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Comparison of the effects of compost versus compost and biochar on the recovery of a mine soil by improving the nutrient content

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ABSTRACT

Numerous studies on the recovery of mine soils focused on the problems caused by metal(loid)s, and did not explore in depth the issue of nutrients and vegetation. In this experiment with soil packed in columns, we studied the capacity of biochar to increase the nutrient supply, pH, total carbon, total nitrogen and cation exchange capacity caused by the compost application. We compost alone and in combination with an oak wood-derived biochar. We also attempted to establish a crop of *Brassica juncea* L. and to verify which treatment produced the best development. The study was carried out at three different depths over the 45-cm length of each cylinder. The treatments applied increased the pH, nutrient, total carbon and total nitrogen values, and the cation exchange capacity. In overall, the most effective treatment consisted of the one using compost + biochar followed by planting *B. juncea* with only some exceptions towards the end of the experimentation period. The ability of biochar to improve the conditions of the settling pond soil to allow plant cover was demonstrated analysing the biomass of the *B. juncea* plants, which was higher in the soil treatments combining compost and biochar.

1. Introduction

Most of the studies on the recovery of mine soils focused on the problems caused by metals, without exploring the issues of nutrients and vegetation. However, the sustainable reclamation of mine soils requires a permanent plant cover that prevents soil erosion, allowing for the long-term the sustainable development of the soil (Juwarkar et al., 2009). Also, the vegetation can return a large proportion of percolating water to the atmosphere through transpiration, thereby reducing the amounts of soluble metals entering watercourses. Plant cover also goes a long way towards reducing the visual scars in the landscape caused by large-scale mining operations. Successful re-vegetation may allow for the recreational use of the land, and even agriculture or forestry if conditions are favourable (Tordoff et al., 2000). The problem with mine soils in terms of supporting vegetation is that they often have poor conditions for plant growth, including poor physical structure, sandy texture, acidity, poor cation exchange capacity (CEC) and low organic matter, salinity and nutrient contents, which limit the establishment of vegetation and intensify erosion caused by rain and wind (Perez-Esteban et al., 2012).

For increasing the content of nutrients in a phytoavailable form in mine soils, a large amount of amendment material need to be used in order to provide organic matter and release nutrients. For this reason, organic wastes have been widely used as amendments in mine reclamation, as they are relatively inexpensive and produced in large quantities (Asensio et al., 2014). Compost made of various manure types provides significant benefits when applied incorporated into the soil, as the organic matter from manure acts as a nutrient pool, improves nutrient cycling, increases the CEC and buffer capacity, reduces compaction, and improves physical soil properties such as aggregation, friability, density, root penetration, water retention capacity and water infiltration (Walker et al., 2004). In addition to the abovementioned characteristics, the compost also improves for microbial, microfauna and mesofauna communities. Several studies, such as Luna et al. (2016) have demonstrated the effectiveness of compost on improving aspects such as the carbon, nitrogen or potassium content in soils. Another amendment currently in use to improve the conditions of degraded soils is biochar. Biochars are biological residues combusted under low oxygen conditions, resulting in a porous, low density, carbon rich material, with a large surface area. When some types of biochar, not all (Jones et al., 2016; Oustrière et al., 2016), are used as a soil amendment, it has been reported to enhance soil fertility and improve soil quality, resulting in increased crop yields. Soil benefits include raising the soil pH, increasing moisture holding capacity, attracting more beneficial fungi and microbes, improving cation exchange capacity (CEC), and retaining nutrients. Given that biochar is highly recalcitrant, the effects of its application may be prolonged over a long period of time. (Beesley et al., 2011; Fellet et al., 2011; Filiberto and Gaunt,

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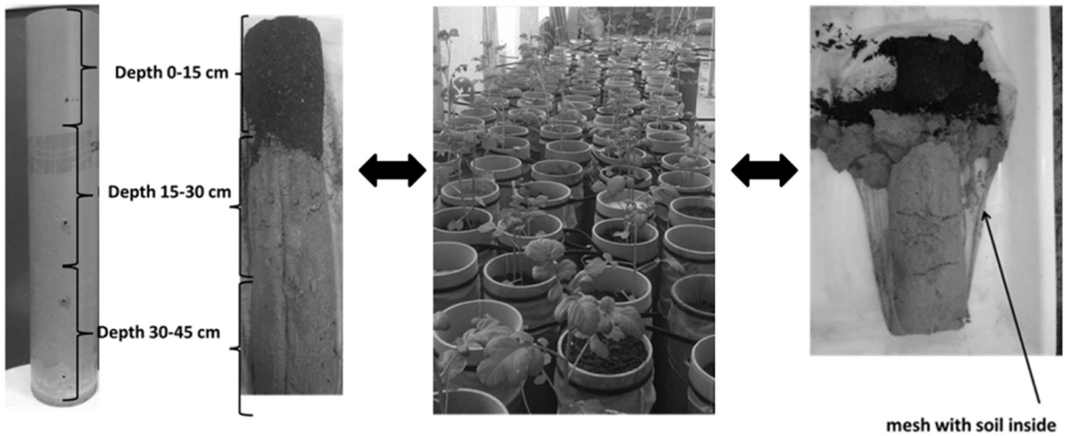

Fig. 1. Cylinder design and the different depths.

