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Increasing the maturity of compost used affects the soil chemical properties and the stability of microbial activity along a mediterranean post-fire chronosequence

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ABSTRACT

Compost addition has been largely employed to improve chemical properties and microbial activities of several disturbed soils. However, few attempts have assessed the adequacy of compost quality considering the level of ecosystem recovery after frequent wildfires in combination with droughts. We investigated the suitability of the addition of 3 ages of compost (i.e. 3 weeks, 3 months and 9 months) crossing with 3 times since fire (i.e. 1, 5 and 18 years of recovery) to increase the soil organic and inorganic resources in frequently burned soils. We hypothesised that resource depending on quality (i.e. maturity) should improve microbial activity and its resistance and resilience against a drastic drought and could have some implication for SOM mineralisation. Our results showed that the more mature compost, richer in organic matter, increases TOC, total N, PO_4^{3-}-P concentrations and pH but regardless the time since fire. Microbial activity weakly responded to this soil resource improvement whereas it was strongly depressed 5 years after the last fire. Mature compost resulted in a loss of resistance and resilience of the microbial activity in comparison with control soils depending on the time since fire, indicating that exogenous resource as compost affects microbial stability. The cumulative C-mineralisation clearly indicated that the loss of microbial activity and stability against drought with the more mature compost would result in an improvement of soil C-accumulation especially 5 years after the last fire.

1. Introduction

Since the 1970s, Mediterranean basin has been marked by socio-economic mutations and an increase in extreme weather events, such as heat waves and droughts [12], favouring the occurrence of extended wildfires and frequency [31]. Frequent fires decrease soil organic matter and nutrients [17,18] and lasting affect the microbial functional resistance (ability to withstand climate stress) and the resilience (i.e. time necessary to return to the pre-stress level) against climatic stress [16]. Drying-rewetting cycles killing sensitive microbial populations induce a pulse in microbial CO_2 emission and then, can reduce C-mineralisation which has some importance for soil C-sequestration [11]. At ecosystem scale, frequent wildfires exacerbated by drought events in next decades could impair the recovery of ecological functions supported by soil microbes and thus, some ecosystem services such as carbon sequestration.

Amendment with organic wastes is frequently used to help in the re-establishment of abiotic and biotic soil properties after fires [20,26,27,33,37,38] and is encouraged to restore degraded soils. Compost amendments can improve soil physical, chemical and biological properties, especially by increasing available nutrients in the organic soil fractions [28]. Biosolid composts are rich in humified organic matter and can be used as a slow-release nutrient source [4]. They have also a high water retention capacity [13] which induces an increase of soil water content [38]. These modifications can positively affect plant cover through an improvement of plant nutrition and growth [20,27,29], and contribute to reduce erosion [19]. Compost addition is frequently referring to improve soil microbial biomass and activities [7,26] but most studies were carried out either under controlled conditions with short incubation experiments or either in the field with only descriptive effects. We propose in this study to combine both the field and the laboratory experiments to test our hypotheses. Currently, little

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attention has been paid to the effects of organic amendment directly in the field in interaction with abiotic stress like drying and rewetting events on i) the microbial activity and its capability to resist and recover [24] ii) the mineralisation of soil organic matter [37] and iii) the potential implications for C-accumulation [1].

Compost addition, by improving nutrient availability, pH or the carbon content and its availability, can favour resistance and resilience (i.e. stability) of microbial functions [23]. The level of soil enrichment depends on the quality of the compost used [20]. Kowaljow and Mazzarino [26] showed that biosolid compost richer in carbon and nitrogen content than municipal compost better improves chemical and microbial properties 12 months after *in situ* amendments. Conversely, an addition of fresh organic matter in a Mediterranean area, lesser improved the soil chemical and microbial properties than a composted organic matter less rich in total carbon and nitrogen [33]. Therefore, the use of compost on burned soils requires to test interaction effects between the chemical properties of the compost used and transfer to soil to assess the resistance and resilience of microbial activity against a drastic stress (i.e. drying and rewetting event) and study the potential implications for soil C-accumulation.

In this study, we examined the potential effect of compost amendments on microbial activity and its stability (i.e. resistance and resilience) against an experimental drought, and consequently, C-accumulation in a Mediterranean post-fire chronosequence. We previously detected a threshold in SOM quality and quantity between 4 and 17 years of time since fire that controls the recovery of microbial activities [17]. Moreover, we also tested the role of C and N availability in controlled conditions on the stability of microbial functions against droughts [16]. Thus, in the current study, we hypothesised that the chemical quality of composts (i.e. maturity depending on time of composting) would control microbial activity, depending on the time since fire, its resistance and resilience that feedback the whole process of C-accumulation. More precisely, we expected that young compost, richer in labile organic compounds and nutrients, would favour the stability of recently burned soil (i.e. lower level of resources) by increasing microbial activities. These effects should be attenuated along the post-fire chronosequence (i.e. recovery of resource availability) and would increase soil C-accumulation. The specific objectives were thus, to assess the effects of 3 compost ages (i.e. 3 weeks, 3 months and 9 months) added to 3 frequently burned soils differing by time since fire (i.e. 1, 5 and 18 years of recovery) on i) soil resource content (total organic C, total N, total P, NO_3^-–N, NH_4^+–N, PO_4^{3-}–P), ii) resistance and resilience of microbial basal respiration to an experimental drying and rewetting event (D/Rw), iii) relationships between soil chemical properties and basal respiration and its stability to D/Rw and iv) cumulative C-mineralisation.

