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Effects on soil phosphorus dynamics of municipal solid waste compost addition to a burnt and unburnt forest soil

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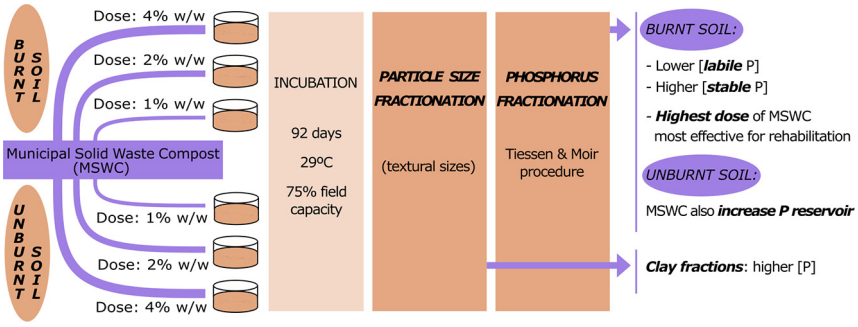
HIGHLIGHTS

- The highest dose of compost was the most effective one for rehabilitation purposes.
- In studied soils most P forms presented higher concentrations in clay fractions.
- Compost increased available P_i and Ca associated P_i available in the long term.
- Compost addition increased total P concentrations in sand and silt fractions.

GRAPHICAL ABSTRACT



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ABSTRACT

The main aim of this research was to assess the effects of municipal solid waste compost (MSWC) addition to a burnt and unburnt calcareous soil, on the distribution of soil P forms in particle-size and extractable fractions. Three MSWC doses (1, 2 and 4% w/w) were added to burnt and unburnt soil samples and were incubated for 92 days at 29 °C and 75% of field capacity moisture. A particle-size fractionation followed by a sequential P extraction procedure was carried out. The burnt soil showed significantly lower concentrations of organic P forms (P_{org}) and significantly higher concentrations of stable P forms than the unburnt soil. Besides, in both burnt and unburnt soils, most P-forms presented higher concentrations in the clay fractions than in the sand and silt fractions, possibly due to the different proportions of microbial synthesized and plant-derived substances in the different particle-size fractions. Finer fractions of MSWC showed higher total P and P_{org} concentrations than coarser fractions. Our results showed that the highest dose of MSWC was the most effective one for the rehabilitation of the burnt soil. MSWC amendment also caused an increase in soil P availability in the unburnt soil which initially contained relatively low levels of P. During the incubation process, a high proportion of organic P contained in the MSWC was mineralized into inorganic P forms. These forms were precipitated with Ca cations which are very abundant in these calcareous soils, significantly increasing the P fraction extracted by HCl in both amended

Abbreviations: MSWC, municipal solid waste compost; C_{org}, organic carbon; AEM, anion-exchange membrane; P_i, inorganic phosphorus; P_{total}, total phosphorus; P_{org}, organic phosphorus; P_AEM, P extracted with anion exchange membranes; P_i_$NaHCO_3$, inorganic P extracted with 0.5 M $NaHCO_3$; P_{org}_$NaHCO_3$, organic P extracted with 0.5 M $NaHCO_3$; P_i_NaOH, inorganic P extracted with 0.1 M NaOH; P_{org}_NaOH, organic P extracted with 0.1 M NaOH; P_HCl1M, P extracted with 1 M HCl; P_HCl_{conc}, P extracted with concentrate HCl; P_HClO_4, P extracted through digestion with concentrate $HClO_4$ (230 °C).

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soils. Hence, adding compost to the soil involved an increase in the available P reservoir in the long term. The combination of particle-size fractionation, chemical sequential extraction and incubation experiments can be a valuable tool for splitting soil phosphorus into different fractions regarding their availability in relation to short and long-term transformations in soil.

1. Introduction

Forest fires are one of the greatest environmental problems in the Mediterranean area, and one of the leading causes of desertification. After forest fires, which often lead to ecological and economic catastrophes, burnt areas must be effectively restored. Disturbances caused by fire in forest ecosystems have immediate effects on soils by eliminating the organic cover, affecting the stability of soil aggregates, altering the microbial community and changing the structural conditions as well as physical, chemical and biological soil properties (Larchevêque et al., 2006). These effects result in a loss of long-term fertility.

Phosphorus is one of the most important elements limiting primary productivity. Phosphorus deficiencies are due to the poor solubility of P salts, its slow diffusion, and high P fixation, that cause a low P availability in soils even though the total soil P concentrations are usually high (Verma and Marschner, 2013).

One of the most useful and studied alternatives for the recuperation of burnt soils in Mediterranean ecosystems is the application of composts from different sources (Cellier et al., 2012; Larchevêque et al., 2006; Malik et al., 2012). An increase in available nutrients, mainly in organic soil fractions, is caused by compost amendment, which enhances physical, chemical and biological soil properties (Larchevêque et al., 2006).

