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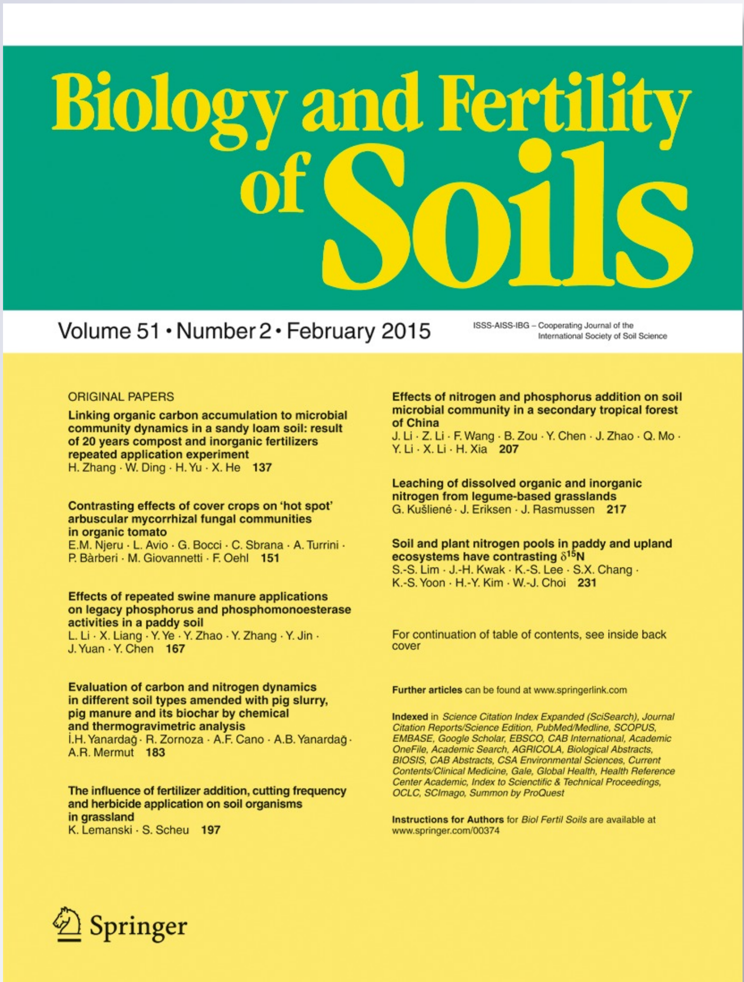

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ORIGINAL PAPERS

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Persistent effect of organic matter pulse on a sandy soil of semiarid Patagonia

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Abstract Studies of degraded semiarid regions have shown that organic residue addition is a sound restoration alternative. We examined the effects of a single dose (40 Mg ha^{-1}) of biosolids compost (BC) and compost of the organic fraction of municipal solid waste (MC) 6 years after they were applied to a sandy soil of NW Patagonia. Results were compared with those of inorganic fertilization (IF, 100 kg N+35 kg P ha^{-1}) treatment and of unamended control. We measured plant cover, biomass, and diversity and chemical, biological, and biochemical soil properties. We did not find any significant effect of treatments on plant attributes. However, effects on soil properties were significant and more persistent with composts than with IF, especially with BC, which had higher organic C and nutrients than MC. Total soil C and N were twice as high in the BC-amended soil as in the control and IF soils. Soil extractable P was 4-fold and 2-fold higher in BC- and MC-treated soils, respectively, than in the control soil, and even higher than in the IF treatment in response to BC. The highest β-glucosidase and acid phosphomonoesterase activities were found in the BC-treated soil, related to higher C and P in the soil and to higher activities of both enzymes in the biosolids compost. The highest phenol oxidase activity was found in MC and in the MC-treated soil. Potential respiration and K_2SO_4-extractable C were higher in the compost-treated soil, but there was no difference in microbial biomass C between the compost-treated and the control soils. Despite the fact that the soil was coarse textured and a single moderate dose of compost was applied, recovery of soil chemical, microbiological, and biochemical properties was long-lasting, indicating that application of urban compost is a feasible restoration practice in this semiarid region.

