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Soil restoration in semiarid Patagonia: Chemical and biological response to different compost quality

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Abstract

Restoration of soils burned by a wildfire using composted amendments of different origin (biosolids and municipal organic wastes) and final particle size (screened and unscreened) was studied after 6 and 12 months of application in a field trial in semiarid NW Patagonia. Composts were applied at 40 $Mg\,ha^{-1}$. A fertilized treatment with soluble N (100 $kg\,ha^{-1}$) and P (35 $kg\,ha^{-1}$), and a non-treated control were also included. As indicators of soil response, chemical (electrical conductivity, pH, organic C, total N, extractable P), biological (potential microbial respiration, potential net N mineralization, N retained in microbial biomass) and physical (temperature and soil moisture) properties were evaluated. Plant soil cover was also estimated. Soil chemical and biological properties showed a high response to organic amendment addition, more evident after the wet season (12 months of application). Soil organic C, total N and extractable P increased significantly with biosolids composts (BC), and soil pH with municipal composts (MC). Potential microbial C respiration and net N mineralization were similar for both MC and BC, and significantly higher than in the control and the inorganic fertilized treatment; when calculated on C or N basis the highest values corresponded to MC. Results imply that in terms of organic C accretion, BC were more effective than MC due to higher amounts of total and recalcitrant C. Screened and unscreened composts did not differ significantly in their effects on soil properties. The increase of organic C with BC did not contribute to increase soil moisture, which was even higher in control plots after the wet season; higher plant cover and water consumption in amended plots could also explain this pattern. Inorganic fertilization enhanced higher plant cover than organic amendments, but did not contribute to soil restoration.
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1. Introduction

The northwestern ecotone of Patagonia is a transitional zone between the narrow strip of humid Andean forests mostly protected as National Parks, and the vast arid–semiarid steppe dominated by extensive ovine production. This forest-steppe ecotone includes from xeric Mollisols to sandy Entisols, and is currently concentrating the main efforts on farming, agriculture and forestry development, acting as a buffer between the less productive steppe and the protected forests (Mazzarino et al., 1998a; Schlichter and Laclau, 1998; Laos et al., 2000; Gyenge et al., 2002). Fires and overgrazing are the most important disturbances affecting the region since the end of the XIX century (Veblen and Lorenz, 1988; Aguiar and Sala, 1998; Laclau, 2003). Currently, the number and intensity of fires is highly variable with the greatest events occurring in years of severe drought; national fire records for northwestern Patagonia indicate that about 17,400 ha of forests and 48,500 ha of shrub-grass steppe were completely burned between 1988 and 1999 (de Torres Curth et al., 2002). Disturbances are leading to modifications of vegetation and accelerated soil degradation, erosive processes being enhanced by the characteristic climate of the region: low precipitations concentrated in winter, strong water deficits in spring and summer, and persistent and intense westerly winds (Paruelo et al., 1998).

In most world ecosystems, fires lead to temporary increase of base cations, phosphorus (P) and pH, but

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losses of organic matter and nitrogen (N) are high during the fire through combustion and volatilization, and after the fire due to favorable conditions for microbial activity, nitrate accumulation, denitrification, leaching and erosion (among others, Walker et al., 1986; Prieto-Fernández et al., 1993; Stark and Hart, 1999). By reducing soil organic matter (SOM) and consequently the energy sources for microorganisms, fires also diminish the soil capacity to conserve N in microbial biomass (Stark and Hart, 1999; Alauzis et al., 2004). In the case of the Patagonian forest-steppe ecotone, these effects are expected to be particularly important in sandy soils with low capacity to protect SOM; after fires, these soils are highly prone to wind and water erosion, and rapid losses of SOM and nutrients (Ferrer, 1981). Because of the high economic and ecological importance of the ecotone, soil and vegetation restoration of disturbed areas constitutes a main goal in order to control erosion, improve soil quality and facilitate the installation of productive agroecosystems (SAGyP, 1995; FAO and SAyDS, 2003).

