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Research article

Field approach to mining-dump revegetation by application of sewage sludge co-compost and a commercial biofertilizer

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ABSTRACT

An approach was devised for revegetation of a mining dump soil, sited in a semiarid region, with basic pH as well as Fe and Mn enrichment. A field experiment was conducted involving the use of co-compost (a mixture of urban sewage sludge and plant remains) along with a commercial biofertilizer (a gel suspension which contains arbuscular mycorrhizal fungus) to reinforce the benefits of the former. Four treatments were studied: unamended soil; application of conditioners separately and in combination. Pistachio, caper, rosemary, thyme and juniper were planted. We evaluated the effects of the treatments using soil quality (physicochemical properties, total content of hazardous elements, nutrient availability, microbial biomass and enzyme activities) and plant establishment indicators (survival, growth, vigor, nutrient content in leaves, nutrient balances and mycorrhizal root colonization). Thyme and juniper did not show a suitable survival rate (<50%) whereas 70–100% of the pistachio, rosemary and caper survived for at least 27 months. In unamended soil, plant growth was severely hampered by P, N, K and Zn deficiencies as well as Fe and Mn excess. Overall, the treatments affected the soil and plant indicators as follows: biofertilizer + co-compost > co-compost > biofertilizer > unamended. The application of co-compost was therefore essential with regard to improving soil fertility; furthermore, it increased leaf N and P content, whereas leaf Fe and Mn concentrations showed a decrease. The combined treatment, however, provided the best results. The positive interaction between the two soil conditioners might be related to the capacity of the biofertilizer to increase nutrient uptake from the composted residue, and to protect plants against Fe and Mn toxicity.

1. Introduction

Surface mining is one of the most complete forms of anthropogenic habitat alteration and degradation. Mining dumps generally accumulate huge amounts of mineral wastes, a fact that disrupts soil physicochemical and biological properties. In most cases, the relatively low concentration of organic matter and available nutrients content, the presence of potentially toxic elements, as well as an extreme pH in the soil, constitute the main chemical limitations that constrain the natural establishment of plant communities (Juwarkar and Jambhulkar, 2008). Although there has been abundant research on the recovery of mine soils, little information is available about soils with a basic pH and high concentrations of Fe and Mn, mainly as oxides. For over three decades, reclamation of mine soils has involved the application of organic amendments, focused mainly upon sewage sludge, an inevitable by-product of wastewater treatment processes (i.e. Asensio et al., 2013; Ojeda et al., 2010; Zornoza et al., 2012). There is scientific evidence that application of sewage sludge provides a series of agronomic benefits such as increases in organic matter and nutrient availability (mainly N and P), metal immobilization, improved microbial activity, structural properties and soil moisture (Asensio et al., 2013; Ojeda et al., 2010; Sevilla-Perea et al., 2014, 2015). In order to remove unpleasant odors and organic pollutants and to prevent harmful effects on soil, vegetation, animals and water, this waste is usually composted (Tarrasón et al., 2010). Additionally, composting of sewage sludge with plant debris improves the physical properties and sanitary conditions of the final product (Tarrasón et al., 2010).

In severely degraded lands, integration of biotechnological techniques is recommended to reinforce the effects of organic amendments and to accelerate soil recovery and vegetation growth (Caravaca et al., 2002; Juwarkar et al., 2004; Juwarkar and

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Jambhulkar, 2008; Ohsowski et al., 2012). Biofertilizers are substances containing living microorganisms which promote growth by increasing the supply or availability of primary nutrients. Arbuscular mycorrhizal fungi (AM) are one of the main microorganisms proposed in biofertilizer formulations (Malusá et al., 2012) because they are globally distributed and form symbiotic associations with over 80% of terrestrial plants (Smith and Read, 2008). It is well documented that AM associations are essential for survival, growth, nutrient uptake (principally P) and water absorption by plants (Barea et al., 2011) while conferring enhanced metal resistance to the host plants (Meharg, 2003). The low inoculum levels of AM fungi in degraded ecosystems can slow the revegetation process, and the reconstitution of these levels is therefore a key factor in successful revegetation programs (Ohsowski et al., 2012). This fact has stimulated the emergence of the use of commercially-produced AM inoculum as a plant-growth promoter (Malusá et al., 2012; Ohsowski et al., 2012). But the efficiency of these commercial products should be tested prior to use in reclamation strategies (Oliveira et al., 2011) since their effectiveness depends on complex relationships between the components of the system such as plants, microorganisms and environmental conditions, particularly those of soil (Malusá et al., 2012). Moreover, pre-inoculating plants with AM inoculum in post-mine substrates has not been fully addressed (Ohsowski et al., 2012).

The objectives of this study were: 1) identify the main factors that could limit vegetation growth in degraded soils with a basic pH and high concentrations of Fe and Mn and 2) assess the effects of several treatments on soil quality and plant establishment and growth. A preliminary field trial was conducted in the mining dump of an abandoned iron mine in an arid Mediterranean area using a co-compost and a commercial biofertilizer as amendments to solve the principal problems related to the soil. The response of this approach was evaluated with the use of selected soil and plant indicators.

