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EXPANDED SUMMARY

SOIL CARBON DYNAMIC ASSOCIATED TO LAND-USE CHANGES IN SEMI-ARID FORESTS OF ARGENTINA

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SUMMARY

Land-use change represents one of the main drivers of global climatic change, affecting the amount and quality of organic matter (OM) in soils worldwide. A reduction in the amount of biomass due to forest management is expected to affect both the amount of new OM going into the soil and its microbial decomposability due to changes in soil environmental conditions. These changes should impact soil microbial communities, their activity and decomposition rates, affecting the amount and quality of organic carbon (OC) remaining in the soil. In order to obtain information on the effect of land-use change on the OM quantity and quality, its origin and its degree of stabilization (i.e., microbial decomposability), we characterized the amount of OC, the lignin and polysaccharide compounds by wet chemical analysis, as well as basal respiration rates across a disturbance gradient (n=20) in a semiarid Chaco forest of central Argentina. Disturbance reduced the amount and quality of litterfall, reflected in a reduction in SOM content. Soil carbohydrates content followed the same trend but lignin was not affected by land-use change. Although basal CO_2 effluxes showed the same pattern than SOM content, when normalized per OC content, they showed the opposite trend, with higher CO_2 released per C in sites with lower OC and carbohydrates content. Our results support the idea that in the semi-arid Chaco forest, chemically labile compounds are more vulnerable to disturbance, but also that OM could be protected and stabilized regardless of its chemical identity.

KEYWORDS: lignin; carbohydrates; soil organic matter

INTRODUCTION

World soils play an important role in the global carbon (C) cycle, not only as C reservoir but also through their contribution to the dynamics of ecosystems (Lal 2005). The process of soil organic matter (SOM) formation is fundamental to the recycling of macronutrients into plant available forms. A wide range of soil properties, including soil structure, water and nutrient holding capacity and biodiversity, are improved by maintaining optimal quantities of SOM (Dungait et al. 2012; Powlson et al. 2011).

Land-use change has profoundly affected the amount and the quality of SOM (Besnard et al. 1996; Don et al. 2011; Lal 2013; Rumpel et al. 2009). The process of C loss from vegetation removal due to forest management and deforestation is often accompanied by C losses from surface soils as a result of a reduction in its physical protection (Martínez-Mena et al. 2002; Post and Kwon 2000) and a reduction in the amount of litter input due to declining productivity (Don et al. 2011; Jandl et al. 2007; Yanai et al. 2003). These changes impact soil microbial communities, their activity and decomposition rates, reducing the amount of organic C in the soil (Diochon et al. 2009).

Land use conversion also result in changes in the quality of SOM (Besnard et al. 1996; Martens et al. 2004; Rumpel and Chabbi 2010; Rumpel et al. 2009). Traditionally, it has been proposed that biochemically recalcitrant bio-macromolecules (p.e., lignin compounds) are more stable and resistant to biological attack (Lorenz et al. 2007) compared to more labile compounds. As a consequence, a higher amount of labile OM could lead to a higher microbial activity. In the same line, it is expected that soils with more lignin contain less degradable OC, which may not be easily used as substrate by microorganisms. However, recent studies have shown that C may persist in soil mainly to physical mechanisms such as aggregation and adsorption to minerals, limiting microbial activity and accessibility (i.e., enzyme production and substrate degradation) (Dungait et al. 2012; Kögel-Knabner et al. 2008; Schmidt et al. 2011; von Lützow et al. 2008). According to this view, the microbial substrate degradation will be mainly related to the accessibility and protection of OM in the soil environment, rather than to the chemical lability or recalcitrance of OM.

In the Chaco forest, now having one of the highest rates of annual cover change globally (Hansen et al. 2013), it is expected that such land cover modifications may lead to important changes in the SOM. Previous works in the area have found a significant reduction in soil organic C (SOC) from the top 0-20 cm due to overgrazing and forest degradation (Abril and Bucher 2001; Bonino 2006). However, to date, underlying mechanisms remain unknown. Moreover, to our knowledge there is no previous works describing the effect of land use change over the OM quality in the Chaco forests.

In order to obtain information on the effects of land-use change on the OM quantity and quality, we characterized the amount of OC, the lignin and polysaccharide compounds by wet chemical analysis (Chabbi et al. 2007; Rumpel and Chabbi 2010; Rumpel and Kögel-Knabner 2002). We also measured basal respiration rates across a disturbance gradient in the semiarid Chaco forest of central Argentina in order to investigate changes in the activity of microbial communities.