2. Material and methods

2.1. Study area

The study was conducted in part of the Maures moutain range (Var, southern France, 43°20′ N and 6°37′ E). The region is characterised by a typical Mediterranean climate with 920 mm of mean annual rainfall and 14 °C of mean annual temperature (1962–2003). The study area (90 km^2) presents a range of altitude from 100 to 400 m above sea level. The mother rock is a gneiss migmatitic (crystalline siliceous rock). Soils along the post-fire chronosequence have a sandy loam texture and are classified as Dystric Leptosol [25]. The study area is characterised by heterogeneous mosaic of Mediterranean forest ecosystems generated by various wildfire frequencies [35]. Plant communities that recover in the first years following fire are dominated by herbaceous (e.g. *Bituminaria bituminosa* L., and Lotus species) and young fast growing woody species (e.g. *Cistus monspeliensis* L., *Calycotome spinosa* L., *Erica arborea* L.) and also tall *Quercus suber* L. that survived to fires. In the late successional stage (i.e. with no fire for at least 59 years), highly covered forests are dominated by a tree canopy of *Q. suber* L., *Quercus ilex* L. and *Pinus pinaster* Aiton subsp. pinaster on maquis.

2.2. Experimental design and soil sampling

The burned surfaces were mapped using a series of aerial pictures spanning a 57-year period from 1950 to 2007 and public fire database [32]. This map was interpreted in order to select study sites according to the number of fires since 1950 and to the time since fire. Nine sites (1000 m^2) were selected because they were similar in terms of number of fires (i.e. 4 fires). This frequency corresponds to a critical fire regime for the northern Mediterranean Basin [17]. Wildfire regime also differed by time since the last fire constituting an atypical Mediterranean post fire chronosequence rarely studied. Sites were categorized as follows:

- 3 independent unburned sites for 1 year (referred as "1y" in Table and or figures). These sites just begun their recovery in term of plant communities (see above). Total elements are close to older sites (Table 1) due to the supply of burned plant material that may counterbalance the combustion of organic matter [9]. It was however expected both low resource quality (i.e. heterocyclic compounds) and nutrient availability [14].
- 3 independent unburned sites for 5 years (referred as "5y" in Table and or figures). These sites did not recover for plant community structure (80–90% covered by C*istus monspeliencis* L.) and soil chemical and microbial properties were strongly affected [17,18]
- 3 independent unburned sites for 18 years (referred as "18y" in Table and or figures). These sites completely recovered in term of plant communities' assemblage [35], total C and N content but did not recover for its quality, nutrient availability or all microbial functions [17,18].

All these sites presented substantial level of total element (Table 1) but modulated by the quality of resource that control the microbial activities [17,18]. We brought different compost qualities expecting that each quality should be adapted to different burned

Table 1
Chemical and microbial properties of burned soils at the beginning of the experiment.

Time since fire (years)	1y	5y	18y
Chemical properties			
TOC (g kg^{-1})	44.9 ± 9.4	43.3 ± 6.5	55.9 ± 14.6
TN (g kg^{-1})	2.9 ± 0.5	2.3 ± 0.3	3.1 ± 1.3
TP (g kg^{-1})	0.49 ± 0.05	0.42 ± 0.11	0.48 ± 0.06
C/N	15.5 ± 1.3	19.3 ± 1.8	18.5 ± 3.2
C/P	95 ± 31	108 ± 35	116 ± 21
NH_4^+–N (mg kg^{-1})	21.3 ± 1.8	22.7 ± 2.8	57.2 ± 22.2
NO_3^-–N (mg kg^{-1})	18.3 ± 1.1	9.5 ± 1.3	18.4 ± 4.7
PO_4^{3-}–P (g kg^{-1})	0.39 ± 0.08	0.29 ± 0.11	0.25 ± 0.09
Soil pH (in water)	6.4 ± 0.1	6.8 ± 0.1	6.4 ± 0.1
Microbial properties			
Basal respiration (μg CO_2–C (g dry soil)$^{-1}$ h^{-1})	3.4 ± 0.7	3.4 ± 0.5	4.6 ± 0.3
Microbial biomass (μg Cmic (g dry soil)$^{-1}$)	1.2 ± 0.2	1.7 ± 0.3	2.2 ± 0.4
qCO_2 (μg CO_2–C (μg C_{mic})$^{-1}$ h^{-1})	2.92 ± 0.62	2.06 ± 0.41	2.22 ± 0.44

Values are means ± standard deviation.