When compost is added to soil, the effect on soil P availability does not only depend on chemical properties of the added compost (Verma and Marschner, 2013), but also on the particle-size distribution of the compost (Gómez-Muñoz et al., 2011) and on the subsequent P redistribution in the soil (Peters et al., 2011). Doublet et al. (2010) and Fangueiro et al. (2008) have studied the mutual dealings between particle-size distribution of composted organic matter and C and N dynamics. However, little is known about the redistribution of added P among the different P pools and particle sizes of soils.

The Tiessen and Moir (1993) sequential fractionation method has been widely used for characterising the organic and inorganic forms of P differing in their availability for plants and microorganisms (Turrión et al., 2000a, 2000b, 2007). Fractionation procedures allow differentiating between inorganic and organic forms of P which participate in short and long-term transformations in the soil. These procedures also help to perform a complete assessment of different forms of P and to evaluate the availability of organic P for plants (Zamuner et al., 2008). Such information is essential to understand soil P dynamics and to determine whether redistribution between inorganic and organic fractions occurs when P is added to the soil.

The current study deals with the use of municipal solid waste compost (MSWC) on recovering burnt forest soils. It was conceived in the context of a reclamation project of a burnt forest area and it also included a field experience of soil recovery using MSWC (Turrión et al., 2012). Besides, it comprises a double benefit for sustainability purposes: the contribution to the recovery of an ecosystem damaged by a forest fire, and the revalorization of waste materials. Our study aims to contribute to achieve efficient alternatives and solutions for soil recovering that could be used as a reference in future restoration projects.

In order to determine which soil properties affect the compost dynamic in the soil, we compared a soil, burnt and unburnt soil, sampled 18 months after the fire, amended with the same compost. Moreover, it is also useful to determine the distribution of the added P taking into account the particle size of the soils. In this context, the main purpose of this research was to determine how the addition of MSWC under laboratory conditions (Pérez-Lomas et al., 2010) affects soil P dynamics in burnt and unburnt soil samples. The main objectives of this research were to assess the effects of three doses of MSWC added to a burnt and unburnt soil on a) soil phosphorus forms, and b) the distribution of soil phosphorus in particle-size fractions.

2. Material and methods

2.1. Location

The study area is located next to Burgos city in Northwest Spain (region of *Castilla y León*) at 897 m above sea level. Mean annual precipitation and mean annual temperature are 564 mm and 10.5 °C, respectively. Soils are developed over calcareous bedrock and they can be classified as *Leptic Cambisols* (*eutric*) by the IUSS Working Group WRB (2006). The area, called *Monte de la Abadesa* (42°19′14″ N, 3°41′11″ W), was forested during the 60s with *Pinus sylvestris* Mill. and *Pinus pinaster* Ait., and suffered the effect of a forest fire in October 2004. In the burnt area, consumption of litter layer could be observed, and no visible alteration of the mineral soil surface was found. Hence, the fire severity can be considered as moderate following the Pausas et al. (2003) classification. The fire only affected a part of the forested area. At the time of sampling, unburnt and burnt forests occurred in adjacent plots.

2.2. Soil sampling and material characterization

Soil sampling was carried out 18 months after the fire. Laboratory incubation assay was performed with soil samples from the burnt and unburnt areas (0–5 cm depth). Composite samples from each area were obtained by mixing five subsamples. The soil samples were taken from burnt and adjacent unburnt plots which were 100 m away from each other. Visible plant litter and root residues were carefully removed and soil samples were sieved (<2 mm).

The compost used for the incubation assay was a MSWC from the city of Burgos (Spain), where a non-selective collection of waste is made up. This is the reason for the high content of carbonates and relatively low percentage of C_{org} in MSWC. MSWC also presents a moderate content of heavy metals (in mg kg^{-1}: Cd 1.83; Cr 57.0; Cu 187; Ni 29.8; Pb 121 and Zn 294).

For soil and MSWC characterization, pH, electric conductivity, total N (N), total C, carbonate and organic C (C_{org}) were determined. Electric conductivity and pH were determined in a 1/2.5 soil/water suspension. Total concentrations of soil C and N were determined in an automated combustion analyser (CHN-2000, Leco). Carbonates were determined by titration (FAO, 2007). Organic carbon was calculated as the difference between total C and carbonate C.

Table 1 shows some properties of the MSWC and soils used for the incubation assay. The increase in carbonate concentration observed in the burnt soil treatment in comparison with the unburnt one could be attributed to the carbonates formation due to fire (Bodí et al., 2014; Quintana et al., 2007). The C_{org}/N ratios of the studied soils are high, but they are in the range of the ratios showed by Cools et al. (2014) under pine species.