MATERIALS AND METHODS

The study was carried out in the southern extreme of the Gran Chaco, in central Argentina (c. 31°17'- 31°50' S and 65°16'- 65°32' W). The climate is subtropical with a mean annual precipitation of 600 mm and a mean annual temperature of 18 °C. Soils are mainly sandy-loam entisols of alluvial origin (Mazzarino et al. 1991). Within the study area we selected 20 sites corresponding to different ecosystem types initially corresponded to the same vegetation, developed under the same climate and on highly similar parental material. These sites were differentiated by contrasting long-term land use regimes. These regimes consisted of combinations of different intensities of livestock grazing, logging and total forest replacement by intensive agriculture (Cabido et al. 1994), resulting in different levels of aboveground standing biomass at each site. The sites corresponded to *primary forest, secondary forest*, *closed species-rich shrubland, open shrubland* strongly dominated by *Larrea divaricata* and *potato crop*. Although initially the sites were chosen in order to match these five different categories, they actually represent a continuum rather than discrete categories, because of the nature of the land-use regimes. Across the land use gradient, we used the amount of aboveground standing biomass (kg m^{-2}) as a measure of the degree of disturbance

(Garnier et al. 2007). During spring 2008, at each site we took three soil samples in the 0 -10 cm layer and sieved them at 2 mm at each of the replicates. Soil samples were then mixed, air-dried and stored in closed plastic bags to make subsequent analysis.

Chemical analysis

The lignin content of the samples was determined after release of the phenol monomers by alkaline CuO oxidation (Hedges and Ertel 1982). This method yields phenols, such as vanillyl (V), syringyl (S), and cinnamyl (C) compounds with aldehydic, ketonic, and acidic side chains. The sum of CuO oxidation products (VSC) is usually taken as an indicator of the total amount of lignin (Hedges et al. 1988). Analytical precision is 10% for VSC. Non-cellulosic sugars were analyzed by gas chromatography as acid alditols after hydrolysis using boiling Trifluoric acetic acid (TFA) (Rumpel and Dignac 2006). TFA is known to hydrolyse only non-cellulosic plant or microbial derived sugars. Analytical precision is 5%.

Basal respiration

A total of 48 g of air-dried soil was placed in a 50-mL sterile polypropylen tube, for a total of 21 tubes. Distilled water was added to each tube until 40% of water holding capacity was reached, and the tubes were placed in controlled conditions at 23°C. CO_2 fluxes were measured using an infra-red gas analyzer (IRGA, EGM-4, pp-system Company) coupled to a chamber adapted to the tubes. This closed dynamic chamber system measured the increase of CO_2 in the chamber at 8-s intervals during 8 to 10 minutes depending on signal fluctuations. The rate of increase was used to calculate CO_2 flux (nmol CO_2 g soil DW^{-1} h^{-1}). Measurements were taken after eight hours (day 1), and after 4, 6, 8, 13 and 35 days, respectively. Air temperature (23°C) and soil water content (c.a. 40% of WHC) were maintained constant throughout the experiment.

RESULTS AND DISCUSSION

Within the study area we found that disturbance profoundly affected SOM quantity and quality in the semiarid Chaco of central Argentina. The amount of aboveground litter fall was significantly affected by biomass removal, decreasing on sites with lower standing aboveground biomass (Figure 1a). The quality of the fallen litter in terms of C to N ratio was also significantly lower in more disturbed sites (Figure 1b), mainly due to changes in the N content of the fallen litter. Changes in litter quality (without including potato crop for which no litter was left on surface) could be related to an increased dominance of more water stress tolerant plant species on sites with less vegetation cover, compared to more diverse and conserved sites where a higher diversity of chemical leaf traits was observed, as found by Conti and Díaz (2013). These trends were reflected in the amount of OC across sites, which was significantly reduced at more disturbed sites (Figure 1c). The amount of OC in the 0-10 cm soil layer ranged between 3.8 g kg^{-1} under potato crops and 17.9 g kg^{-1} at the most conserved sites. Several meta-analysis showed that after conversion from forest to cropland, at least 30% of the SOC may be lost (Don et al. 2011; Guo and Gifford 2002; Murty et al. 2002). Here we found a difference of 79% in OC content between the most conserved and the most intensively used site. Previous studies carried out in the area have shown similar values of OC for sites under natural vegetation, and also found a reduction in the amount of OC due to overgrazing and degradation (Abril and Bucher 2001; Bonino 2006; Mazzarino et al. 1991).

