

# Contrasting impacts of grazing on soil properties and plant communities between semiarid and temperate rangeland ecosystems

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**Abstract.** We discuss how grazing by large herbivores as a land use option does not necessarily involve a trade-off in terms of soil carbon (C) storage, by presenting results from field grazing gradient experiments from rangeland ecosystems under different climatic conditions in semiarid grasslands from Central Mexico and temperate ecosystems from Northern England. In general, moderate grazing pressure did not reduce soil C in both ecosystems after comparisons with long-term grazing exclusions, and moderate grazing even showed higher soil C in the semiarid area. In the semiarid area, our results are likely explained by grazing tolerance of plant species in moderate grazing pressure, and by effects of herbivores on plant community structure and proportion of bare soil in heavy grazing pressure. In the temperate area, C losses might be more linked to temperature-limitation on heterotrophic soil C respiration. Our results indicate that moderate grazing is compatible with soil C storage, although we also provide warnings against this generalisation under scenarios of climate warming.

**Keywords:** Grazing, soil carbon, plant communities, semiarid rangelands, temperate rangelands.

## Introduction

There is growing interest in recognising trade-offs that management practices can impose on ecosystem goods and services provisioning (MEA 2005). Such interest is particularly urgent in terms of the effects of management practices on soil carbon (C), since this is seen as a free-risk strategy to mitigate anthropogenic CO<sub>2</sub> emissions (Molina *et al.* 2009). Rangeland ecosystems, which cover the largest area of the Earth land surface (Booker *et al.* 2013), have been recognised for their potential to sequester significant amounts of C in their soils. Given climatic conditions that limit agriculture, rangeland ecosystems are usually managed for extensive grazing by large domestic herbivores (Holechek *et al.* 1995). It has also been suggested that changes in grazing management of rangelands might yield benefits for soil C sequestration. However, there is great debate on this subject since results from different studies have been contradictory, with some studies showing increases, decreases or null effects of grazing on soil C storage (Conant *et al.* 2001, Booker *et al.* 2013).

In this work, and based on findings of herbivore impacts on soil by Medina-Roldán *et al.* (2008) and Medina-Roldán *et al.* (2012), we show how two rangeland

ecosystems of contrasting geographical and climatic conditions display different responses to long-term grazing management in terms of soil C pools based mainly on the response of their plant communities to grazing.

## Material and Methods

We compared results from two different studies carried out in geographical regions with contrasting climate and subjected to different grazing regimes. The first study area is located in Central Mexico (around 21.8°N; 101.61°W; 2200 m a.s.l.). Climate is semiarid, with 450 mm average annual precipitation and a mean annual temperature of 17–18°C. Soils (mainly xerosols) are shallow with silty clay to sandy loam textures, a nearly neutral pH, and low organic matter content (0.6–2 %). Vegetation is dominated by the shortgrass prairie characterized by *Bouteloua gracilis* H.B.K. Lag ex Steud, *Aristida divaricata* Humb. & Bompl., *Microchloa kuntii* Desv. Heavy overgrazing here usually occurs on poorly-managed common land and causes severe plant cover losses (>90% bare soil), drastic declines in plant standing biomass (from 800–1200 down to 80–240 kg dry matter /ha, Aguado-Santacruz and García-Moya 1998), and reductions in cover of *B. gracilis*. The second study was carried out in Ingleborough National Nature Reserve

northern England (54.18°N; 2.36°E). Climate here is temperate maritime, with mean annual precipitation of 1840 mm (averaged for 10 years). Vegetation included acidic grasslands dominated by *Nardus stricta* L., *Festuca ovina* L., and *Agrostis capillaris* L., which are extensively used by the grazing industry in the UK (Rodwell, 1992). Soils are acidic with a pH of 4.5, an organic surface horizon of 20-30 cm depth, and exposed to water-saturated conditions for prolonged periods. Changes in the grazing pressure and livestock composition (from cattle to sheep) have led to the replacement of dwarf- shrub dominated vegetation (*Calluna vulgaris*) by acidic grasslands (Thompson *et al.* 1995). Thus, restoration projects exclude grazing to increase the abundance of dwarf-shrubs.

