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Quality of trace element contaminated soils amended with compost under fast growing tree *Paulownia fortunei* plantation

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ABSTRACT

The use of fast growing trees could be an alternative in trace element contaminated soils to stabilize these elements and improve soil quality. In this study we investigate the effect of *Paulownia fortunei* growth on trace element contaminated soils amended with two organic composts under semi-field conditions for a period of 18 months. The experiment was carried out in containers filled with tree different soils, two contaminated soils (neutral AZ and acid V) and a non contaminated soil, NC. Three treatments per soil were established: two organic amendments (alperujo compost, AC, and biosolid compost, BC) and a control without amendment addition. We study parameters related with fertility and contamination in soils and plants. Paulownia growth and amendments increased pH in acid soils whereas no effect of these factors was observed in neutral soils. The plant and the amendments also increased organic matter and consequently, soil fertility. Positive results were also found in soils that were only affected by plant growth (without amendment). A general improvement of "soil biochemical quality" was detected over time and treatments, confirming the positive effect of amendments plus paulownia. Even in contaminated soils, except for Cu and Zn, trace element concentrations in leaves were in the normal range for plants. Results of this mid-term study showed that *Paulownia fortunei* is a promising species for phytoremediation of trace element polluted soils.

1. Introduction

The use of fast growing trees is an encouraging tool for reducing atmospheric CO_2 and production of agroforestry plantations for biomass production (Calfapietra et al., 2010). However negative effects on soil fertility have been attributed to this type of plants (Alfaia et al., 2004), because their high nutrient demands are removed as harvested products (Szott et al., 1991). The use of compost in this kind of plantations could be an alternative to industrial fertilizers and could provide an interesting recycling solution for wastes. Composts, in addition to nutrient release (Larchevêque et al., 2006), may offer additional benefits to mineral fertilizers by reducing planting shock since it can also improve soil structure and, consequently, create better conditions for root development (porosity, aeration, and water-holding capacity; Pagliai et al., 1981).

Besides the increase in soil fertility, in heavy metal contaminated soils, the use of wastes and byproducts as amendments enhances those processes (sorption, precipitation and complexation reactions) that take place naturally in soils to reduce mobility and bioavailability of trace elements. For that reason, organic amendments could be considered as a complement of any phytoremediation strategy (Adriano et al., 2004). Phytoremediation is a low cost and environmental friendly technique that has been spread for remediation technologies (Ali et al., 2013). Among different strategies of phytoremediation, phytostabilization involves the establishment of a plant cover on the surface of the contaminated sites with the aim of reducing the mobility of contaminants. The process includes transpiration and root growth that immobilizes contaminants by reducing leaching, controlling erosion, creating an aerobic environment in the root zone, and adding organic matter. Phytostabilization can be enhanced by using soil amendments that immobilize metal(loid)s combined with plant species that are tolerant of high levels of contaminants and low-fertility soils or tailings (Bolan et al., 2011).

Trees can be successfully used in phytostabilization because of their ability to grow on nutrient poor soil, deep root system, fast rate of growth, metal-resistance traits and economically viable secondary use. Thanks to these features, trees are able to stabilize, extract, degrade or volatilize soil contaminants (Azzarello et al.,

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2011). Most of the studies of phytoremediation using trees focus on the use of varieties of willows or poplars (Lepp and Madejón, 2007; Ciadamidaro et al., 2013; Vervaeke et al., 2003) have been chosen because of an array of characteristics (e. g. fast-growing tree, producing large yields and having a high energy potential, high capacity to stabilise polluted substrates, recycle nutrients and accumulate pollutants in their tissues). However, recently some studies have also focused on Paulownia spp (Doumett et al., 2008; Macci et al., 2012, 2013).

Paulownia spp is an extremely fast-growing deciduous tree species with vegetative propagation and tolerance to different soil and climate conditions (Wang and Shogren, 1992). This tree is original of China and its natural distribution ranges from tropical through to cool temperate climates. Paulownia could be considered as a low demand water plant, in spite of not growing in arid zones (Lucas-Borja et al., 2011). This species has an elevated biomass production during its growth phase (Chirko et al., 1996) and it has been calculated that each Paulownia tree could produce a cubic meter of wood at the age of 5–7 years, producing annually 150 t ha^{-1} of biomass in intensive plantations with about 2000 trees by ha (Lucas-Borja et al., 2011).

This work aims to propose an integrated solution to increase the fertility of contaminated soils for the production of *Paulownia fortunei* to obtain biomass that could be used for energy purposes reusing at the same time organic wastes and the potential use of this tree for phytoremediation. The use of these materials in soil reclamation could fulfill three objectives: i) recycling of wastes and byproducts, ii) immobilization of trace elements and iii) restoration of quality and increase productivity of soil.

2. Materials and methods

2.1. Experimental design

The experiment was carried out under semi field conditions using two trace element moderately contaminated soils, Aznalcázar (AZ) and Vicario (V), and a non-contaminated control soil (NC) (Table 1). Trace-element contaminated soils, AZ and V, were collected in the area affected by a mine spill, the Aznalcóllar mine accident (28th April 1998) in South West of Spain (Grimalt et al., 1999). Non-contaminated soil (NC) was collected in the experimental farm "La Hampa" (IRNAS-CSIC) in Coria del Río (Southern Spain). The experiment was carried out in 27 containers (90 L of volume and 1 m height) that were placed outdoors. Containers filled with the soils were arranged according to a complete randomized block design with three treatments (two organic amendments and a control without amendment addition) and three replicates per treatment. The organic amendments were: AC, "alperujo" compost (alperujo is a solid by-product from the extraction of olive oil), and BC, biosolid compost.

