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Soil respiration in Patagonian semiarid grasslands under contrasting environmental and use conditions

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ABSTRACT

Grasslands comprise 85% of Southern Patagonia land area and play a critical role in the global carbon cycle. We evaluated seasonal dynamics to identify differences in soil respiration rates between contrasting grasslands across a climate gradient (rainfall), long term grazing intensity (moderate and high stocking rates) and land uses (silvopastoral system, primary forest and grassland). Soil respiration varied from 0.09 g CO_2 h^{-1} m^{-2} in winter to a maximum of 1.43 g CO_2 h^{-1} m^{-2} in spring. We found that the soil respiration rate was 30% higher in moderately grazed grasslands than in heavily grazed grasslands. Land-use changes showed that soil respiration followed the order silvopastoral system > native forest > grassland. While almost all plant and soil variables had a significant effect on soil respiration, soil carbon concentration, litter cover and depth and bare soil cover were the main factors explaining 78–83% of the variance in soil respiration. Soil respiration rates were correlated strongly to air and soil temperatures and to a lesser extent with mean monthly rainfall and soil volumetric water content. The information provided in the present work about soil respiration is essential to estimate carbon balance for a range of important and widespread ecosystems in Patagonia.

1. Introduction

In Santa Cruz province (area of 243,943 km^2, from 46° to 52° 30′S), grasslands comprise approximately 85% of the total land area, where the main activity is extensive sheep production, with stocking rates ranging from 0.13 to 0.75 head ha^{-1} yr^{-1}. In this province, deciduous *Nothofagus antarctica* forest cover 159,720 ha in a narrow (50 km wide) and long (1000 km) strip of land along the Andes Mountains, which has been historically used as silvopastoral systems, with livestock feeding on natural grasslands that grow in the understory of thinned forests (Peri et al., 2009a).

Concern about global climate change has focused attention on the stocks and flows of the global carbon cycle mainly under Article 3.4 of the Kyoto Protocol of the United Nations Framework Convention on Climate Change (IPCC, 2001). In Southern Patagonia (Santa Cruz and Tierra del Fuego provinces), mean maximum annual temperature is predicted to increase by 2–3 °C in 2080 between 46 and 52° 30′ SL (Kreps et al., 2012) and this would have significant effects on Patagonian ecosystems. In this context, data on C storage in forests, grasslands and shrublands are essential for understanding the importance of rapidly increasing level of CO_2 in the atmosphere and its potential effect on global climate change. In Southern Patagonia, studies have estimated the C sequestration in different ecosystems (Peri and Lasagno, 2009, 2010; Peri et al., 2010; Peri, 2011). Total C storage (above- and belowground-biomass) ranged from 4.9 Mg C ha^{-1} (dominant *Jarava chrysophylla* and *Poa spiciformis* grassland with 40% bare soil) to 182.0 Mg C ha^{-1} (optimal growth stands in *N. antarctica* forest growing at good quality sites). Also, the effect of long-term livestock grazing on C content of the plant-soil grassland system (0.30 m depth) of Dry Magellanic Grass Steppe and Sub-andean Grassland areas in Southern Patagonia has been reported (Peri, 2011). On these extensively managed grasslands, grazing intensity was the main management practice that affected ecosystem C levels with values ranging from 50 Mg C ha^{-1} at a heavy stocking rate (0.70 ewe ha^{-1} yr^{-1}) to 130 Mg C ha^{-1} under low grazing intensity (0.10 ewe ha^{-1} yr^{-1}). Peri et al. (2009b) reported the aboveground and belowground C sequestration for different components of trees and pasture (green and dead leaves, pseudostem and coarse and fine roots), and the C storage in leaf litter in an

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N. antarctica silvopastoral system which varied according to silviculture practice (thinning intensity) and site quality. In these Patagonian ecosystems, soil C constitutes between 79 and 90% of the total C depending on plant functional types and environmental conditions (Peri and Lasagno, 2009, 2010; Peri et al., 2010; Peri, 2011). This is important because soils contain up to three times more carbon than the global vegetation pool and atmosphere combined and this large carbon pool is vulnerable to land-use change and management (Trumbore, 2009).