Keywords Biosolids compost · Municipal solid waste compost · Soil chemical properties · Biological indicators · Enzymatic activities

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Introduction

Above- and belowground communities are intrinsically linked in terrestrial ecosystems, the main example being the regulation of soil microbial processes by the quantity and quality of organic material entering the soil. Due to low primary productivity, the inputs of organic matter in arid and semiarid ecosystems are very low. Consequently, they are characterized by low concentrations of soil organic C, typically <1 % (Klemmedson 1989). Soil microorganisms release enzymes into the soil that catalyze different biochemical processes, such as organic matter decomposition, providing nutrients for plant growth (Nannipieri et al. 2002). The positive feedback between above- and belowground communities is mediated by organic matter and disrupted by anthropogenic disturbance.

Domestic grazing is the main land use in arid and semiarid ecosystems and has many effects on ecosystem functioning, the most pronounced being the decrease of plant cover, which can reduce C inputs to soil (Bisigato and Bertiller 1997; Abril and Bucher 2001) and soil organic matter levels, especially under high stocking rates (Wu et al. 2012). Another frequent disturbance in arid lands is fire, both natural and anthropogenic, which can also lead to a decrease of soil organic matter (Walker et al. 1986; Snyman 2003). Records for northwestern (NW) Patagonia indicate that about 56,000 ha of shrub-grass steppe were burned between 1973 and 2011 (Oddi et al. 2013) with a decrease of more than 50 % of soil organic matter in some areas (Kowaljow and Mazzarino 2007).

Attempts to restore soil organic matter in arid and semiarid ecosystems have involved applications of organic amendments, especially urban and agro-industrial residues (Moffet et al. 2005; Nicolás et al. 2012; Cellier et al. 2014). In addition to increasing the amount of organic matter, they stimulate soil microbial activity and the recycling of C and nutrients. The use of organic amendments in agriculture and restoration also contributes to the reduction of waste landfilling and its associated environmental problems. Application of organic matter stabilized by composting has additional advantages over fresh residues, such as the slower release of nutrients, which reduces nitrate leaching (Cooperband 2000; de la Fuente et al. 2013).

In the short term, compost addition leads to an increase of plant cover, soil organic matter, and soil biological activity (Martínez et al. 2003; Ros et al. 2003; Bastida et al. 2008b; Cordovil et al. 2011). In fine-textured soils of Mediterranean semiarid ecosystems, where soil organic matter decomposition is slow due to protection by clay and climatic constraints, a long-term effect of single, high-dose applications has been observed (Pascual et al. 1999; Bastida et al. 2008a). In sandy soils, however, where the protection of organic matter by the mineral matrix is low (de León-González et al. 2000; Weber et al. 2007), the positive responses to a single dose of organic amendments can disappear in the long term (García-Gil et al. 2000; Hargreaves et al. 2008). The use of high doses or frequent applications is limited in large areas like Patagonia, where population density is low and transport costs are high. Therefore, we are interested in examining the duration of responses to a single moderate dose of urban composts. As the Patagonian steppe is a cold semiarid region, a long-lasting effect might be expected due to slow rates of organic matter decomposition, although this could be counteracted by the sandy texture of the soils.

A long-term experiment was established in a degraded, burned site of NW Patagonia in 2004, applying a single moderate dose of urban composts and an inorganic fertilizer; the most important effects 3 years after application were increases of soil organic C, total N, and microbial activity (Kowaljow et al. 2010). Composts also led to increased aboveground plant biomass but this effect was higher with inorganic N-P fertilization. The main objective of the present work was to compare the effects of these treatments on vegetation and soil properties 6 years after application. We hypothesized that (1) organic amendments would have more persistent positive effects than inorganic fertilizer on plant community characteristics and on soil chemical, microbiological, and biochemical properties and (2) the effects would differ between amendments (biosolids compost and compost of the organic fraction of municipal waste), reflecting their nutrient contents and organic matter quantity and quality.

Materials and methods

Study site

The study site is located in the shrub-steppe of NW Patagonia (Argentina) at 40° 34′ 24″ S, 70° 49′ 57″ W and 720 m a.s.l. in an area altered by grazing and burned by a wildfire in January 2004. According to AIC (Autoridad Interjurisdiccional de Cuencas), the mean annual temperature is 11.5 °C, and mean annual precipitation is 300 mm, concentrated from May to August (late fall and winter). The soil is coarse textured and classified as Xeropsamment (Ayesa et al. 2002). Vegetation in adjacent unburned areas is distributed in patches consisting of a mixture of shrubs and grasses and affected by different intensities of sheep, cattle, and deer grazing. Dominant shrubs are *Mulinum spinosum* (Cav.) Pers., *Senecio filaginoides* DC., and *Senecio subumbellatus* Phil., and dominant grasses in order of importance are *Poa ligularis* Neeseu. Steud., *Pappostipa speciosa* (Trin. & Rupr.) Romasch., and *Festuca argentina* (Speg.) Parodi. Compared to the unburned area, the burned soil suffered a significant decrease (of about 40–60 %) of organic C, total N, and extractable P (Kowaljow and Mazzarino 2007).