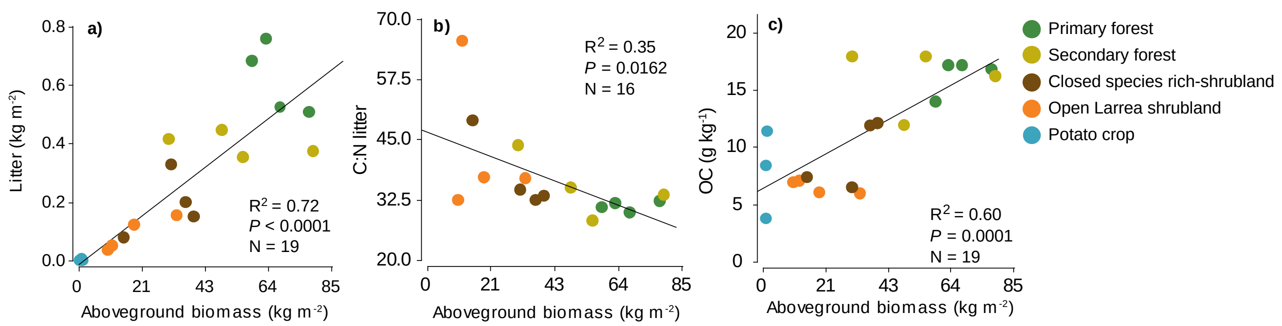

Figure 1. Simple linear regression analysis between aboveground standing biomass and a) the amount of litter (kg m^{-2}), b) C to N ratio of standing litter, and c) OC content (g kg-1) in 0-10 cm soil layer from the semiarid Chaco of central Argentina.

The non-cellulosic carbohydrate content ranged between 0.61 and 3.94 mg g^{-1} soil across the land-use gradient. Disturbance significantly and negatively affected the carbohydrate content of soils (Figure 2a). In the case of the soil lignin content, our results showed that disturbance did not significantly affect the amount of lignin found in the soil (Figure 2b). Lignin compounds ranged between 0.06 and 0.81 mg g^{-1} soil across all sites.

A change in the quality of OM is expected after a change in the quality of the litter decomposing in the soil. Studies using physical fractionation procedures also showed that the light fraction of SOM often respond more rapidly to land-use change than bulk SOM (Six et al. 1998), which is in accordance with the results found here. After land-use changes, the carbohydrate content of SOM decrease, which could indicate the rapid decomposition of labile carbohydrates which were formerly protected within soil aggregates in forest soils (Besnard et al. 1996). We did not find a correlated change between the lignin content and the OC content of the soils, indicating that lignin is not part of the labile carbon fraction, which is easily lost upon cultivation, as found previously (Rumpel and Chabbi 2010; Thevenot et al. 2010).

