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Use of urban composts for the regeneration of a burnt Mediterranean soil: A laboratory approach

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ABSTRACT

In Mediterranean region, forest fires are a major problem leading to the desertification of the environment. Use of composts is considered as a solution for soil and vegetation rehabilitation. In this study, we determined under laboratory conditions the effects of three urban composts and their mode of application (laid on the soil surface or mixed into the soil) on soil restoration after fire: a municipal waste compost (MWC), a compost of sewage sludge mixed with green waste (SSC) and a green waste compost (GWC). Carbon (C) and nitrogen (N) mineralisation, total microbial biomass, fungal biomass and soil characteristics were measured during 77-day incubations in microcosms. The impact of composts input on hydrological behaviour related to erodibility was estimated by measuring runoff, retention and percolation (i.e. infiltration) of water using a rainfall simulator under laboratory conditions. Input of composts increased organic matter and soil nutrient content, and enhanced C and N mineralisation and total microbial biomass throughout the incubations, whereas it increased sporadically fungal biomass. For all these parameters, the MWC induced the highest improvement while GWC input had no significant effect compared to the control. Composts mixed with soil weakly limited runoff and infiltration whereas composts laid at the soil surface significantly reduced runoff and increased percolation and retention, particularly with the MWC.

1. Introduction

The Mediterranean climate is characterized by a long dry summer and strong winds favouring recurrent forest fires (Bagnouls and Gaussen, 1957; Scarascia-Mugnozza et al., 2000; De Luis et al., 2001). Fires induce major alterations to the ecosystem. Their frequency, duration and intensity are important factors determining the impact on biological, chemical and physical properties of the ecosystem: the more fires are recurrent and serious, the more their marked impact (Boerner, 1982).

Fire can produce a partial or total destruction of the vegetal cover and the soil organic horizons (Guerrero et al., 2001). Subsequently, burned soils are prone to erosion and could decline in stability (Kutiel and Inbar, 1993; Hart et al., 2005). For example, part of the nutrients are oxidised and volatilised by fire (Grogan et al., 2000; Hart et al., 2005) and can easily be lost by wind erosion and runoff (DeBano and Conrad, 1978; Boerner, 1982; De Luis et al., 2001) aggravated by an increase of soil hydrophobicity (DeBano, 2000). Thus, Mediterranean soils are often deficient in organic matter (OM) (Archibold, 1995). Another biological change due to fire is the activity and structure of the microbial community, with a shift to communities in which heat-resistant microorganisms dominate (Vásquez et al., 1993; Hart et al., 2005).

The use of composts as an amendment for soil restoration and forest regeneration in frequently burnt or degraded Mediterranean ecosystems is increasing (Navas et al., 1999; Martinez et al., 2003; Román et al., 2003; Curtis and Claassen, 2009; Kowaljow and Mazzarino, 2007). The spreading of biosolids stabilized by composting, can improve the low fertility of soils and constitutes an alternative to landfill disposal. Moreover, this stabilization decreases risks of heavy metal leaching (Garcia et al., 1990; Planquart et al., 1999).

Compost amendment improves physical, chemical and biological properties of soils, in particular by increasing available

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nutrients mainly in the organic soil fractions (Larchevêque et al., 2005a). This induces an increase of soil microbial biomass (Borken et al., 2002) and positively affects plant cover by an improvement of plant nutrition (Villar et al., 1998; Guerrero et al., 2000, 2001; Caravaca et al., 2003; Larchevêque et al., 2005b, 2006; Larchevêque et al., 2010). The increase of microbial activity can induce a better aggregate stability (Guerrero et al., 2001; Caravaca et al., 2003), and, combined with the development of plant biomass, reduces the risk of erosion (Guerrero et al., 2000).

The objective of this study was to i) compare the effects of different types of composts and the mode of application on some chemical and microbial properties under laboratory conditions in a Mediterranean burned soil, and ii) to determine how these amendments modify the soil's hydrologic response using rainfall simulations.

2. Materials and methods

2.1. Soil and composts characteristics

The soil was collected in a burnt *Pinus halepensis* (Mill.) ecosystem on calcareous substrate under Mediterranean climate in south-eastern France (43°28′47″N–5°27′55″E, 245 m altitude). The sampling was realised on 30 sampling points in the burnt area over 20 cm depth (including surface ashes) in February 2006, 6 months after the fire. The fire was intense (high calorific power) but rapidly progressed because of a strong wind. Fire affected crown and soil surface. Consumption of litter layer could be observed, organo-mineral layer had been eroded or was missing, but there was no visible alteration of the surface of the mineral soil. Burned trees were still standing but no vegetation had begun to grow. The soil was homogenized by sieving (<4 mm) for the experiments. Three urban composts sieved at 10 mm were studied: green waste compost (GWC), sewage sludge (1/5 volume) mixed with green waste compost (SSC) and municipal solid waste compost (only organic wastes, MWC). Levels of heavy metals in composts studied were below the minimum current standards (NFU 44-095 AFNOR, 2002; NFU 44-051 AFNOR, 2006). Soil and compost were stored at 4 °C before incubations. According to the self-heating test depending on the maximum temperature reached (T_{max}) (FCQAO, 1994), GWC was stabilized whereas SSC and MWC were unstabilized (Table 1).

