had been added 5 months before the sampling date. This waste was directly added with trucks and then spread on the soil surface, without being mixed in with the mine soil. The final depth of this new layer was 20 cm, with a volume of 280 tons per ha. The properties of this amendment are similar to those reported by Camps Arbestain et al. (2008). The general characteristics of the added waste were pH 8–10, more than 150 g kg^{-1} of total organic C, more than 100 mg kg^{-1} of total Cu and more than 300 mg kg^{-1} of total Zn. Only spontaneous herbaceous vegetation grew on B4, measuring 100 m^2 and at a height of 339 m above sea level. B4 was an Urbic Technosol with two horizons: AC (B4A) and C (B4B). B4B was also sampled to compare it with the untreated sample (B1) as it was considered to be analogous of the control soil. B4A was 20 cm deep, and B4B was 40 cm deep.

As the use of waste amendments in this area began only 5 months before the sampling date, there are no samples that are representative of the long-term effects of amendment, or both treatments at the same time (vegetation and amendment).

2.3. Mine tailing samples

The control sample in the mine tailing (M1) was in an untreated area, and is classified as Spolic Technosol. M1 was 336 m above sea level and covered an area of 1.20 ha, with an AC horizon 20 cm deep.

The second sampled area (M2) was chosen because of its old vegetation, as it was vegetated with pine trees in 1989. It also had spontaneous vegetation: gorse (*Ulex* sp.), heather (*Erica* sp.), *Agrostis* sp. and bryophytes. This soil is also a Spolic Technosol, covering an area of 0.60 ha and 340 m above sea level, with an AC horizon 20 cm deep. The C horizon of this soil was also sampled to be compared with the untreated one (M1), as it is similar to the original bare soil but with the amendment on top of it. The AC horizon was named M2A and the C horizon M2B. M2A was 4 cm deep and M2B was 20 cm deep.

The M3 soil is an Urbic Technosol created with sewage sludge and paper mill residue. These sludges were added 6 months before the sampling date by trucks, and then spread on the soil surface. The final depth of this new layer was around 3 m, covering an area of 0.8 ha. The amount of wastes added was around 158 tons per ha. These wastes were the same as those used in the settling pond. This soil was 178 m above sea level and only had natural herbaceous vegetation.

The fourth area (M4) was selected because it was vegetated and amended at the same time. This area was vegetated with eucalyptus and amended in 2000 with the same type of wastes as M3. The amount added in M4 was 297 tons per ha and the final depth of this new layer was around 70 cm. This area also had spontaneous vegetation (gorses, brambles, pine trees and bryophytes). The M4 soil is also an Urbic Technosol, measuring 1.5 ha and 336 m above sea level.