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Soil quality improvement by the establishment of a vegetative cover in a mine soil added with composted municipal sewage sludge

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ABSTRACT

The effect of two different composts of urban sewage sludge was investigated for the establishment of three different plant species (ryegrass, tomato and ahipa) on a mine soil (Alquife, SE Spain). The treatments consisted in a non-amended mine soil, and mine soils amended with composted sewage sludge (CSL) or composted sewage sludge with olive prune wastes (CLV) at 2, 5 and 10% (*w/w*). Different soil and plant parameters were measured. Soil pH was slightly modified but soil conductivity and soil organic C increased with compost addition and remained constant along incubation. Soil respiration and dehydrogenase activity increased more when amended with CSL than with CLV. At the end of the incubation period a decrease in enzyme activities was measured with increasing CSL doses suggesting a possible toxic effect of CSL above 5%. The plant species responded differently to both composts. In ahipa, the treatments did neither affect the leaf photosynthetic pigments nor the plant growth. In tomato and ryegrass, the 2% dose improved biomass but at 10% increased plant mortality and inhibited plant growth. Composted sewage sludge (≤5%) appeared to be the best solution when used as soil conditioner for improving plant establishment in this mine soil.

1. Introduction

The mining activity was the core of social and economic life in Alquife (Granada, Spain) during the 20th century. This activity started in 1895 and was abandoned in 1998, giving rise to the subsequent cultural, social and economic problems similar to other mining areas all over the world experiencing a collapse (Ruiz Ballesteros and Hernández Ramírez, 2007; Sevilla Perea, 2014). As the result of open mining operations up to 260 ha of waste materials was disposed (Sevilla-Perea et al., 2014). This iron-open cut mine produced about 3.3 million metric tons per year in the mid-nineties (Díez et al., 2009). The main ore minerals in Alquife outcrop are hematite, goethite and siderite (Torres Ruiz, 1980). The studied area is located in the Guadix–Baza depression formed primarily on consolidated Quaternary sediments which are calcareous in the north (Sierra de Baza) and metamorphic in the south (Sierra Nevada). The mining processes have left vast areas covered by mine wastes hostile for plant establishment while displaced waste rocks and overburden covering the ore body have changed radically the landscape and left it without vegetation.

In such a scenario plant survival and growth are severely limited by unfavorable physical, chemical and biological factors such as weak soil structure, low soil water holding capacity, and very low organic matter (OM) and available nutrients contents, especially N (0.9 g kg^{-1}) and P (Sevilla-Perea et al., 2014). Soil recovery might be promoted by the establishment of a vegetation cover to mitigate erosion and the addition of organic amendments to improve soil quality. Land application of treated sewage sludges can contribute to sustainable environmental management, through the return of organic matter and nutrients to soils (Brown et al., 2003). Municipal wastewater treatment generates huge volumes of sewage sludge and its disposal represents one of the most serious environmental challenges of the process (Albiach et al., 2001). To recycle sewage sludges as a soil amendment is environmentally-safe and economically-advantageous, based on the agronomic benefits after enriching soils with nutrients and organic matter (Haug, 1993; Pascual et al., 1999). Sludge must be stabilized before use to prevent unacceptable levels of pollutants, bad odors and the risk of diseases (Marttinen et al., 2004). Aerobic and anaerobic digestions are the most common stabilization processes and nowadays several post-treatment processes are applied to reduce their water content and toxicity (EC, 2000). Of all sludge post-treatments, co-composting with plant debris is the most widespread. Composted sewage sludge, an industrial by-product resulting from wastewater and microbiologically stabilized, is high in organic matter and nutrient contents that can be used as a horticultural soil fertilizer (Casado-Vela et al., 2007). Composted sewage sludge contains both beneficial and non-beneficial (heavy metals and soluble salts) elements requiring to study its impacts on plants and on soil physical and chemical properties to optimize its application.

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The aim of this study was to evaluate two types of sewage sludges, composted sewage sludge (CSL) and composted sewage sludge with olive prune wastes (CLV), as amendments for the reclamation of a degraded mine soil. The improvement in soil quality and plant cover establishment was assessed by the combined use of soil physicochemical and plant indicators. This is part of a multidisciplinary approach to investigate waste reutilization strategies to recover degraded soils of Andalusia for their use in agriculture.

2. Materials and methods

2.1. Soil, amendments and plant species

The soil was sampled from a waste dump in the Alquife mine (37° 11′ 50″ N 3° 6′ 4″ W). Five soil subsamples were collected (0–15 cm) and mixed to obtain a composite sample (ALQ). The mine soil is classified as a technosol (WRB, 2007) consisting of 8% of clay with slightly basic pH and low concentrations of hazardous metals (Table 1), except for As. Almost 70% of the soil samples in Alquife area exceed the upper limit for arsenic although their high carbonate contents reduce the risks for the environment (Díez et al., 2009). Samples were air dried for 2 weeks and either passed through a 6 mm mesh sieve for pot experiments or through a 3-mm mesh sieve for incubation assays. Two different sludge composts were evaluated, a composted sewage sludge (CSL) from a wastewater treatment plant (EMASESA, Seville, Spain) and compost of sewage sludge with olive prune wastes (CLV) from Biomasa del Guadalquivir (Granada, Spain). CSL, a dehydrated sewage sludge resulting from an anaerobic digestion, was preliminary dried to reach 45–50% humidity, piled in windrows, and regularly turned during 6 months, so that all pile parts were subjected to the same heat treatment. On the other hand, CLV was produced by composting both sewage sludge resulting from an anaerobic digestion (30–40 °C for 15 days) and agricultural by-products (branches and twigs pruned from olive trees). The mixture was turned regularly to prevent anaerobic processes at environmental humidity (without artificial moistening) during 6–10 months of maturation. Some properties of the soil and amendments are shown in Table 1. Iron and Al oxides, together with CaO and SiO_2, add up to 80% of the soil composition (Rodríguez-Liébana et al., 2013).

