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A strategy for marginal semiarid degraded soil restoration: A sole addition of compost at a high rate. A five-year field experiment

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ABSTRACT

This work evaluates the mid-term impact of the addition of large amounts of an organic amendment on the recovery of the physical, chemical and, particularly, the microbiological properties of a marginal semiarid degraded soil and on increasing the soil organic C pool. In order to perform this study, a semiarid degraded soil was treated with composted urban waste at doses equivalent to the addition of 1% (S + CCD1) and 3% (S + CCD2) of organic C (C_{org}). Changes in soil characteristics in the amended soils were evaluated with respect to a control soil without organic amendment for a period of 5 years after the organic amendment was applied. A spontaneous vegetal cover developed on both amended and unamended soils 3–4 months after the organic amendments were added, yet the level of vegetal biodiversity was lower in the amended plots. Compost-amended soils showed higher concentrations of C_{org}, water-soluble C and water-soluble carbohydrates than the control soil throughout the experimental period. Furthermore, all of these C fractions were significantly higher ($p \leq 0.05$) in S + CCD2 than in S + CCD1 and the control soil. However, compost addition also increased soil electrical conductivity and nitrate content, particularly at the higher dose. Likewise, compost addition produced a 4- to 10-fold increase in soil heavy metal concentrations, although the levels of heavy metal were under the limits allowed in soils. Five years after the organic amendment was added, the soil water holding capacity, stable aggregate percentage, porosity and nutrient and humic substance and humic acid content were greater in amended soils than in control soil, and the higher dose produced greater increases than the lower dose. Soils receiving the highest dose of compost also showed the highest values of basal respiration, dehydrogenase activity and β-glucosidase and phosphatase activity, as well as a greater abundance of total PLFAs, bacterial and fungal PLFAs, and saturated and monounsaturated fatty acids. A greater level of functional diversity was also observed in amended soils, particularly in the soil receiving the higher dose of compost. It can be concluded that the addition of high doses of compost can be a suitable strategy for restoring semiarid degraded soils and for fixing C in these soils, provided that the organic material is of high quality and has a low concentration of heavy metals.

1. Introduction

The increase in the generation of organic waste around the world poses a problem that demands an immediate solution. Likewise, the high level of soil degradation in large areas of Spain and southeastern Europe resulting from years of aggressive human activity and adverse weather conditions (semiarid) is also a problem that demands an immediate solution.

The low level of organic matter in semiarid soils is the key factor in their degradation (García and Hernandez, 1996). The fact that the traditional sources of organic matter (peat and manure) are scarce in extensive areas in Spain and in other European countries, particularly in southern Europe, has led to the use of organic matter contained in organic waste as a source of soil organic matter. Organic matter derived from municipal organic wastes (sewage sludge and organic waste from households) has been used in particular because it is inexpensive and in ready supply. The goal of using such matter is twofold: it not only improves the quality and fertility of degraded soils but also simultaneously eliminates organic waste in a rational and environmentally friendly manner.

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At the same time, this strategy could promote carbon sequestration by increasing the stable carbon reserves in the soil, helping to mitigate the negative effects of CO_2 emissions in the atmosphere (Swift, 2001; García et al., 2012).

Applying organic amendments improves the physical properties of the soil, increasing soil structural stability and water retention capacity and reducing apparent density, thereby increasing porosity (Caravaca et al., 2002). Organic amendments also improve the chemical and microbiological characteristics of the soil, enriching it with compounds similar to humic substances and with macro and micronutrients (Doni et al., 2014; Hernandez et al., 2014; Jain et al., 2014). At the same time, such amendments stimulate the development and activity of soil microbial populations (Ros et al., 2003; Tejada et al., 2006; Pajares et al., 2009; Macci et al., 2012). For all of these reasons, organic amendments are considered to be an invaluable source of organic matter for improving the quality of degraded soils.

Soil microorganisms are responsible for important cycles in the soil due to their key role in almost all reactions taking place in the soil. These microorganisms intervene as much in the decomposition of organic matter at the ecosystem level as they do in processes like humification. Monitoring the modifications that these microorganisms undergo is extremely useful in studying changes in the soil after a given disturbance, such as the addition of organic materials, the presence of contaminants, drought, etc., since microorganisms are the first to respond to any changes occurring in the ecosystem.

An effective way to find out how any action performed on the soil affects soil microbial populations is to estimate the enzyme activity, since soil enzymes are responsible for catalysing most of the chemical reactions that occur in the soil (Tiquia, 2002). Measuring enzyme activity gives us information about the potential of the soil to perform specific reactions that play a significant role in nutrient cycling, which is extremely important in terms of soil quality. Extracellular enzymes such as hydrolases provide information on the cycles of C (β-glucosidase), N (urease) and P (phosphatase) in the soil (García et al., 2002). These enzymes are also involved in soil fertility, making available the nutrients that the plants and the soil microorganisms themselves need for development.