As part of a long-term study to assess the effects of compost application on the restoration of this area, we established 16 permanent plots of 6×11 m each in a 1-ha enclosure in November 2004 (10 months after the fire). The following treatments were applied: (i) non-treated control (C), (ii) inorganic fertilization (IF), (iii) biosolids compost (BC), and (iv) compost of municipal solid waste (MC). Municipal compost (MC) was produced from the organic fraction of municipal solid waste in the MSW Treatment Plant of Villa La Angostura city; the final compost was sieved (5-mm mesh). Biosolids compost (BC) was produced employing wood shavings and yard trimmings as bulking agents in the Biosolids Composting Plant of Bariloche city, and the final product was not sieved. The two composts differ in organic matter quantity and quality, nutrient concentrations, and other properties (Table 1). In both cases, potentially toxic elements were below the most restrictive limits for composts of several European countries (BioAbfV 1998; AFNOR 2005; BOE 2005).

All amendments were applied to the surface, the two composts at a rate of 40 Mg dw ha^{-1} (equivalent rates of C, N, and P are given in Table 2) and the inorganic fertilizer at a rate of 100 kg N and 35 kg P ha^{-1} (as urea and diammonic

Table 1 Characteristics of the applied organic amendments. Values are from Kowaljow and Mazzarino (2007), except enzyme activities, which were measured in more recent samples (March 2011) taken from the same compost facilities

	Biosolids compost (BC)	Municipal compost (MC)
pH	5.4	7.8
Electrical conduct. (dS m^{-1})	1.23	0.48
Total organic C (g kg^{-1})	289	128
Total N (g kg^{-1})	18.5	7.7
Total P (g kg^{-1})	5.4	4.0
Extractable P (mg kg^{-1})	1700	160
Cellulose (%)	39	52
Lignin (%)	25	11
Enzyme activities (μmol g C^{-1} h^{-1})		
β-Glucosidase	2.47	1.37
Acid phosphomonoesterase	26.1	17.5
Phenol oxidase	44.2	103.1
Leucine-aminopeptidase	7.8	4.6

phosphate). Treatments were replicated four times in a randomized complete block design.

Plant community characteristics

Total canopy cover, including shrubs, grasses, and forbs, was visually estimated in six randomly located quadrats (1 m^2). Also, plant species (sorting by native or exotic species) and percentage cover for each plant species were determined in four quadrats (1 m^2). Species richness was estimated as the number of plant species per treatment. Diversity was calculated using the Shannon-Weaver index (H′) according to the following equation:

$$H' = -\sum_{i=1}^{n} (P_i \times \log P_i)$$

where P_i is the proportion of individuals of species i relative to the total number of individuals and n is the total number of species.

Aboveground biomass of grasses and forbs was assessed in November 2010 by manually cutting vegetation in three randomly selected quadrats (0.25 m^2) in each plot. Vegetation samples were separated into living biomass and senescent leaves and litter.

Table 2 Rates of C, N, and P of the organic amendments

	Biosolid compost (BC)	Municipal compost (MC)
Organic C (Mg ha^{-1})	11.6	6.04
Total N (Mg ha^{-1})	0.74	0.31
Total P (Mg ha^{-1})	0.21	0.16

Soil chemical and physical properties

Soil samples, each a composite of three cores, were collected at 0–10 cm after removing litter and compost particles. Soils were sieved (2-mm mesh) and analyzed for electrical conductivity and pH in water (1:5 and 1:2.5 soil to water ratios, respectively); total C and total N were determined with an elemental analyzer (Thermo Electron Corporation Flash EA 1112) according to Nelson and Sommers (1996); P extracted in 0.5 M $NaHCO_3$ (1:20, soil to solution ratio) and determined by the molybdate ascorbic acid method (Kuo 1996). Bulk density was measured in the topsoil (0–10 cm) by the core method; three randomly distributed samples were taken in each plot.

