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Research article

Reductions of plant cover induced by sheep grazing change the above-belowground partition and chemistry of organic C stocks in arid rangelands of Patagonian Monte, Argentina

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ABSTRACT

The objective of this study was to estimate the size and chemical quality of the total organic C stock and its partition between above-belowground plant parts and soil at sites with different plant cover induced by sheep grazing in the arid Patagonian Monte. This study was conducted at six representative sites with increasing signs of canopy disturbance attributed to grazing pressure. We used faeces density as a proxy of grazing pressure at each site. We assessed the total plant cover, shrub and perennial grass cover, total standing aboveground biomass (AGB), litter mass and belowground biomass (BGB) at each site. We further estimated the content of organic C, lignin and soluble phenols in plant compartments and the content of organic C, organic C in humic substances (recalcitrant C) and water soluble C (labile C) in soil at each site. Total plant cover was significantly related to grazing pressure. Standing AGB and litter mass decreased with increasing canopy disturbance while BGB did not vary across sites. Total organic C stock and the organic C stock in standing AGB increased with increasing total plant, shrub, and perennial grass cover. The organic C stock in litter mass increased with increasing total plant and shrub cover, while the organic C stock in BGB did not vary across sites. Lignin content in plant compartments increased with increasing total and shrub cover, while soluble phenols content did not change across sites. The organic C stock and the water soluble C content in soil were positively associated with perennial grass cover. Changes in total plant cover induced by grazing pressure negatively affected the size of the total organic C stock, having minor impact on the size of belowground than aboveground components. The reduction of perennial grass cover was reflected in decreasing chemical quality of the organic C stock in soil. Accordingly, plant managerial strategies should not only be focused on the amount of organic C sequestered but also on the chemical quality of organic C stocks since C chemistry could have an important impact on ecosystem functioning.

1. Introduction

The above-belowground partitioning of organic C stocks may vary among biomes, ecosystems, environmental conditions and managerial practices (Derner and Schuman, 2007; Locatelli and Leonard, 2001; Zhao et al., 2004). Soils are the largest organic C reservoir in the biosphere in most terrestrial ecosystems (Lal, 2004, 2011; Schlesinger, 1997). Soil organic C gains and losses are strongly related to the mass and decay rates of senesced plant tissues (Costa et al., 2012; Kröpfl et al., 2013; Larreguy et al., 2014). Our ability to predict and mitigate C losses would depend on a better understanding of the distribution, amount, concentration of labile and recalcitrant compounds (chemical quality) and degradability of the organic C stocks (Chapin and Ruess, 2001).

In the arid ecosystems the scarce plant cover, life history of plants, and the rate of herbivory are main controls of the size and dynamics of C stocks (Golluscio et al., 2009; Milchunas and Lauenroth, 1993). In these ecosystems, vegetation is mostly dominated by woody species along with perennial grasses. Woody plants have high amount and diversity of chemical (e.g. soluble phenols) and/or structural (e.g. spines) defenses against desiccation, herbivory, pathogens and UV radiation. In contrast, perennial grasses have low protection against both abiotic factors and herbivory and are more affected than woody species by herbivores

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(Aerts and Chapin, 2000; Carrera et al., 2009; Hättenschwiler and Vitousek, 2000; Moreno et al., 2010). Accordingly, the amount and chemistry of above and belowground litter mass may differ between plant groups. Moreover, the relative dominance of different plant groups may have consequences on the organic matter decay and C cycling (Aerts and Chapin, 2000). In general, litter with low concentration of secondary compounds decomposes fast, and may contribute to enhance the content of soil labile C (Montané et al., 2010; Su et al., 2004). In contrast, litter with high concentration of lignin and/or soluble phenols are usually recalcitrant to decomposition leading to the formation of humic substances (Almendros et al., 2005; Schaeffer et al., 2015).

Disturbances such as those induced by grazing may cause changes in the spatial arrangement and abundance of plant species and/or plant growth forms, affecting the contribution of AGB and BGB to litter, with consequences to the size and quality of organic C stocks and the rates of biogeochemical cycles (Angassa, 2012; Oñatibia et al., 2015; Zhao et al., 2009). The most conspicuous effects of grazing disturbance in Patagonian Monte ecosystems are the reduction of plant cover and biomass, the replacement of non-woody species (mainly perennial grasses) by evergreen woody plants, and the reduction in litter amount and chemical quality (Bertiller and Ares, 2011; Bertiller and Bisigato, 1998; Carrera et al., 2008; Carrera and Bertiller, 2013). On the other hand, changes in root biomass were less noticeable (Rodríguez et al., 2007; Larreguy et al., 2014) as in other ecosystems (Costa et al., 2012; Milchunas and Lauenroth, 1993). Additionally, increasing bare soil or sparsely vegetated areas may be strongly impacted by wind and water soil erosion (Breshears et al., 2003; Tongway et al., 2003) causing losses of fine soil material and the associated organic matter (Bisigato et al., 2008; Neff et al., 2005).