In the semiarid area (DG), we sampled soil in summer 2004 across a gradient in grazing pressure which included a 26 year (at the time of sampling) 1-ha grazing exclusion on common land (hereafter DG0), a moderately grazed site privately owned (DG+) and two heavily grazed sites on common land (DG<sub>1++</sub>, DG<sub>2++</sub>). Stocking rates information was not available for our sites in the shortgrass prairie, but it was qualitatively estimated based on species-composition and extension of bare soil. Given the large area occupied by plant interspaces on this semiarid grassland, we sampled soil at 2 microsites - bare soil space (Inter) and under *B. gracilis* plants (Plant). There were 5 randomly placed transects per site, 6 cores per microsite per transect split into 2 depths (0-15 and 15-30 cm) and soil from each depth pooled into a composite sample (in this paper we report data on both depths pooled). On our temperate site (WG), we sampled shallow soil (down to 10 cm) along a year starting from 2007 on 2 adjacent sites (6 randomly located plots per site) of similar topography and altitude, but with contrasting recent grazing management. One site is a 170 ha enclosure fenced in 2000 (WG0), and the other site (WG+) is an immediately adjacent 58 ha acidic grassland continuously grazed with a 4 ewes/ha stocking rate (reduced in winter season).

Soil and vegetation samples were processed by standard methods and analysed with appropriate statistical techniques (for details see references cited in the introduction). On the semiarid study area, we measured soil C content (elemental analysis), and soil ammonium

(colorimetric analysis); and results from vegetation from other nearby study site are shown to describe effects of grazing on vegetation composition and structure. On the temperate study area, we present data on soil C content (elemental analysis), ammonium potential mineralisation (dark incubation and colorimetric analysis), soil basal respiration (incubation) and vegetation. Data for biogeochemical variables were statistically analysed on a mass-basis, but are reported on an area basis using average soil bulk density (since grazing did not have a consistent effect on it, data not shown) and the depth of soil sampling (0-30 in DG and 0-10 in WG sites respectively).

## Results

Although we did not measure vegetation composition in our grazing gradient in the DG sites, data from Medina-Roldán *et al.* (2007) exemplify the main vegetation response to grazing in the shortgrass prairie. Thus, increased grazing pressure leads to a significant reduction in the abundance of *B. gracilis*, and increases in plant species considered of lower foraging value. Higher grazing pressure in the DG sites reduced significantly ( $P < 0.001$ ) total plant cover, thus increasing the amount of bare soil. For the WG sites, grazing exclusion increased the abundance of dwarf-shrubs ( $20.4 \pm 1.1$  vs  $2.9 \pm 3.4\%$ , WG0 vs WG+) and a decrease in the proportion of graminoid species ( $23.0 \pm 4.8$  vs  $43.0 \pm 4.7\%$ ). In the DG sites, grazing pressure decreased root biomass significantly ( $P < 0.01$ , Fig. 1), but grazing management did not have any effect on this variable in the WG sites (Fig. 2). In the WG sites other biomass pools (mainly a horizon of partially decomposed plant remains named L horizon) are important in terms of their C content and biogeochemical consequences. Grazing exclusion increased marginally the size of the L horizon ( $980 \pm 124$  vs  $590 \pm 67$  g/m<sup>2</sup>, WG0 vs WG+).

Grazing pressure had a significant ( $P < 0.01$ ) effect on total soil C in the DG sites; differing by almost 30% between the moderate grazing treatment (DG+) and the extremely heavy grazing treatment (DG<sub>2++</sub>) ( $5043$  g C/m<sup>2</sup> vs  $3901$  g C/m<sup>2</sup> respectively; Figure 3, left-panel). Two main trends were of interests here. Firstly, there was a trend for a non-linear response of total soil C to grazing pressure; and secondly, the importance of plant cover

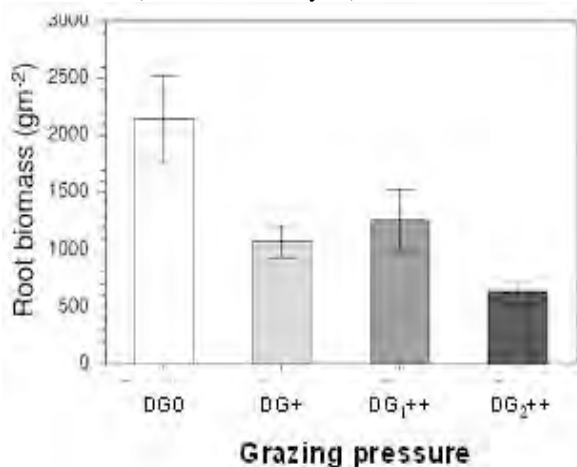


Figure 1. Effects of grazing pressure on root biomass ( $\pm$ s.e.) in our semiarid study area. Treatment code as per text.