Soil microbiological and biochemical properties

Soil respiration was measured as CO_2 production in 1.5-L glass jars containing 75 g fresh soil (moistened to 60 % of field capacity) and incubated at 25 °C for 16 weeks. Evolved CO_2 was trapped with 0.2 M NaOH and titrated with 0.1 M HCl after Ba_2Cl addition. Vials were replaced and analyzed at 2, 4, 8, 12, and 16 weeks (Kowaljow and Mazzarino 2007). Soil respiration was expressed as mg C kg $soil^{-1}$ day^{-1}.

Both microbial biomass and enzyme activities were determined on dry soil incubated for 10 days at 25 °C at field capacity prior to the analysis. Microbial biomass C was determined by the fumigation-extraction method (Vance et al. 1987); the C extracted was measured by K_2SO_4 with dichromate oxidation. In addition, we used the C extracted by K_2SO_4 without fumigation as a proxy for dissolved organic C (Hofman and Dusek 2003).

The enzyme activity assays were conducted in soil to water suspensions (1:10), which probably mainly include extracellular stabilized enzyme activities. β-Glucosidase, acid phosphomonoesterase, leucine-aminopeptidase, and phenol oxidase were determined. Aliquots of sample suspension (1 mL) were incubated at 25 °C with 1 mL of each enzyme substrate at specific conditions; a sample control (sample suspension+buffer) and a substrate control (substrate+buffer) were also incubated (Sinsabaugh et al. 1999). Since enzyme activities of composts were not measured at the beginning of the experiment, we analyzed compost samples taken more recently (March 2011) from the same composting facilities. Results were included in Table 1 where compost properties are given.

Statistical analysis

The significance of the differences of means of all variables was evaluated by ANOVA. Means were compared with a post hoc Tukey test. The STATISTICA program (STATISTICA 6.1. StatSoft, Inc., Tulsa, USA) was used for analyses.

Results

Plant community characteristics

Six years after treatment, no significant effects on vegetation were found for any of the measured plant community characteristics: biomass, litter, and the sum of the two (Fig. 1) as well as plant cover, species richness, number of exotic species, and plant diversity (Table 3).

Soil chemical and physical properties

Six years after application, we still detected significant changes in soil chemical properties of plots amended with composts, while the IF treatment did not differ from the control (Table 4). Total C and N increased almost 2-fold with the addition of BC, while MC application increased electrical conductivity almost 2-fold compared to the control and IF but did not modify total C and N contents.

Soil extractable P increased under both types of compost with respect to the control, being almost 4-fold and 2-fold higher with BC and MC, respectively; extractable P in the IF treatment did not differ from the MC treatment and the control but was 2.5 times lower than in the BC treatment. The increased organic matter with BC application did not affect values of bulk density, which did not change with any treatment (Table 4).

Soil microbiological and biochemical properties

We did not detect significant differences in microbial biomass C between treatments (Fig. 2a), while extractable C increased significantly with both types of composts (Fig. 2b). The ratio

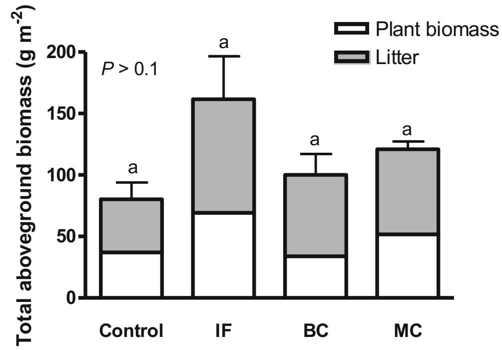

Fig. 1 Plant biomass and litter after 6 years after treatment. *BC* biosolids compost, *MC* municipal organic waste compost, *IF* inorganic fertilizer. *Different letters* indicate significant differences among treatments for total aboveground biomass (n=4)

of microbial biomass C to extractable C showed that more C was incorporated into microbial biomass in control plots per unit of extractable C (Fig. 2d); similar results were obtained per unit of total C (data not shown). After 16 weeks of sample incubation, cumulative microbial respiration of the BC-treated soil was 2-fold higher than that of the control soil (Fig. 2c).

Soil enzyme activity varied significantly among treatments, in particular for enzyme activities involved in C degradation and P mineralization (Fig. 3). Plots amended with BC enhanced soil β-glucosidase and acid phosphomonoesterase activities (Fig. 3a and b), while MC-amended plots had a higher soil phenol oxidase activity than the control (Fig. 3d). Soil leucine-aminopeptidase activity did not change with compost addition with respect to the control (Fig. 3c). Enzyme activities of composts showed a similar pattern to compost-treated soils: BC had two times more β-glucosidase and acid phosphomonoesterase activities than MC (expressed per unit of organic C), while the latter had two times more phenol oxidase activity (Table 1).