The amendments were added in November 2011 at a dose rate of 30,000 kg ha^{-1}. High acidity, low OM content and moderately high values of total trace elements of soil V (Table 1), advised a second addition of 25,000 kg ha^{-1} of each amendment in March 2012. In each container a *Paulownia fortunei* sapling from the Huelva University nursery was planted (saplings height around 10–15 cm). Amendments characteristics are shown in Table 2.

Containers were irrigated daily during the higher growth stage (May to October), though a drip irrigation hose with two emitters of 3 L h^{-1}per container. The mean water dose during this time was 333 ml per container and day. This value was calculated taken into account the evapotranspiration demand to keep the soil moisture close to its water holding capacity.

Soil pore water was sampled by 'Rhizon' samplers (Eijkelkamp Agrisearch Equipment, The Netherlands) inserted laterally into the containers at 20 cm depth. Pore water was sampled at regular intervals (after rainfall episodes; Fig. S1) throughout the experimental period using removable needles attached by a Luer–Lock connection to the sampler and vacuum tubes to extract soil pore water from the sampler.

Soil samples at 0–15 cm depth were taken in November 2011 (first sampling) in May 2012 (second sampling) and May 2013 (third sampling). The soil was sieved (2 mm) and stored at 4 °C for a few days to prevent moisture loss before assaying for microbiological analysis. One sub-sample was air dried, crushed and sieved (first <2 mm and then <60 μm) for chemical analysis.

Leaves were sampled in 2013 previous the cut down of each Paulownia tree to obtain total biomass (including shoots, leaves and trunk).

2.2. Soil chemical properties determination

Soil pH was measured in a 1 M KCl extract (1:2.5, m/v) after shaking for one hour (Hesse, 1971) using a pH meter (CRISON micro pH 2002). Electrical conductivity (EC) of soil was measured in the extract 1:5 soil/water. The available trace element (As, Cd, Cu, Pb and Zn) concentrations in soils were determined in 0.01 M $CaCl_2$ (1:10 m/v) extracts after shaking for three hours (Houba et al., 2000). Pseudo-total trace element concentrations in soil samples (<60 μm) were determined by digestion with *aqua regia* (1:3 v:v

Table 1
Characteristic and total trace element content in the studied soils (NC; no-contaminated, AZ; Aznalcázar site, V; Vicario site). Mean values (SE of three replicates).

	NC	AZ	V
pH	7.5 (0.01)	6.93 (0.14)	3.68 (0.07)
TOC (g kg^{-1})	5.10 (0.26)	15 (6.9)	5 (2.8)
As (mg kg^{-1})	8 (3)	100 (90).0	300 (80)
Cd (mg kg^{-1})	0.59 (0.09)	4 (2.1)	1 (0.4)
Cu (mg kg^{-1})	19 (3.5)	200 (70)	180 (30)
Pb (mg kg^{-1})	15 (0.69)	236 (20)	600 (20)
Zn (mg kg^{-1})	52 (5.79)	310 (60)	370 (70)

Table 2
Main Characteristics of the two compost used as amendments. Mean values (the standard deviation of three replicates).

Parameters	AC	BC
Moisture (%)	14.9 (0.79)	15.6 (0.81)
pH	8.10 (0.21)	7.09 (0.28)
Organic matter (%)	29.1 (1.63)	22.6 (0.39=)
P (%P_2O_5)	2.54 (0.10)	3.43 (0.11)
K (% K_2O)	2.30 (0.05)	0.82 (0.04)
Ca (% CaO)	13.8 (0.15)	12.5 (0.37)
Mg (% MgO)	1.48 (0.02)	1.23 (0.04)
S (% SO_3)	0.90 (0.01)	2.24 (0.06
Na (mg kg^{-1})	0.17 (0.001)	0.10 (0.01)
Ni (mg kg^{-1})	15.0 (1.15)	29.3 (0.49)
Fe (mg kg^{-1})	11550 (100)	20800 (700)
Cu (mg kg^{-1})	94.2 (1.12)	188 (10.9)
As (mg kg^{-1})	2.45 (0.22)	13.5 (0.60)
Co (mg kg^{-1})	4.11 (0.07)	7.09 (0.10)
Cd (mg kg^{-1})	0.25 (0.00)	1.94 (0.09)
Pb (mg kg^{-1})	9.77 (0.06)	61.4 (4)
Mn (mg kg^{-1})	360 (5.34)	570 (36)
Zn (mg kg^{-1})	185 (11.1)	600 (32.0)
DHA (μg INTF g^{-1} dry soil h^{-1})	1.0 (0.1)	4.8 (0.31)
BGA (μg PNF g^{-1} dry soil h^{-1})	90 (23)	29.3 (1.70)
UA (μg N–NH_4 g^{-1} dry soil h^{-1})	20 (9)	20 (20)

DHA = dehydrogenase activity; BGA = β-glucosidase activity; UA = urease activity; PNP = p-nitrophenol; INTF = iodonitrotetrazolium formazane; CA = compost of "Alperujo"; CB = compost of biosolids.