Soil and compost initial characteristics are presented in Table 1. Soil is a Haplic Cambisol (Calcaric) (FAO, 1998).

2.2. Laboratory incubations

Soil–compost mixtures were incubated in 2 L jars hermetically closed at 28 ± 1 °C, in the dark. Composts were mulched or mixed with soil at field capacity. The rate of compost used was 10 g of compost in each jar corresponding to 27 Tm ha^{-1} of fresh matter. The amount of soil in each jar was 150 g and corresponded to 20 cm depth of soil sampling. Soil OM, total N, organic C, total phosphorus, K_2O contents, soil C/N ratio, C and N mineralisation and biological activities were measured periodically during 77 days. Measurements were made only on the soil fraction for the mulched composts.

2.3. Carbon mineralisation

C mineralisation during incubation was based on the amount of CO_2 produced during the incubation time. A flask with 25 ml of NaOH 1 N and another with 10 ml of water were introduced into each 2 l jar. The jars were opened to change the flasks and to renew the atmosphere on days 2, 4, 7, 10, 14, 21, 28, 35, 49, 63 and 77. Five replicates for the 2 modes of application were made for the 3 composts. 5 controls of soil without compost were also done. C-CO_2 trapped in NaOH was analysed by colorimetry at 550 nm with a continuous flux analyser (SKALAR, Netherlands) after acidification with H_2SO_4 solution (100 mg/L), and addition of phenolphthalein (pH = 8.6, 50 °C).

Table 1
Initial microbiological, chemical and physical characteristics of composts and soil. Values of the Dewar indice.

	Soil	MWC	SSC	GWC	Methods
pH	8.1	7.8	6.6	8.0	NF EN 12176
Water content (%)	27.09 ± 0.86	21.94 ± 4.83	22.03 ± 5.00	26.52 ± 0.88	
Conductivity (mS/m)	15	3.02	0.85	1.38	Extr. Water 1/5 (V/V) and Conductivity NF EN 13039
OM (g/kg)	84.4	712	454	357	NF EN 12879
Total N (g/kg)	2.4	15.1	22.1	14.2	Attack Kjeldahl + colorimetry
C/N	17.0	23.0	10.0	12.0	Organic C/total N
N-NH_4^+ (mg/kg)	0.06	3419.0	3407.7	147.9	Extraction KCl M & dosage, Berthelot
N-($NO_3 + NO_2$) (mg/kg)		3.48	0.80	12.67	Extraction KCl M & dosage, Griess and Ilossay's
Total phosphorus (g/kg)	0.04	0.32	0.08	0.34	ISO 11-263-1 adapted
K_2O (g/kg)	3.4	8,0	7.91	12.6	NF EN 13346, Dosage ICF AES NF EN ISO 11885 extraction with *aqua regia*
Total microbial biomass (mg C/kg)	269	4788	2481	2324	Vance et al., 1987
Fungal biomass (mg/kg)	4.61	12.17	0,0	4.64	Gessner and Schmitt, 1996
T_{max} (°C)	–	71	58.5	22	FCQAO, 1994
Dewar indice	–	I	II	V	

Units are related to dry matter of soil.

2.4. Nitrogen mineralisation

The measurements of N mineralisation were destructive and were carried out on days 0, 14, 28, 49 and 77. At each date, 5 controls of soil without compost and 5 replicates for each mode of application and for the 3 composts were performed. For mulch application, the compost layer was removed before the sampling. Mineral N was extracted with KCl 1 N (1/4, soil mass/KCl volume) by agitation during 1 h and decantation. Mineral N was measured on the filtered supernatant (Whatman, GF/C) by colorimetric methods (Berthelot's method for N-NH_4^+ at 660 nm and Griess and Ilossay's method for N-($NO_3 + NO_2$) at 540 nm; SKALAR, Netherlands).

2.5. Total microbial and fungal biomass

The measurements of total microbial and fungal biomass were destructive and were carried out on days 14, 28, 49 and 77 for 5 controls of soil without compost, 5 replicates for each mode of application and for the three composts. As for nitrogen mineralisation, only the soil below compost was analysed for mulch application. Total microbial biomass was measured on 24 g of the soil–compost mixture or the soil under mulch by fumigation-extraction (Vance et al., 1987). Microbial extractable C was estimated from the difference in C released between fumigated and unfumigated samples (Wu et al., 1990). Fungal biomass in soil was determined from ergosterol concentrations using solid-phase extraction and high-performance liquid chromatography (HPLC; Gessner and Schmitt, 1996).