Discussion

Six years after a single application of composts, we found positive effects on soil organic matter, nutrients, microbial activity, and enzyme activities, even though the dose was relatively low compared to those commonly used for ecosystem restoration in semiarid regions (Pascual et al. 1999; Martínez et al. 2003) and the soil was coarse textured with low capacity to protect organic matter. However, the applied composts stimulated different metabolic pathways of the soil microbial community, which could have implications for soil C content in the long term. As in other studies of semiarid soils, the effects on soil physical properties were not significant, suggesting the need for larger rates of application (or more frequent additions at low rates) to induce physical changes (Stamatiadis et al. 1999).

Table 3 Plant community characteristics 6 years after treatment. Values are means (SE)

	Plant cover (%)	Diversity index (Shannon-Weaver)	Species number	Exotic species number
Control	7.2 (1.48)	0.10 (0.011)	4.7 (1.65)	1.5 (0.64)
IF	12.4 (4.06)	0.15 (0.038)	5.5 (1.32)	2.0 (0.40)
BC	15.6 (8.55)	0.18 (0.062)	5.2 (0.47)	2.0 (0.40)
MC	11.9 (3.79)	0.15 (0.040)	4.7 (0.75)	1.7 (0.47)

No significant differences among treatments were found for any variable (n=4, P<0.05)

BC biosolids compost, *MC* municipal organic waste compost, *IF* inorganic fertilizer

It is interesting to note that compared to the amount of C incorporated into the soil with BC during the first year, 27 % more C was incorporated 6 years later (Kowaljow and Mazzarino 2007). This effect reflects the quantity of C (it was two times higher in BC than in MC; Table 2) and the quality of the applied C since the concentration of recalcitrant C in the form of lignin was twice as high in BC as in MC due to the use of woody residues in the composting of biosolids (Table 1). Linked to lower lignin in MC, we found more labile soil C (i.e., higher respiration per unit of C) in the MC treatment after the first and second year of application (Kowaljow and Mazzarino 2007; Kowaljow et al. 2010). This difference with respect to the BC treatment was attenuated after 6 years, i.e., respiration and extractable C were similar with both types of composts, indicating that the labile C pools of the MC-treated soil was decreased. Lower total C and higher labile C in MC resulted in lowered persistence of applied C in soil. By considering a mean bulk density of 1.13 g cm^{-3} and a depth of 10 cm and subtracting the control value, the amount of C that remained in soil after 6 years was approximately 38 % in the MC treatment compared with 53 % in the BC treatment.

The pattern of soil total N followed a trend similar to organic C since both depend on the decomposition and incorporation of added organic matter. In the short term (1 year), there was no change in total N in the BC-amended treatment (Kowaljow and Mazzarino 2007), but 6 years later, N values were double than those of the control and the IF treatments. Considering that N is the most limiting nutrient for plant growth in semiarid ecosystems (Charley and Cowling 1968; Skujins 1981), the increase and persistence of soil N with BC after 6 years may induce a greater response of vegetation in the long term.

Soil extractable P values were higher with both types of composts than with IF after 6 years, indicating that the effects of the inorganic N-P fertilization were less persistent than those of organic amendments. Extractable P was especially high in the BC treatment throughout the experiment (see also Kowaljow et al. 2010), although values were not excessive compared to limits recommended elsewhere to avoid water pollution (Allan and Killorn 1996; Hesketh and Brookes 2000). Moreover, the levels of extractable P maintained in the soil by this single application of BC, and even MC, indicate that these types and rates of composts constitute a viable alternative to inorganic P fertilization. Argentina is completely dependent on imported P, and the use of composts would not only reduce P imports but also reduce the consumption of P natural resources (Cordell et al. 2009; Elser and Bennett 2011).

The low persistent effects of the inorganic fertilization were also evident in the increase of soil pH and decrease of electrical conductivity with respect to the first year of the experiment, when urea hydrolysis and nitrification led to a lower pH and higher soluble salts than the control. Similarly, the strong alkaline effect of MC on soil at the beginning of the experiment, possibly attributable to Ca carbonates formed during composting (Beck-Friis et al. 2003), is decreasing over time, although electrical conductivity is still higher than in all other treatments.