Three plant species were selected for the experiments: two of agricultural interest, tomato (*Lycopersicon esculentum* Mill.), ryegrass (*Lolium perenne* L.), and ahipa (*Pachyrhizus ahipa* (Wedd.) Parodi), whose tuberous root could be used for biofuel production.

Table 1
Some properties of Alquife mine soil (ALQ) and of the composts of sewage sludge (CLV and CSL).

	ALQ	CLV	CSL
pH	8.2	7.0	6.8
EC (dS m^{-1})	0.11	4.2	3.0
OC (%)	0.23	16	10
Clay (%)	8		
Silt (%)	28		
Loam (%)	64		
HIX	1.41	2.16	2.21
SUVA (L g^{-1} cm^{-1})	2.3	2.8	1.3
P_2O_5 (%)	0.1	3.1	4.1
SiO_2 (%)	22.4	15.7	23.2
CaO (%)	15.9	20.5	15.5
Al_2O_3 (%)	12.2	7.8	10.5
Fe_2O_3 (%)	27.5	2.9	4.8
N-NO_3^- (mg kg^{-1})	–	104	1215
N-NH_4^+ (mg kg^{-1})	–	3753	202
Cu (mg kg^{-1})	49	256	314
Zn (mg kg^{-1})	70	586	934
Ni (mg kg^{-1})	0	33	71
As (mg kg^{-1})	49	52	0
Cr (mg kg^{-1})	0	111	154
S (mg kg^{-1})	127	9495	14,012

EC: electrical conductivity. OC: organic carbon. SUVA: specific UV absorbance. HIX: humification index.

2.2. Soil incubation procedure and determination of soil properties

Seven soil treatments were set for the experiment: non-amended soil, as a control (ALQ), CSL at 2, 5 and 10%; and CLV at 2, 5, and 10%. Mine soil was thoroughly mixed with the composts and incubated for 45 d. The mixtures, carried out with air-dried soil (ALQ) and the amendments at 2, 5 and 10% (CSL2, CSL5 and CSL10, for composted sludge and CLV2, CLV5 and CLV10 for compost of sewage sludge with olive prune wastes, respectively), were placed in plastic trays covered with aluminum foil with small holes to minimize moisture loss and to allow gas exchange. The moisture was initially brought to 40% of the soil field capacity with deionized water and then periodically adjusted, and the mixtures were placed in the dark at room temperature (20 ± 2 °C). A subsample was regularly taken for physicochemical measurements (pH and electrical conductivity (EC)) and for the analysis of dehydrogenase activity (DHA) and soil induced respiration (SIR). At the end of incubation, the remaining soil samples were air dried and aliquots were kept frozen (−18 °C) for analysis of the humification index (HIX), specific UV absorbance (SUVA) and enzymatic activities.

2.3. Soil and compost analyses

The soil particle size distribution was determined by sieving and sedimentation, applying the Robinson's pipette method after removal of organic matter with H_2O_2, using sodium hexametaphosphate as dispersing agent. Field capacity was obtained from water retention of disturbed soil samples using ceramic pressure plates at an air pressure of 0.03 MPa. Soil pH and EC values were determined using a sample/deionized water ratio of 1/2.5 (*w*/*v*) for soil and mixtures of soil and composts, and 1/10 (*w*/*v*) for composts. N-forms were extracted with 0.01 M K_2SO_4 at a ratio of 1:10 (*w*:*v*), shaking for 30 min at room temperature (22 °C) and centrifuging. In the supernatant, NO_3 was measured by absorbance at 220 nm and subtracting the absorbance at 275 nm caused by organic matter (APHA, 1985). Ammonia was analyzed with the indothymol blue method at 690 nm. For the soil, composts, and mixture samples consisting of both soil and compost, organic C (OC) content was determined by a modified Walkey and Black method (Mingorance et al., 2007), as well as HIX (Zsolnay, 2003) and SUVA (L g^{-1} cm^{-1}) (Hernández-Soriano et al., 2011), which were measured using sample/deionized water ratios of 1/4 (*w*/*v*). The estimation of element content was performed with a wavelength dispersive X-ray fluorescence instrument (BRUKER S4 Pioneer), equipped with an Rh anode X-ray tube (60 kV, 150 mA). Apart from oxides (SiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, TiO_2 and P_2O_5), elements analyzed included S, Cl, Cr, Ni, Cu, Zn, Ga, As, Br, Rb, Sr, Y, Zr, I and Ba. Samples were analyzed in triplicate.

2.4. Soil induced respiration and microbial biomass C

The measurements of soil induced respiration (SIR) were carried out in defrozen soil samples using a µTrac 4200 (Sy-Lab, Gomensoro, Madrid, Spain). In brief, ca. 5 g soil was mixed with 50 mg of talc:glucose (10:1 ratio) and introduced into a measuring vial, equipped with electrodes containing 2 mL of an aqueous 2% KOH solution. The CO_2 evolution (every 5 min) followed the decrease of solution impedance of the tightly closed vial, which was kept at 30 °C for 20 h. Results are expressed as mg CO_2 100 g^{-1} h^{-1}.

Soil microbial biomass C (SMBC, mg C 100 g^{-1} soil) was estimated from the SIR measurement and calculated from the CO_2 (mL 100 g^{-1} h^{-1}) evolved after 6 h of soil incubation: $SMBC = 40.04 \times CO_2 + 0.37$ (Anderson and Domsch, 1978).