Effects of livestock management on carbon stocks and fluxes in grassland ecosystems in the Pyrenees

Casals P.[1], Garcia-Pausas J.[1], Romanyà J.[2], Camarero L.[3], Sanz M.J.[4] and Sebastià M.T.[1]
[1]*Technology and Forestry Centre of Catalonia (CTFC), E-25280 Solsona, Spain*
[2]*Laboratory of Soil Science, University of Barcelona, E-08028 Barcelona, Spain*
[3]*Centre d'Estudis Avançats de Blanes, CSIC, E-17300, Blanes, Spain*
[4]*Fund. Centro de Estudios Ambientales del Mediterráneo (CEAM), E-46980 Paterna, Spain*

Abstract

Grassland ecosystems can constitute a source or a sink in the global C balance, and their management affect their position in that balance. We aim to assess soil organic carbon (SOC) content and determine how grazing affects C fluxes and stocks in grasslands at high altitude in the Pyrenees. In a preliminary survey we found that total SOC ranges from 65 to 300 Mg ha^{-1} in these ecosystems, and is partially explained by complex combinations of variables representing topography, macroclimate and bedrock. In a second, more detailed survey, we improved the modelling of SOC by introducing management variables and standing biomass. Preliminary results of this work suggested that abandoned areas had lower SOC than grazed areas, and the higher SOC contents occurred when both sheep and cattle grazed in the area. The importance of management in soil carbon accumulation was confirmed in an experiment developed in two subalpine locations, where we found a sharp increase in active soil organic matter in grazed compared to non-grazed plots. The Eddy covariance method showed that an intensely grazed area was a slight sink for C, in spite of the elevated C efflux in August, when temperatures were very high and vegetation had been heavily grazed.

Keywords: subalpine grasslands, pasture, soil organic matter fractions, C sequestration

Introduction

Following the Kyoto Protocol, the need for a better understanding of the processes and mechanisms leading to loss and sequestration of soil organic carbon (SOC) was widely recognized. The assessment of SOC reservoirs is of interest because soil may act as a major source or sink for the increased atmospheric CO_2. In addition, increases in SOC improve soil physical, chemical and biological properties related to productivity and the buffering capacity of the environment. While changes in land use are widely accepted as key drivers of global C dynamics, the role of grassland management has only recently received attention as a substantial potential C sink (Conant *et al.*, 2001). In grasslands, C enters the soil through litter fall, root turnover and carbon exudation from the roots, and is released from the soil through heterotrophic respiration and by leaching. A fraction of the C from decomposing materials is transformed into stable organic complexes. Grazing or plant defoliation affects root dynamics in a complex way. Research on the effects of grazing on SOC is inconsistent to date, with both increases and decreases reported with increased grazing pressure (Murty *et al.*, 2002). A clear understanding of the effects of management on the distribution and dynamics of different SOC fractions is essential to the development of sound models to evaluate SOC storage and dynamics. Active carbon fractions have been identified as a sensitive indicator of the effects of land use and management on SOC accumulation. This work aims to quantify the C stored in the soils of alpine and subalpine grasslands in the Pyrenees, and to determine the effects of grazing on their potential for C sequestration.

Materials and methods

We conducted a preliminary survey to determine SOC content in soils of alpine and subalpine grassland in the Central and the Eastern Pyrenees. This survey included the determination of SOC of the entire soil profile, in 34 locations. We modelled SOC introducing variables related to topography, climate and bedrock. We conducted a second survey mainly centred in two Spanish pyrenean regions. In July 2003 we sampled 66 sites. At each site we recorded topography and bedrock, took 1 m^2 aboveground biomass distributed in four 0.5 × 0.5 m samples, and collected a sample of the first 20 cm of soil. Soil samples were analysed to determine total organic C. Climatic variables were estimated using a model that combines climatic data and topographic variables into a GIS system (Ninyerola *et al.*, 2000). Management had been previously determined by archive sources and was later verified in the field. Four livestock managements were identified: abandoned, cattle, sheep, and cattle and sheep. We used a backward regression to select climate, topography and management variables that better explained the variation in SOC in the first 20 cm of soil.