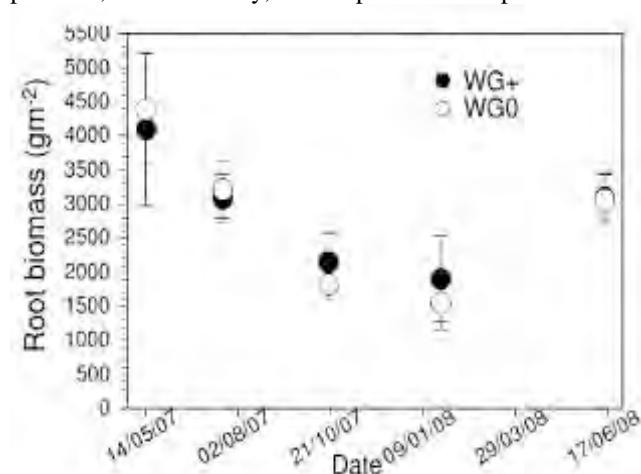
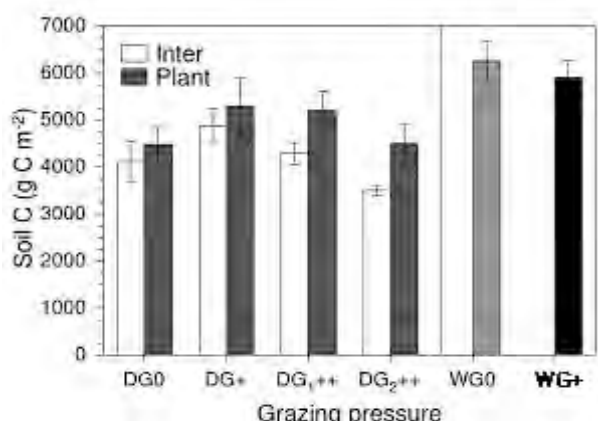


Figure 2. Effects of grazing management on root biomass ( $\pm$ s.e.) on the temperate study area across different sampling dates. Treatment code as per text.



**Figure 3.** Effects of grazing pressure (left panel) and grazing management (right panel) on soil C ( $\pm$ s.e.) content in semi-arid and temperate rangelands respectively. Treatment code as per text.

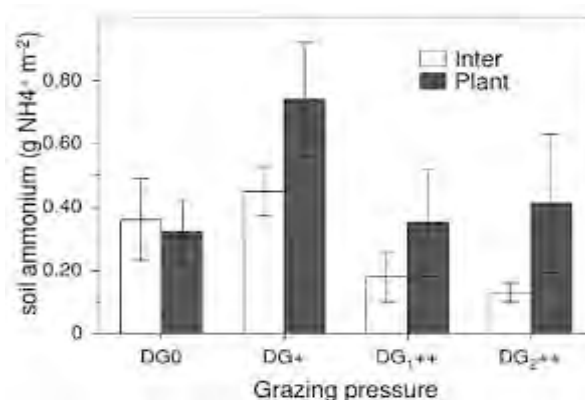
enhancing the soil C pool (difference between plant and interspace microsites) increased as grazing pressure increased. However, in our WG sites, although grazing tended to decrease soil C content in comparison with the exclusion, there was no statistical difference in total soil C between the exclusion and the continuously-grazed treatment (Fig. 3, right-panel).

Soil ammonium ( $\text{NH}_4^+$ ) availability increased at moderate grazing pressure in comparison with the exclusion in the DG sites, but it decreased at both extremely heavy grazing treatments ( $P < 0.01$ , Fig. 4). A similar response was seen in the WG sites (Fig. 5), where rates of  $\text{NH}_4^+$  mineralisation were greater in soils of WG+ than in those of WG0 across almost all sampling times in 2007. There was a significant ( $P < 0.01$ ) inter-action between grazing treatment and season.