Several studies have shown that soils amended with organic residues from different origins (municipal solid waste, agro-

Table 4 Soil chemical and physical characteristics 6 years after treatment

	Bulk density (g cm^{-3})	pH	Electrical conduct. (mS cm^{-1})	Total C (g kg^{-1})	Total N (g kg^{-1})	Extractable P (mg kg^{-1})
Control	1.16 (0.02)a	6.8 (0.04)ab	0.034 (0.004)bc	6.3 (0.91)b	0.4 (0.07)b	11.4 (0.80)c
IF	1.14 (0.01)a	7.0 (0.03)a	0.028 (0.002)c	5.5 (0.32)b	0.4 (0.03)b	16.1 (0.95)bc
BC	1.12 (0.01)a	6.5 (0.02)b	0.041 (0.0005)b	11.7 (0.69)a	0.8 (0.04)a	39.6 (1.13)a
MC	1.11 (0.02)a	6.6 (0.08)b	0.063 (0.003)a	8.4 (0.73)b	0.6 (0.05)b	19.3 (2.71)b

Different letters indicate significant differences among treatments (n=4, P<0.05)

BC biosolids compost, *MC* municipal organic waste compost, *IF* inorganic fertilizer

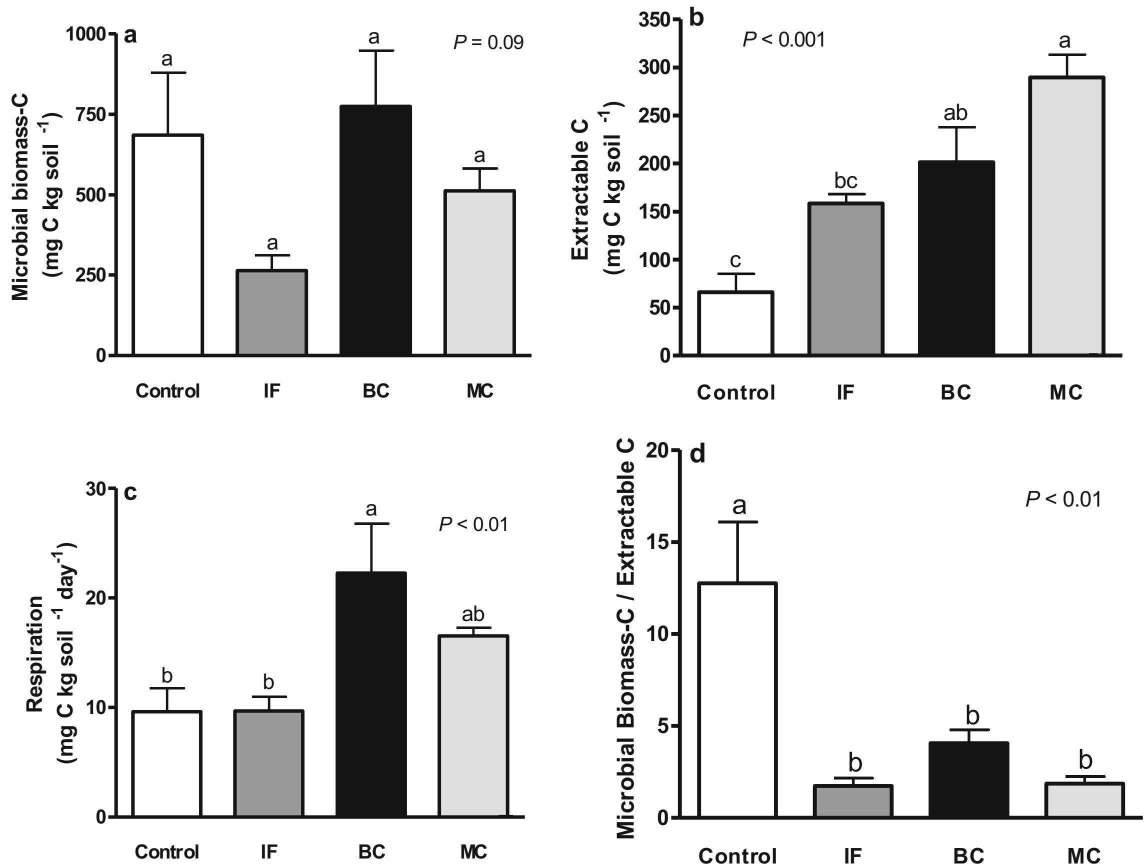

Fig. 2 Soil labile organic and microbial C pools 6 years after treatment. **a** Microbial biomass C. **b** Extractable C. **c** Soil respiration. **d** Microbial biomass C/Extractable C. *BC* biosolids compost, *MC* municipal organic waste compost, *IF* inorganic fertilizer. *Different letters* indicate significant differences among treatments (n=4)