However, it is necessary to quantify the net amount of C sequestration of all C pools and fluxes within an ecosystem in order to best estimate its contribution and effectiveness in mitigating atmospheric CO_2. Soil respiration, produced mainly by roots and soil organisms (mycorrhizal fungi and microbial), and to a lesser extent, chemical oxidation of carbon compounds, is the primary pathway for CO_2 fixed by plants to return to the atmosphere. Soil respiration is therefore a key process that needs to be considered to understand the terrestrial carbon cycle. Several studies in different ecosystems and land uses (grasslands, forests and agroforestry systems) have analysed the relative contribution of environmental (soil temperature and moisture, substrate availability and quality) and management (grazing, cropping) on soil respiration (Lloyd and Taylor, 1994; Raich and Tufekcioglu, 2000; Lee and Jose, 2003; Hibbard et al., 2005; Wang and Fang, 2009). Soil respiration also varies with vegetation and among major biome types (Raich and Schlesinger, 1992). Such findings indicate that environment, human activities and vegetation type are important determinants of soil respiration rate, and therefore that changes in these factors have the potential to modify the responses of soils. In this context, this study is the first to examine and compare the soil respiration within temperate and semiarid grassland ecosystems in Southern Patagonia. Our objective was to evaluate the main factors that might influence soil respiration rates in response to climate, grazing and land use. For this, we evaluated: 1. the seasonal dynamics of soil respiration rates between contrasting grasslands across a climate (precipitation and temperature) gradient; 2. the effects of long term grazing intensity on temporal variation of soil CO_2 efflux from dry and humid Magellanic grass steppe areas in Southern Patagonia and 3. soil respiration in response to land-management practices by comparing silvopastoral systems, primary forest and the adjacent open grassland site. In this context, we hypothesized that: (i) vegetation type mainly influences soil respiration rates across a climate and vegetation gradient in grasslands under low-moderate grazing intensity, (ii) high stocking rates mostly affects negatively soil respiration through its effect on plants and soil parameters and (iii) soil respiration in woody communities is higher than in grasslands.

2. Materials and methods

The study was conducted in permanent plots established as part of PEBANPA network (Biodiversity and Ecological long-term plots in Southern Patagonia). In Santa Cruz province, rainfall decreases from 800-1000 mm–200 mm yr^{-1} from west to east across the Andes Mountains that act as an orographic barrier to moist winds coming from the west. The wide range of precipitation and soil characteristics in Patagonia, between the deciduous *Nothofagus* forest in the west and the steppe in the east, constitutes an outstanding vegetation gradient. The climate in this region is dry, cold and windy. Temperatures are highest from December to February, and at a minimum in June–July. Summers are short, but with long days due to latitude. The windiest season is from November until March. The predominant wind direction is from the south-southwest. Severe and frequent windstorms occur in spring and summer, with windspeeds over 120 km h^{-1} (Peri and Bloomberg, 2002).

2.1. Study sites in a vegetation and climate gradient

To identify potential differences in soil respiration rates related to contrasting grasslands across a climate gradient, three study areas of 25 km^2 (5 × 5 km) were selected representing main grassland ecosystems in the Magellanic grass steppe (centre of study area located at 51° 30′ 51″S, 70° 04′ 55″W), “mata negra” Matorral Thicket (51° 07′ 23″S, 70° 58′ 38″W) and Andean (51° 12′ 54″S, 72° 08′ 29″W) ecological areas in Santa Cruz province, southern Patagonia, Argentina. The selected study sites corresponded to a low-moderate grazing intensity. The estimation of carrying capacity was based on the biomass production of short grasses and forbs that grow in the space among tussocks of each ecological area and the requirements of 530 kg DM yr^{-1} for 1 Corriedale ewe of 49 kg of live weight which represents a “Patagonian sheep unit equivalent (PSUE)” (Borrelli, 2001). Most of the grazing plans consisted of an adaptive scheme based on year-round continuous grazing with variable animal stocking rate adjusted yearly according to herbage mass assessments.