Since arid ecosystems occupy more than 35% of the global land area, they are considered important reservoirs of soil organic C (Lal, 2004). However, the impact of grazing on the amount and chemical quality of above-belowground organic C stocks has been scarcely explored in these ecosystems. Previous studies showed positive (Reeder and Schuman, 2002), neutral (Shrestha and Stahl, 2008) or negative effects of grazing (Pei et al., 2008) on the size of soil organic C stocks (Baisden and Amundson, 2003). However, none of these studies analyzed whether these responses were associated with changes in the C partitioning or in chemical quality (recalcitrant or labile C) of organic C stocks.

Our objective was to estimate the size and chemical quality of the total organic C stock and its partition among above, belowground plant parts and soil at sites with different plant cover induced by sheep grazing in the arid Patagonian Monte. We hypothesized that the reduction of plant cover induced by sheep grazing affects C partitioning by increasing the size of belowground-C relative to aboveground C stocks and by increasing recalcitrant C in arid ecosystems.

2. Materials and methods

2.1. Study area and sampling sites

The study was carried out in northeastern Patagonia (Patagonian Monte). Mean annual temperature is 13.7 °C and mean annual precipitation is 177.6 mm (series from 1952 to 2009, CENPAT, 2014; INTA, 2014). Vegetation corresponds to the shrubland of *Larrea divaricata* Cav. and *Stipa* spp., characteristic of the southern portion of the Monte Phytogeographic Province (León et al., 1998). Soils are a complex of Typic Petrocalcids-Typic Haplocalcids in which the presence of a calcium carbonate layer approximately 35–40 cm deep (del Valle, 1998; Soil Survey Staff, 1998) with a variable degree of compaction is in many cases a physical barrier to root penetration (Súnico, 1996).

In the Patagonian Monte, sheep grazing (mainly Merino breed) was introduced at the beginning of the last century to produce mainly fine wool and was typically organized in ranches of about 4 paddocks of 2500 ha each sharing a single permanent watering point. Since then, the mean historical stocking rate has been 0.11–0.14 sheep ha^{-1} (including adults and juveniles), keeping sheep in the same paddock throughout the year. This in turn led to the formation of extended piospheres (1500–4000 m) around watering points where the spatial pattern of vegetation, the dominant plant traits, and the upper soil conditions were modified by the frequent visit of grazers (Ares et al., 2003; Bisigato and Bertiller, 1997; Bisigato et al., 2008; Larreguy et al., 2014). These domestic herbivores weigh between 40 and 60 kg and feed mainly on perennial grasses and some shrubs (Baldi et al., 2004). Accordingly, the size of shrub patches, perennial grass cover, and total plant cover decreases near the watering point (Bär Lamas et al., 2013; Bertiller et al., 2002; Bertiller and Ares, 2008; Pazos et al., 2007). In order of importance, *Pappostipa speciosa* (ex *Stipa speciosa*), *Nassella tenuis* (ex *Stipa tenuis*), and *Poa ligularis* are the dominant perennial grass species in the area. Among them, *P. speciosa* is less preferred by herbivores than the other species. Other less abundant and highly preferred perennial grass species are *Elymus patagonicus* and *Jarava neaei* (ex *Stipa neaei*) (Bisigato and Bertiller, 1997). Faeces counts and density of sheep paths (Bisigato and Bertiller, 1997; Pazos et al., 2007), vegetation structure assessed by remote sensing (Ares et al., 2003) as well as to reductions in soil organic C with increasing grazing disturbance (Carrera et al., 2008; Prieto et al., 2011) are indicators usually used to confirm the existence of areas affected by grazing disturbance around watering points (piospheres).

This study was conducted at six sites (Supplementary material Table 1) with similar soil conditions, topography and vegetation type and increasing signs of canopy disturbance attributed to grazing pressure (Bär Lamas et al., 2013; Brooks et al., 2006; Larreguy et al., 2014). The gradient of grazing disturbance used in this study is consistent with those reported for the shrubland of *Larrea divaricata* and *Stipa* spp. characterized by decreasing total, perennial grass and in some cases shrub cover, as well as reduced shrub patch size with increasing grazing disturbance in the Patagonian Monte (Bär Lamas et al., 2013; Bertiller et al., 2002; Bertiller and Ares, 2008; Bisigato and Bertiller, 1997; Bisigato et al., 2008; Carrera et al., 2008; Pazos et al., 2007, 2010). We used the total faeces density assessed for these sites by Bär Lamas et al. (2013) in 2009 as an index of grazing pressure (Lange and Willcocks, 1978).

2.2. Plant cover

Total plant cover and the cover of dominant plant growth forms (shrubs and perennial grasses) were assessed at four randomly located 25-m linear transects by the line intercept method (Muller-Dombois and Ellenberg, 1974) at representative areas (3 ha each, minimal area *sensu* Muller-Dombois and Ellenberg, 1974) of each site in autumn 2010. We further calculated the absolute total plant cover and the relative shrub and grass cover. We estimated the grazing disturbance level at each site by comparing the perennial grass cover at each site with those reported in other areas of the Patagonian Monte. These areas encompassed a site excluded from domestic herbivores for 12 years, and sites with low, moderate and high grazing disturbance (>3000 m far from the watering point, ca. 600 m and <300 m from the watering point, respectively) (Bisigato and Bertiller, 1997; Carrera et al., 2008; Larreguy et al., 2012; Pazos et al., 2007; Prieto et al., 2011). Additionally, at each transect, we assessed the number of plant patches and the area, maximum height, plant growth form composition of each intercepted patch