industrial byproducts, animal manures, and sewage sludge), as single or repeated doses, show a higher microbial and enzyme activity than the respective control soil, and they depend on application rates (Pascual et al. 1999; García-Gil et al. 2000; Plaza et al. 2004; Negassa et al. 2011). The persistence of this depends on the degree of enzyme protection in soil, i.e., free (diffusible) enzymes would have a short-lived activity because they can be rapidly denatured, degraded, or inhibited, while those protected by soil colloids like clay and soil organic matter (immobilized enzymes) can retain their activity for long time (Nannipieri et al. 2002; Bastida et al. 2008a; Nannipieri et al. 2012; Burns et al. 2013). In our case, and despite the coarse texture of soil, an increase of enzyme activities in amended plots was still detectable after 6 years, and the response depended on the type of compost.

The quality of the organic matter applied determines the main microbial metabolic pathways, and this can affect soil organic matter content (Ng et al. 2014). The enzymatic load of organic amendments might also be responsible for the increase of enzyme activities of soil, especially in the short term (Perucci 1992). Biosolids compost increased β-glucosidase and acid phosphomonoesterase activities in the treated soil, which was related to higher activities of both enzymes in this type of compost and to higher concentrations of C in the soil. β-Glucosidases catalyze the last step of cellulose hydrolysis, releasing glucose which is directly available to microorganisms. Its potential activity is associated with C substrate availability (Sinsabaugh et al. 2008) and usually increases with compost addition, especially at high rates (Puglisi and Trevisan 2012). Phosphomonoesterase activity can be reduced by inorganic P fertilization (Olander and Vitousek 2000; Negassa et al. 2011). However, when composts with high concentrations of available P are applied, such as those of biosolids and manures, the effects on soil phosphatase activity are mixed (positive and negative) depending on the degree of enzyme protection (stabilized extracellular phosphomonoesterases can remain active), microbial activity, accumulation of organic P, or inhibitory effects (García-Gil et al. 2000; Bastida et al. 2008b). Recently, some authors suggested that in composted or digested animal manures, a fraction of the total P is available for enzyme hydrolysis (Pagliari and Laboski 2013); something similar may be involved in the long-lasting effect of BC on soil extractable P availability and higher phosphomonoesterase activity.

The composts differed also in phenol oxidase activity, which was 2-fold higher in MC than in BC. The most