To study the effects of grazing intensity on SOC fractions, we designed an experiment in two locations in the Eastern Pyrenees. At each location we established one large plot where three treatments were randomly assigned to six 25 x 25 m subplots. The treatments were: abandoned (non-grazed); light grazing (one adult cow per subplot); heavy grazing (three adult cows per subplot). The grazing treatments were applied at the end of July for three days, the time taken for the forage in the most heavily grazed subplots to become exhausted. We collected soil samples immediately before grazing took place and one month afterwards. In each plot we sampled four 5 x 5 cm cores of soil up to 30 cm depth. Soil cores were divided into three layers, 0-5 cm, 5-15 cm and 15-30 cm. From each fresh soil sample we extracted the active C after chloroform fumigation using a K_2SO_4 solution (0.5 N, 1:5 w:v). Changes in active SOC were calculated as the difference between the active C measured one month after grazing and immediately before the introduction of the animals. In an adjacent extensive heavily grazed area we established the instrumentation to record net carbon fluxes from the ecosystem by the Eddy covariance method.

Results and discussion

In the first survey we found that SOC ranged from 65 to 300 Mg ha^{-1} in subalpine and alpine grasslands in the Pyrenees. The combination of topography, macroclimate and bedrock partially explained the wide range found (R^2_{adj} = 0.33, P = 0.02). SOC in the first 20 cm of soil constituted around 68 % of the total SOC in the soil profile. In the second survey, SOC from the first 20 cm ranged from 14.8 to 146.6 Mg ha^{-1}. The predictive power of SOC from the model increased with the addition of variables representing grazing management, interacting with climatic variables, and standing biomass (R^2_{adj} = 0.48, P < 0.001). Abandoned areas showed lower C stocks while areas grazed by both cattle and sheep had the higher SOC content (Figure 1). For all grazing treatments, predicted SOC decreased with increased precipitation (Figure 1).

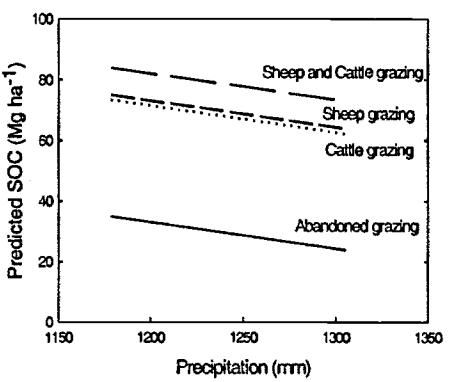

Figure 1. Predicted values of the organic carbon (SOC) in the first 20 cm of soil in relation to changes in precipitation for each grazing management. Other variables in the model were kept constant to their media values.

CO_2 fluxes measured during the six months, June to November, at the heavily grazed area in Vall d'Alinyà by the Eddy covariance method suggested that the studied grasslands act as a small carbon sink, in spite of the high temperatures and intensive grazing in August. The extent to which the soil can be a sink for C depends on the balance between the rates of the processes of C acquisition and the rate of breakdown of both the resident and the newly acquired C. Preliminary results from the controlled grazing experiment suggested that grazing produces a sharp increase of the active SOC, at least in the first 15 cm of the soil (Figure 2). This increase may be either stabilised in more recalcitrant SOC fractions or mineralised and released from soil as CO_2. The balance between these two processes will determine the role of grazing in the sequestration of C in the soil.

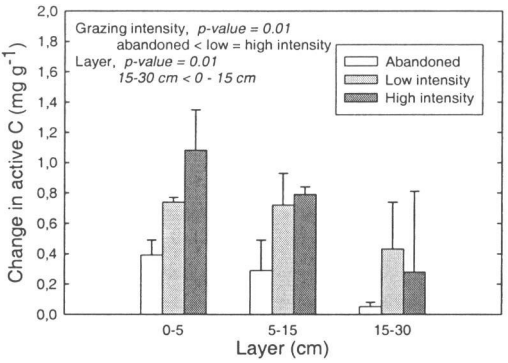

Figure 2. Effect of grazing intensity in active SOC fraction changes in three soil layers.

Conclusions

This work suggests that extensive grazing increases SOC sequestration in grassland soils at high altitudes in the Pyrenees, at least in the first 20 cm. However, further analysis should be performed to verify this hypothesis. One process that needs to be explored in more detail is the fate of the increased active SOC fractions.

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