Low SOM levels in semiarid grasslands can be increased using inorganic N and P fertilizers, since they enhance plant growth and litter production, which ultimately increase SOM and N (Rasmussen and Collins, 1990; Galantini and Rosell, 2006). However, inorganic fertilizers are costly and a high proportion of N can be lost during the first year of application (Westerman and Tucker, 1979; Nissen and Wander, 2003). Addition of organic wastes is other recommended practice for degraded soils of semiarid regions (Pascual et al., 1998; Martinez et al., 2003; Ros et al., 2003), with promising results in the reclamation of burned soils (Villar et al., 1998; Guerrero, et al., 2001). These C-rich materials improve soil structure and the capacity to store water and nutrients, sustain microbial activity and growth, enhancing biogeochemical nutrient cycles, and accelerate vegetation re-establishment. The use of organic wastes is also an environmentally and economically sound alternative since it provides a locally available source of nutrients and reduces the risks of pollution and costs of disposal (Laos et al., 2000).

Composting is an effective strategy to stabilize raw organic wastes prior to land application; this process avoids the rapid release of nutrients from fresh residues and, consequently, reduces negative environmental impacts, such as subsurface water contamination through nitrate leaching (Cooperband, 2000). The beneficial effects of composted amendments on the chemical, physical and biological properties of soils have been well documented, and are closely linked to soil condition, application rates and frequency, and organic matter quality (among others, Giusquiani et al., 1995; Laos et al., 2000; Gabrielle et al., 2004; Tu et al., 2006). Composts with high contents of labile organic matter enhance biological activity and nutrient release, whereas recalcitrant or slow decomposable organic matter improves water and nutrient storage, and soil structure, increasing soil resistance to erosion. In semiarid regions both aspects, increase of recalcitrant and labile organic matter, are key factors to recover soil fertility and plant cover. Although quality and quantity of compost organic matter are mainly dependant on the original feedstocks (Cooperband, 2000; Laos et al., 2000; Gabrielle et al., 2004), screening of the final product can play an important role by removing oversized particles rich in poorly degradable C-rich compounds, such as corn cobs, wood chips, yard trimmings, etc. (Tognetti et al., 2005).

Considering that in Patagonia the knowledge on soil restoration with organic inputs is scarce, our objective was to study the response of soils affected by wildfires to composted amendments of different origin (biosolids and municipal organic wastes) and final particle size (screened and unscreened). As indicators of soil response, chemical (electrical conductivity, pH, organic C, N, extractable P), biological (potential microbial respiration, potential N mineralization, N retained in microbial biomass) and physical properties (temperature and soil moisture) were evaluated in a field experiment on burned sandy soils in semiarid NW Patagonia. We hypothesized that amendments of different organic matter quality would differently affect nutrient and water dynamics and SOM: (i) composts with more recalcitrant organic matter would increase SOM, soil moisture and N immobilization, and (ii) composts with more labile organic matter would increase microbial activity (potential microbial respiration, potential N mineralization) and nutrient release, reducing their long-lasting effect on SOM accretion.

2. Materials and methods

2.1. Site description and experimental design

The study was conducted in a site of semiarid shrub-grass steppe, which was completely burned by a wildfire in January 2004. It was located 105 km to the northeast of Bariloche city (Argentina), at 40°34′24″S latitude, and 70°49′57″W longitude. Its elevation is 720 m a.s.l., with a slope of 4.1%, SW oriented. According to Autoridad Interjurisdiccional de Cuencas (AIC), historical mean annual temperature is 11.5 °C, and mean annual precipitation is 300 mm concentrated from May to August (late autumn to early winter) as rain or snow. During the experimental period, mean air temperature was 10 °C, with a mean daily minimum of 4.8 °C and a mean daily maximum of 17.2 °C; annual rainfall was 270 mm. Soils have a sandy texture and are classified as Xeropsamments (Ayesa et al., 2002). The unburned adjacent areas presented a random patchy structure consisting in large patches of shrubs and perennial grasses, and interspaces of scattered grasses and bare soil. Vegetation was dominated by the shrubs *Mulinum spinosum*, *Senecio filaginoides* and *Senecio subumbellatus*, and the perennial grasses *Stipa speciosa*, *Poa ligularis* and *Festuca argentina*.

The experiment was carried out in a 1 ha exclosure established in the burned area 10 months after the fire (November 2004). At this time, burned soils showed a

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