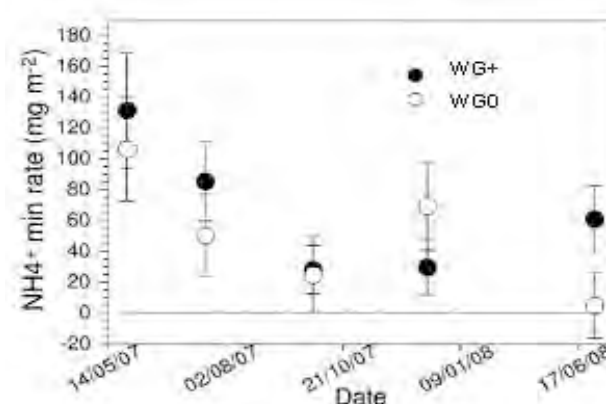
For soil properties that were only measured in the temperate area, grazing exclusion caused a 20 % reduction in soil basal respiration ( $P < 0.0001$ ;  $6.4 \pm 0.8$  vs  $8.1 \pm 0.8$  L  $\text{CO}_2/\text{g}$  soil/h between WG0 vs WG+).

## Discussion

Our objective was to contrast responses of rangeland ecosystems under different climatic conditions to grazing by large domestic herbivores. We focused on soil properties, mainly soil total C content, to explore potential ecosystem services trade-offs to management options exemplified by grazing and grazing-exclusions. In the semi-arid area, moderate grazing pressure tended to increase soil C content, whereas in the temperate area, moderate grazing did not have a significant effect on soil C. Beyond climatic controls, such contrasting results to grazing between our study sites might be explained by differences in the tolerance of plant species of each ecosystem to grazing, as well as changes induced by grazing on plant community structure, mainly extension of plant cover and proportion of bare soil. In the case of the shortgrass prairie, *B. gracilis* is a grazing-tolerant grass with a long-grazing evolutionary history which displays compensatory growth in response to defoliation and/or grazing (Detling *et al.* 1979; Milchunas *et al.* 1988). Such compensatory response and the stimulation of soil N might explain higher rates of



**Figure 4.** Effects of grazing pressure on soil ammonium ( $\text{NH}_4^+$ ) availability ( $\pm$ s.e.r) in the semi-arid study area. Treatment code as per text.



**Figure 5.** Effects of grazing management on soil  $\text{NH}_4^+$  mineralisation rate ( $\pm$ s.e.) in the temperate study area. Treatment code as per text

productivity under moderately-grazed conditions which ultimately translate in higher belowground litter inputs and higher soil C sequestration (Conant and Paustian 2002). However, heavy grazing pressure in this semi-arid grassland leads to high reductions in soil C content as heavy grazing reduces plant cover and root biomass, and increases abundance of species with lower productivity. Thus, the grazing-optimisation model (McNaughton 1979) is a reasonable descriptor of grazing effects on soil C in this semi-arid grassland. For the temperate area, on the other hand, moderate grazing did not differ from the grazing exclusion in terms of soil C content, even though other soil and vegetation properties showed typical stimulatory responses caused by grazing (*i.e.*, increases in soil N availability and soil microbial activity). For these temperate ecosystems, N stimulatory responses of grazing have been explained by changes on plant functional types (graminoids) with higher biomass turnover rates and which produce litter of higher quality (lower C: N and lignin to N ratios, and lower phenolic compounds) in comparison with ungrazed systems (Berendse 1998). Given the stimulatory N effect, it was expected continuous grazing to reduce soil C content as a result of higher soil microbial activity - and presumably higher soil heterotrophic respiration rates as a result of N-limitation release (Paz-Ferreiro *et al.* 2012) - since grazing did not affect root and shoot biomass, but this

was not the case. This is consistent with other studies in temperate grasslands that show a lack of response of soil C to grazing exclusion, even after more than 30 years (Marrs *et al.* 1989), and recent results suggest C losses to be more dependent on temperature limitation (Paz-Ferreiro *et al.* 2012).

Overall, results from these two ecosystems suggest that grazing might not imply a management trade-off in terms of soil C storage as an ecosystem service, at least when grazing pressure is kept at levels which do not cause large modifications in plant community structure. Although informal since both studies do not form part of the same sampling scheme, this comparative approach allowed us to qualitatively discern how differences between both ecosystems in term of their response to grazing influence soil C. Apart from this, another main limitation of our approach is that other ecosystem C pools were not taken into account, particularly the L horizon in the temperate area. This pool was shown to be reduced under continuous grazing, and although much lower than soil organic C, it contains a considerable amount of C (Ward *et al.* 2007). Additionally, we did not consider the response of soil C to other drivers of global change. It has been shown that grazing might increase the thermal sensitivity of soil C, which might increase soil C losses in response to climate warming (Paz-Ferreiro *et al.* 2012). These last two facts (C stored in other C pools and grazing-induced sensitivity of soil C) have to be taken into account when prescribing moderate grazing as a use management option for temperate areas.

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