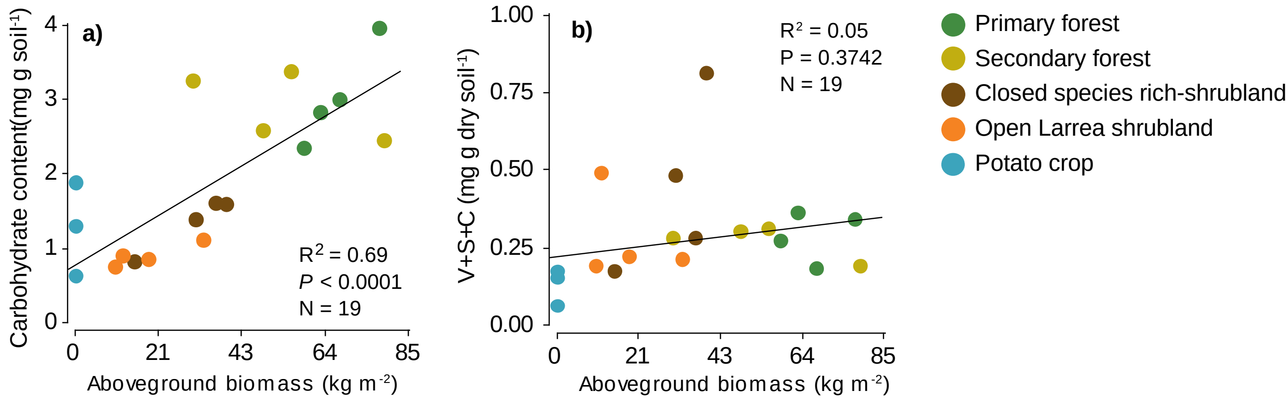

Figure 2. Simple linear regression analysis between aboveground standing biomass and a) carbohydrate content (mg) per soil (g) and b) lignin content (mg) per soil (g) from the semiarid Chaco of central Argentina.

Potential microbial activity measured as soil CO_2 effluxes during incubation under optimal conditions were significantly affected by disturbance. At the beginning of the incubation (instantaneous CO_2 efflux), lowest activities were measured at the most disturbed sites. When normalized per gram of C, although mostly marginally significant, the trend was opposite in all cases, with a lower CO_2 efflux per gram of C in most conserved sites. The cumulative CO_2 in the sampled time interval (35 days) followed the same pattern that instantaneous CO_2 fluxes (Figure 3a & b). These results showed that although microbial activity is lower at more degraded sites (with lower OC content), CO_2 efflux per unit of C is higher compared to undisturbed forests (with higher SOC and carbohydrates content). These results suggest a lower protection and stabilization of OC at degraded sites. As soil lignin content was lower at degraded sites, SOC stabilization might be tightly linked to physical mechanisms such as aggregation and adsorption to minerals, which would limit microbial activity and accessibility (Von Lutzow et al. 2006; Kögel Knabner et al. 2008; Schmidt et al. 2011; Dungait et al. 2012).

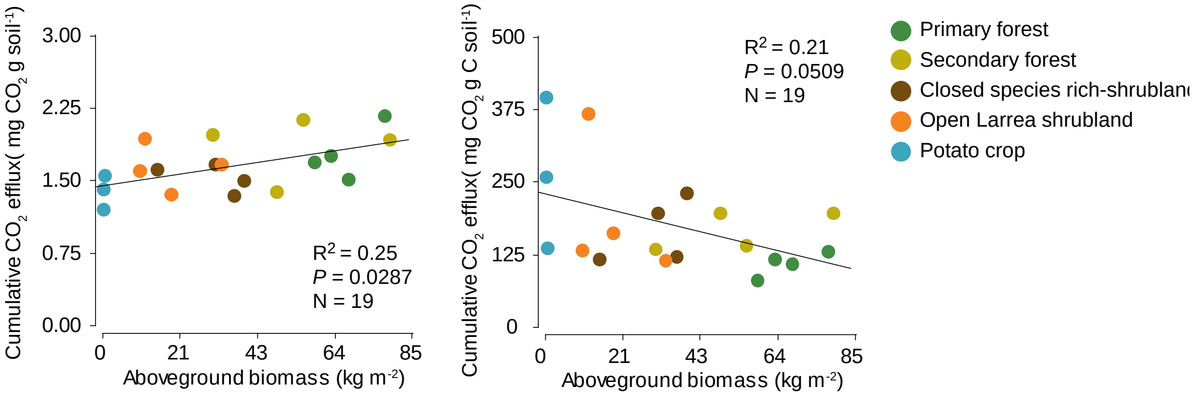

Figure 3. Simple linear regression analysis between aboveground standing biomass and a) cumulative CO_2 efflux (mg) per soil (g) and b) normalized cumulative CO_2 efflux per gram of C to soil OC (g kg^{-1}) during 35 days, from the semiarid Chaco of central Argentina.

CONCLUSIONS

Our results indicate that forest management and conversion to crops is associated with changes in the amount and quality of SOM. The work presented here, partially support the idea that both mechanisms, the OM chemical characterization and the protection within stabilized soil aggregates, are the main factors controlling the dynamic of SOM in the semiarid Chaco forest of central Argentina. At present, Chaco forests are quickly being replaced by intensively managed systems, and this trend is likely to continue or even accelerate. If so, then a severe reduction in the amount and quality of SOM in the semi-arid Chaco forest is likely. This would add to the broader set of losses of ecosystem services associated with these land-use trajectories at local, regional and global scales.

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