2013). However, the biochar can also contain too many salts (Na), induce some trace element deficiencies or release soluble organic matter. The ability of biochar to retain nutrients indicates that biochar could be used in combination with other amendments in order to retain the nutrients they provide. Indeed one of the problems associated with the use of some types of compost is that once it is applied to the soil, it quickly loses the nutrients it contains, and the carbon it provides is not very recalcitrant. For this reason, some organic amendments are combined with biochar. This can enhance the positive effects of the compost, as demonstrated by Fowles (2007). Biedermand and Harpole (2013) analysed the results of 371 independent studies: the addition of biochar to soils resulted in increased above-ground productivity, crop yield, soil microbial biomass, rhizobia nodulation, plant K tissue concentration, soil potassium (K), soil total nitrogen (TN), and soil total carbon (TC) compared to control conditions. Using these amendments aim is to recover degraded soils, for establishing an initial vegetation cover. The early stage of vegetation establishment is particularly crucial and requires good site preparation practices for maximising the successful of the revegetation process. Site preparation practices have the potential of modify soil physicochemical properties, thereby influencing nutrient availability and the plants establishment (Reverchon et al., 2015).

This study aimed at comparing the effectiveness of four different treatments on recovering nutrients, increasing soil pH, total carbon, total nitrogen, and the cation exchange capacity in a settling pond soil from a mine (Touro, north-west Spain). The treatments were made using compost with and without biochar, and were vegetated with *B. juncea* or left unplanted. Some authors studied the characteristics of the Touro mine soil (Asensio et al., 2014; Quintela-Sabarís et al., 2017; Rodríguez-Vila et al., 2016), but these experiments were not carried out at different depths. For comparing the treatments at different depths, we put settling pond soil from a depleted copper mine in 50-cm cylinders to reflect as closely as possible the first few centimetres of soil. Another objective was to determine the ability of biochar to fix nutrients and enhance the positive effects of compost, for establishing a continuous crop of *Brassica juncea* L. Studies by authors such as Lombi et al. (1999), Do Nascimento et al. (2006), and Rodríguez-Vila et al. (2014) successfully used *Brassica juncea* L. in polluted mine soils.

2. Material and methods

2.1. Soil sampling

The sampled zone is located in an old copper mine at Touro, north western Spain (8° 20′ 12.06″ W 42° 52′ 46.18″ N). The climate in this zone 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, 2015). One soil and three amendments were selected: the soil chosen came from a settling pond (S) comprised of waste material resulting from the flotation of sulphides during copper processing. The pool has been dry for several years, and is considered to be soil according to the latest version of the FAO (2014). The three materials used as amendments were sand, compost and biochar. Sand consisting of washed sea sand was provided by the company Leboriz S.L.U, and was used as a neutral control. The compost (C) was made from horse and rabbit manure mixed with grass cuttings, fruit and seaweed, and was provided by the company Ecocelta Galicia S.L. (Ponteareas, Pontevedra, Spain). The biochar (B) used was made from *Quercus ilex* wood with a pyrolysis temperature of 400 °C for 8 h, provided by the company PROININSO S.A.

2.2. Greenhouse experiment

The greenhouse experiment was carried out in cylinders with the aim of reflecting the top 45 cm of soil; the cylinders were made of PVC, with a height of 50 cm and a diameter of 10 cm. A porous mesh was placed inside the cylinders, and the settling pond soil was poured inside. The mesh used for the settling pond soil was not in contact with the PVC for a long period of time (Fig. 1). The cylinders were filled with settling pond soil (S, negative control) settling pond soil and sand (SS, neutral control), and the following treatments:

- Settling pond soil + compost (SC)
- Settling pond soil + compost + vegetated with *Brassica juncea* L. (SCP)
- Settling pond soil + compost + biochar (SCB)

Settling pond soil + compost + biochar + vegetated with *Brassica juncea* L. (SCBP).

The amendment ratios used are detailed in Table 1. The total weight of each cylinder was 3.5 kg. The treatments were incorporated in the superficial part (0 cm) of the -settling pond soil. In mines such as the

Table 1
Proportions used to make the controls and the different treatments.

	Soil	Sand	Compost	Biochar
S	100%			
SS	85%	15%		
SC	85%		15%	
SCP	85%		15%	
SCB	85%		11%	4%
SCBP	85%		11%	4%