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Research article

Three-year study of fast-growing trees in degraded soils amended with composts: Effects on soil fertility and productivity

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ABSTRACT

Currently, worries about the effects of intensive plantations on long-term nutrient supply and a loss of productivity have risen. In this study two composts were added to degraded soils where this type of intensive crops were growing, to avoid the soil fertility decrease and try to increase biomass production. For the experiment, two degraded soils in terms of low organic carbon content and low pH were selected in South-West Spain: La Rábida (RA) and Villablanca (VI) sites. Both study sites were divided into 24 plots. In RA, half of the plots were planted with *Populus* x *canadensis* "I-214"; the other half was planted with *Eucalyptus globulus*. At the VI site, half of the plots were planted with *Paulownia fortunei*, and the other plots were planted with *Eucalyptus globulus*. For each tree and site, three treatments were established (two organic composts and a control without compost), with four replications per treatment. The organic amendments were "alperujo" compost, AC, a solid by-product from the extraction of olive oil, and BC, biosolid compost. During the three years of experimentation, samples of soils and plants were analyzed for studying chemical and biochemical properties of soil, plant growth and plant nutritional status and biomass production. The composts increased total organic carbon, water-soluble carbon, nutrients and pH of soil only in the most acidic soil. Soil biochemical quality was calculated with the geometric mean of the enzymatic activities (Dehydrogenase, β-glucosidase, Phosphatase and Urease activities) determined in soils. The results showed a beneficial improvement in comparison with soils without compost. However, the best results were found in the growth and biomass production of the studied trees, especially in *Eucalyptus*. Nutritional levels of leaves of the trees were, in general, in the normal established range for each species, although no clear effect of the composts was observed. The results of this study justify the addition of compost to guarantee good biomass production and maintain or improve soil management in degraded soils, especially in acid soils.

1. Introduction

Biomass of trees is one of the main sources of energy and is currently the most important supply of renewable energy in the world (Lauri et al., 2014). By 2050, FAO (2001) infers that these plantations will cover 5–10% of the world's forested land area; therefore, their effects on the environment, and in particular on soil, have to be studied.

From the environmental point of view, fast-growing tree biomass production replaces non-renewable carbon materials and promotes carbon sequestration and other ecosystem services such as improvement of soil and water quality, reduced erosion and increased biodiversity (Evangelou et al., 2012). Moreover, the proportion of biomass plantations could be considered part of the global strategy for enhancing rural development and could reduce the net atmospheric accumulation of CO_2 (García Morote et al., 2014). However, worries about the effects of these intensive plantations on long-term nutrient supply and loss of productivity of soils have arisen (Vanguelova and Pitman, 2009). In particular, in the Mediterranean region, the increasing pressure on agricultural land can result in high nutrient loss and declines in soil fertility (Cuvardic et al., 2004). These soils are often deficient in organic

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matter, nitrogen, and phosphorus (Rashid and Ryan, 2004) causing decreases in nutrient supply and, in turn, direct effects on plant productivity. In these types of degraded areas, soils present weakened ecosystems with low organic matter and nutrient content, which are prone to irremediable degradation processes (López Bermúdez and Albaladejo, 1990).

One method for recovering degraded soils is to incorporate organic matter from organic waste (Pascual et al., 1998). These organic materials can improve microbial activity and growth, enhancing biogeochemical nutrient cycle (Ros et al., 2003; Lakhdar et al., 2011). Moreover, the application of organic wastes with a high quality to soils can reduce the environmental impact associated with waste disposal and enhance the productivity of biomass production systems (Quaye et al., 2011). This study is an advance in using organic wastes in degraded soils. The addition of compost from organic material easily available and inexpensive, is an interesting option to improve not only soil fertility, but also to increase the value of these soils for fast biomass crops, increasing plant nutrition and yield.

The aim of this three-year-study was to evaluate (at short and midterm) the influence of two stable composts on chemical and biochemical productivity of two soils planted with three common fast growing trees: a hybrid of *Populus nigra* and *Populus deltoids*, *Eucalyptus globulus* and *Paulownia fortunei*. We hypothesize that composts could improve soil quality and, therefore, increase biomass production in degraded soils.

2. Materials and methods

2.1. Study site and experimental design

Two degraded soils were selected in the province of Huelva (Andalucía, South-West Spain). One was located at the University of Huelva, Campus of La Rábida (RA) (UTM, zone 29S, X: 684875, Y: 4119130, 15 m.a.s.l.); the other degraded area was located in the area of Villablanca town (VI), (UTM, zone 29S, X: 649340, Y: 4132898, 129 m.a.s.l.). The main soil characteristics are showed in Table 1.