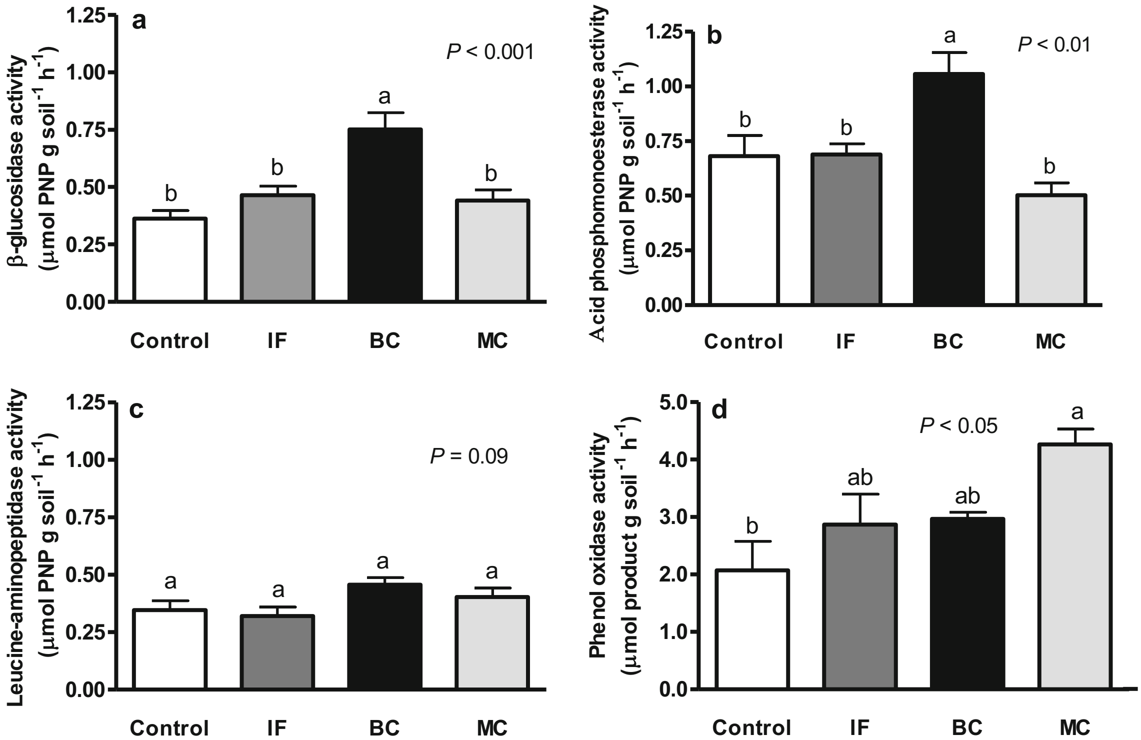

Fig. 3 Soil enzyme activities 6 years after treatment. **a** β-Glucosidase activity. **b** Acid phosphomonoesterase activity. **c** Leucine-aminopeptidase activity. **d** Phenol oxidase activity. *BC* biosolids compost, *MC* municipal organic waste compost, *IF* inorganic fertilizer. *Different letters* indicate significant differences among treatments (n=4)

characteristic biochemical response of the MC treatment was the increase in soil phenol oxidase activity (an enzyme involved in organic matter oxidation, including recalcitrant compounds like lignin); similarly, in other works with municipal waste composts, an increase in soil phenol oxidase activity has been reported (Puglisi and Trevisan 2012). In natural soils, phenol oxidase activity is positively correlated with soil pH and negatively correlated with organic matter accumulation (Waldrop et al. 2004; Sinsabaugh 2010). Two contrasting examples are the high accumulation of organic matter in peatlands, where oxidative activities are low due to acid pH and low oxygen availability and the low accumulation of organic matter in arid ecosystems, where oxidative activities are high, related to poor organic matter inputs, alkaline pH, and enzyme stabilization (Burns et al. 2013). In our experiment, soil pH was slightly acidic and did not differ between MC and BC treatments after 6 years; however, the alkaline MC increased soil pH to values significantly higher than all other treatments during the first years (Kowaljow and Mazzarino 2007). The lower persistence of organic matter under the MC treatment may indicate that, in the long term, the stimulation of soil phenol oxidase activity by MC limits organic matter storage.

Although soil microbial biomass C did not show a clear change with treatments, the microbial community of control plots seems to have been more efficient in substrate utilization than those of other treatments: a higher proportion of labile C was incorporated to microbial biomass and the ratio of respiration to microbial biomass ratio was the lowest. This implies that the addition of C and nutrients with the organic amendments can increase soil microbial activity and organic matter decomposition but not microbial biomass. This was particularly evident for MC, which supplied less and more easily degradable organic matter than BC and maintained high respiration and oxidative enzyme activity. Additionally, soil organic matter accumulation may be limited because it has been proposed that the cell wall envelopes of bacteria and fungi significantly contribute to soil organic matter formation (Miltner et al. 2012).

It has been suggested that, in the long term, the positive effects of organic amendments on soil biochemical fertility are mediated by plant growth and root exudates that provide the substrate needed for microbial activity. Bastida et al. (2008a), for example, reported a significant positive correlation between enzyme activity and plant cover and diversity. However, at the time scale of our study, the direct effect of composts is still evident. For example, in the MC treatment, there was a positive and significant correlation between extractable C and phenol oxidase activity (r=0.69) but not with plant cover (r=0.13; P>0.05) or plant biomass (r=0.11; P>0.05).

In conclusion, the application of urban composts appears to be a feasible restoration practice in semiarid Patagonia, where it can contribute to a long-lasting recovery of ecosystem processes related to nutrient and C cycling. The positive effects found six years after applying a single dose of composts increase the feasibility of using this type of amendments in Patagonia, an extensive arid region of low population density. Moreover, this study highlights the importance of understanding the effects of organic amendments of different origin on soil enzyme activities, which may determine soil C storage in the long term. Both composts (MC and BC) differed in nutrient contents, organic matter quantity and quality, and enzyme activities, resulting in more positive persistent effects with BC than with MC applications. Further research is needed to determine if the stimulated enzyme activity depends only on the type of compost or also on its interaction with the environment and on microbial-community composition.

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