Other indicators can give us an accurate idea of the impact of adding organic amendments on the soil microbial community, such as the overall metabolic activity of the soil microorganisms (respiration, ATP and dehydrogenase activity); changes in the microbial community structure (fatty acid profile of phospholipids, PLFAs); and the functional diversity of the microbial community (Biolog).

The functional diversity of microbial communities present in a soil can be evaluated based on the ability of microbial populations to use various carbon sources. The degree of utilisation of various substrates applied to a sample thus provides information on the different physiological capacities of the organisms that compose the sample, representing the community level physiological profile (CLPP) (Degens and Harris, 1997). The “Biolog Ecoplate” identification system is a quick and effective procedure for assessing the functional diversity of microbial communities present in soils (CLPP). Despite its limitations, this technique can be used to get an overview of the microbial functional diversity as it provides useful information regarding the potential activity of the bacterial community that is able to grow on a given substrate (Braun et al., 2010). The “Biolog Ecoplate” has also been recognised as a good tool for comparing the bacterial communities of soils (Ros et al., 2006) and for controlling the changes produced in the microbial community by environmental conditions or soil management practices (Ovreas, 2000).

Phospholipid fatty acid analysis (PLFA) is another technique for describing soil microbial communities. Fatty acids are derived from the membranes of the cells of microorganisms, and their presence in the soil is therefore an indicator of the existence of viable biomass. Fatty acids are considered useful biomarkers for detecting different groups of microorganisms (Díaz-Raviña and Bååth, 2001).

Several previous studies have established the suitability of adding organic amendments for degraded soil bioremediation (Ros et al., 2003; Crecchio et al., 2004; Masciandaro et al., 2013). However, there is little information regarding whether degraded soils in semiarid environments are capable of supporting large quantities of organic matter. Furthermore, little is known concerning either the mid-term impact of the rate of application of such residues on soil recovery or the extent to which the exogenous carbon is fixed in the soil.

For this reason, the aim of this work was to evaluate the mid-term impact of the addition of large amounts of an organic amendment (urban waste compost) on the recovery of the physical, chemical and, particularly, the microbiological properties of a semiarid degraded soil. An additional goal was to determine the mid-term effect of adding this amendment on the chemical fixation of C in this semiarid soil.

2. Materials and methods

In a marginal area with abandoned, degraded soils formerly used for agricultural purposes, 30 m^2 plots were established and subjected in triplicate to the following rehabilitation treatments: i) the addition of commercial compost at rate of 1% C_{org} (150 t compost ha^{-1}, fresh weight), (S + CCD1); ii) the addition of compost at rate of 3% C_{org} (450 t compost ha^{-1}, fresh weight) (S + CCD2); and iii) no amendment (control). Compost was only applied at the beginning of the experiment (a sole addition of compost).

The experimental site was located in the Region of Murcia, a Mediterranean area in south-east Spain with a semiarid climate (average annual temperature, 18 °C; average annual rainfall, 200 mm). The soil was a Calcic Xerosol (FAO-UNESCO, 1988), and the organic amendment used was a commercial compost made from a mixture of the organic fraction of domestic household and sewage sludge at a ratio of 2:1. The main characteristics of this compost are shown in Table 1.

Soil samples were collected from the upper soil layer (0–15 cm) at the beginning of the experiment and then 1, 3 and 5 years after the organic amendment was added. Samples were composed of 8 subsamples, which were taken from around the entire experimental plots and then homogenised, passed through a 2 mm sieve

Table 1
Compost characteristics (dry wt) (means ± standard error, n = 3).

pH (H_2O, 1:2.5)	7.06 (0.26)
Electrical conductivity (1:5) (dS m^{-1})	4.17 (0.12)
Total organic carbon (g $100g^{-1}$)	28.05 (0.80)
Total nitrogen Kjeldahl (g $100g^{-1}$)	2.00 (0.06)
Total phosphorus (g $100g^{-1}$)	1.08 (0.06)
Total potassium (g $100g^{-1}$)	0.81 (0.03)
Humic substance C (g $100g^{-1}$)	0.61 (0.1)
Humic acid C (g $100g^{-1}$)	0.36 (0.05)
Cu (mg kg^{-1})	294.58 (8.50)
Zn (mg kg^{-1})	621.05 (17.92)
Fe (mg kg^{-1})	18420.42 (531.76)
Mn (mg kg^{-1})	182.09 (5.26)
Pb (mg kg^{-1})	98.97 (2.86)
Ni (mg kg^{-1})	49.86 (1.44)
Cd (mg kg^{-1})	2.13 (0.06)
Cr (mg kg^{-1})	139.36 (4.02)