The total area of each site was 720 m^2. Both study sites were divided into 24 plots (30 m^2 per plot). In RA, half of the plots (12) were planted with *Populus x canadensis* "I-214", which is a hybrid of *P. nigra* and *Populus deltoides* (PO). The other 12 plots were planted with *Eucalyptus globulus* "O-ENCE" (E). In VI, half of the plots (12) were planted with *Paulownia fortunei* "Pw-UHU" (PA), and the other 12 plots were planted with *Eucalyptus globulus* "O-ENCE" (E). In each plot, 15 plants of the corresponding crop were established. At the time of planting (between April and June 2011), the vegetative material consisted of *Eucalyptus* plants of 25 cm in height coming from rooted softwood cuttings, *Paulownia* plants of 15–20 cm in height coming from rooted and sprouted root cuttings, and poplar hardwood cuttings of 20 cm in length. For each plant species and site, three treatments were established (two organic composts and a control without a compost addition), with four replications per treatment. The organic amendments were: alperujo compost, AC, a solid by-product from the extraction of olive oil provided by the company "Coto Bajo" Córdoba Southern Spain, and biosolid compost, BC, provided by EMASESA, Sevilla, Southern Spain, constituted of wastewater sludge from a water treatment plant and green waste from parks and gardens. The main characteristics of the two composts are shown in Table 2. The compost application was done in November 2011 around each tree in the following doses: four kg of Alperujo Compost in AC plots and 2.25 kg of Biosolid Compost in BC plots. The doses were equivalent to 300 kg of N per ha. The same compost application was done in the same plots in November 2012. Each year, from May to September and according to the rainfall, 250–350 mm of water was provided by drip irrigation in order to offset summer drought at both sites.

Table 1
Soil general characteristics (Mean values; n = 10, in brackets standard deviation).

Parameter	RA	VI
pH	6.49 (0.04)	4.68 (0.08)
EC (dS m^{-1})	91.4 (9.52)	68.9 (10.7)
TOC (g kg^{-1})	8.54 (3.63)	7.64 (3.99)
N-Kjel (g kg^{-1})	0.66 (0.17)	0.54 (0.27)
Avail-P (mg kg^{-1})	8.47 (1.57)	4.96 (0.16)
Avail-K (mg kg^{-1})	55.0 (7.55)	54.7 (4.72)

2.2. Soil and leaves samples

Three soil samplings were performed in both sites in spring of 2012 (first sampling), spring of 2013 (second sampling) and spring 2014 (third sampling). Soil samples were taken around the trees at 0–20 cm depth. The soil was sieved (2 mm) and one sub-sample was stored at 4 °C for a few days to prevent moisture loss before assaying for microbiological analysis. The other sub-sample was air dried, crushed and sieved (<2 mm and <60 μm) for chemical analysis.

At each plot a representative sample of leaves of each tree was collected at the same time than soil samples. Vegetal material (leaves) was washed with a 0.1 N HCl solution for 15 s and with distilled water then for 10 s. Washed samples were oven dried at 70 °C. Dried plant material was ground and passed through a 500-μm stainless-steel sieve prior to preparation for analysis.

2.3. Shoot growth and biomass production

Crop development was followed through periodic measurements of height (H) and stem diameter at the base (D), measured 7 cm aboveground). This is every three months, three trees per plot were measured for height (H) and 5 trees per plot were measured for diameter (D).

Part of biomass assessment was carried out by cuttings and direct weighing (39 trees of Populus, 28 trees for Eucalyptus and 12 for Paulownia). These measures were carried out at different seasons and years to weigh different sizes of trees. The other part of the biomass assessment was done using allometric equations which relate the diameter at the base and/or the height of the main stem with the aboveground dry biomass (Pannacci et al., 2009; Paris et al., 2011; Bouvet et al., 2013).

The equations for the three-year experiment to calculate the

Table 2
Main characteristic of the amendments.

Parameter	Alperujo compost	Biosolids compost
pH	8.10	7.09
Organic matter (%)	30.1	24.6
N (%)	1.56	2.27
P (%P_2O_5)	2.54	3.43
K (% K_2O)	2.30	0.82
Ca (% CaO)	13.8	12.5
Mg (% MgO)	1.48	1.23
S (% SO_3)	0.90	2.24
As (mg kg^{-1})	2.45	13.5
Cd (mg kg^{-1})	0.25	1.94
Cu (mg kg^{-1})	94.2	188
Mn (mg kg^{-1})	360	573
Pb (mg kg^{-1})	9.77	61.4
Zn (mg kg^{-1})	185	601