In the Magellanic grass steppe, the vegetation is dominated by the tussock *Jarava chrysophylla* (40–60%) and associated with *Poa spiciformis*, *Carex andina*, *Rytidosperma virescens*, *Acaena* sp., dwarf-shrubs *Nardophyllum bryoides, Ephedra frustillata* and *Perezia recurvata*, and shrubs *Berberis microphylla* and *Junellia tridens*. The mean long term stocking rate was 0.31 ewe ha^{-1} yr^{-1}, mean annual precipitation (MAP) of 235 mm yr^{-1} and mean annual temperature (MAT) of 7.1 °C (mean of 11.9 °C in summer and 1.2 °C in winter).

The vegetation of the Matorral Thicket site is dominated by the shrub *J. tridens* (30–35%) and associated with grasses *J. chrysophylla*, *Jarava ibari*, *Bromus setifolius*, *Festuca pyrogea*, dwarf-shrubs *Clinopodium darwinii*, *Nassauvia aculeata*, *Nassauvia glomerulosa*, *N. bryoides* and herbs (*Cerastium arvense*, *Acaena poeppigiana*). The mean long term stocking rate was 0.22 ewe ha^{-1} yr^{-1}, MAP of 155 mm yr^{-1} and MAT of 6.5 °C.

The vegetation in the Andean ecological area is dominated by *Festuca pallescens* (20–30%), *Phleum alpinum*, *B. setifolius*, *Agrostis flavidula*, *Carex argentina, Poa pratensis* and *Azorella monantha*. The mean historical stocking rate was 0.45 ewe ha^{-1} yr^{-1}, MAP of 390 mm yr^{-1} and MAT of 4.9 °C.

2.2. Study sites for grazing intensity

Two study areas of 25 km^2 (5 × 5 km) were selected in both the dry and humid Magellanic steppe areas, to evaluate two long term grazing intensities (moderate and high stocking rates) on soil respiration. In the dry Magellanic steppe, moderate stocking rate represented 0.26 ewe ha^{-1} yr^{-1} (centre of study area located at 51° 32′ 40″S, 69° 16′ 38″W) and high stocking rate had 0.51 ewe ha^{-1} yr^{-1} (51° 31′ 01″S, 69° 30′ 31″W). The vegetation is dominated by tussocks of *Festuca gracillima* and associated with short grasses *P. spiciformis*, *B. setifolius* and *Hordeum comosum*, graminoids (*Carex* spp.), herbs (*Viola maculata*, *Calceolaria uniflora*) and dwarf-shrub (*N. bryoides*, *Nassauvia ulicina*, *Azorella fuegiana*). The MAP is 240 mm yr^{-1} and MAT of 7.7 °C (mean of 12.8 °C in summer and 1.5 °C in winter).

In the humid Magellanic steppe, moderate stocking rate represented 0.40 ewe ha^{-1} yr^{-1} (centre of study area located at 51° 48′ 19″S, 69° 40′ 38″W) and high stocking rate had 0.85 ewe ha^{-1} yr^{-1} (51° 54′ 44″S, 69° 39′ 12″W). The vegetation is dominated by tussocks of *F. gracillima* (20–30%) and associated with grasses *Festuca magellanica*, *P. spiciformis*, *R. virescens*, *B. setifolium*, *Agropyron fuegianum*, graminoids (*Carex* spp.), dwarf-shrubs (*C. darwinii*, *Senecio laseguei*) and herbs (*Calceolaria polyrrhiza*). The site is characterized