2. Materials and methods

2.1. Site description

This study was conducted in the Alquife mine (Southeast Spain), whose ore deposit consists of Fe oxides and hydroxides (fundamentally goethite and hematite), strata bound in Permo-Triassic marbles. The mining generated large amounts of wastes, which accumulated for many years in a mining dump (the study site), covering over 260 ha and ranging in height from 60 to 90 m. In the dump, the soil is classified as Splolic Technosol (International Union of Soil Sciences, 2006).

The area has a continental Mediterranean climate with low mean annual precipitation (average 357 mm), mainly concentrated in autumn and winter. Summers are extremely dry with a maximum temperature of 35 °C. Winters are cold with frequent frosts and low temperatures close to 0 °C in January.

A composite sample comprising 5 subsamples covering 1 ha was taken from the surface of the dump where the experimental field was located. The soil sample was air dried and sifted through a 2 mm sieve. The soil physicochemical properties, according to standard methods, consisted of 41.5% coarse fragments, 63.9% sand, 28.3 silt, 7.6% clay, 1.7 g cm^{-3} bulk density, 224 g kg^{-1} $CaCO_3$, 2.44 g kg^{-1} organic carbon (OC), 0.6 g kg^{-1} N_{Total}, 0.2 g kg^{-1} P_{Total}, 355 g kg^{-1} Fe_{Total}, 10.3 g kg^{-1} Mn_{Total}.

2.2. Co-compost, biofertilizer and plant species

The co-compost of sewage sludge and plant remains (SVC) was supplied by Biomasa del Guadalquivir S.L., Granada (Spain). It was produced by composting a sewage sludge resulting from an anaerobic digestion treatment and agricultural by-products, particularly branches and twigs pruned from olive trees. The mixture was kept in stacks approximately 3–4 m high during 6–10 months of maturation. The material was sifted through a 10 mm sieve before use. Analysis of the co-compost indicated that it had a pH of 7.32, electrical conductivity (EC) 11.4 dS m^{-1}, OC 194 g kg^{-1}, N_{Total} 26.0 g kg^{-1}, P_{Total} 20.6 g kg^{-1}, Fe_{Total} 204 g kg^{-1}, Mn_{Total} 0.28 g kg^{-1}, Cd 1.6 mg kg^{-1}, Cr 53 mg kg^{-1}, Cu 161 mg kg^{-1}, Ni 26 mg kg^{-1}, Pb 60 mg kg^{-1} and Zn 517 mg kg^{-1}; Co mg kg^{-1} < the detection limit of the method.

The commercial biofertilizer was provided by Mycovitro from Granada (Spain). This product comprises a semisolid gel suspension with a concentrate of AM fungus cultured in vitro. The gel contains over 2000 propagules or propagating material per cm^3 (spores, mycelium hyphae and infective mycorrhizal root residues).

Plant species were selected based on their potential for survival in hostile environments as well as their adaptation to arid climates with well-developed root systems capable of penetrating the compacted soil. Among the species that exhibited these characteristics, those with possible commercial use were selected. *Thymus zygis* (thyme), *Rosmarinus officinalis* (rosemary) and *Capparis spinosa* (caper) are native species widely distributed around the mine zone and are ecologically adapted to the prevailing environment. The three species were reported as surviving in other hostile environments where high concentrations of Fe and Mn as well as other metals were also found (Affholder et al., 2013; Parraga-Aguado et al., 2013). *Pistacia vera* (pistachio) is an agricultural species planted in some areas around the mine and in arid and semiarid regions and is a sustainable alternative for the recovery of degraded lands (Groninger, 2012). Finally, *Juniperus horizontalis* (juniper) was selected for its potential in slope stabilization (Comino and Marengo, 2010).

2.3. Seedling treatment

Seedlings of pistachio (approximately 40 cm in height), thyme, rosemary, juniper (approx. 10 cm in height) and caper (approx. 3 cm in height) were provided by a local nursery. Half the plants of each species were transplanted directly to a peat substrate. The other half was inoculated in the laboratory by immersing the root ball in biofertilizer prior to being transplanted to the peat substrate. For the pistachio seedlings, the biofertilizer was applied by irrigation once they had been transplanted to the peat substrate. The biofertilizer was added at the dose described by the manufacturer (5 mL per 1 L of substrate). The seedlings were grown for one month in a lath house and no additional chemical fertilizer was used.

2.4. Field experiment design and monitoring

An area lacking vegetation cover and with a slope <5% (flat) was selected. Four plots (3 × 5 m) spaced 1–2 m were delimited. Rock fragments were manually removed and the first 15–20 cm of the soil profile was turned. Two factors were combined in the experimental design; amendment of soil with co-compost (SVC) and inoculation of seedlings with biofertilizer (B). As a result four treatments were obtained: unamended soil and untreated seedlings (s) or control, unamended soil and inoculated seedlings (s + B), addition of co-compost to soil and non-inoculated seedlings (s + SVC) and finally, addition of co-compost and inoculated seedlings (s + SVC + B).

In February 2011, the co-compost was added to the two corresponding plots at a dose of 75 t ha^{-1} and mixed with the surface soil with a rake. One month later, seedlings of a similar height from