Agriculture, Ecosystems and Environment 253 (2018) 62–81

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Review Article

Critical review of the impacts of grazing intensity on soil organic carbon storage and other soil quality indicators in extensively managed grasslands

M. Abdalla[a,*], A. Hastings[a], D.R. Chadwick[b], D.L. Jones[b], C.D. Evans[b], M.B. Jones[c], R.M. Rees[d], P. Smith[a]

[a] Institute of Biological and Environmental Sciences, School of Biological Sciences, University of Aberdeen, Aberdeen, AB24 3UU, UK
[b] School of Environment, Natural Resources and Geography, Bangor University, Bangor, Gwynedd, LL57 2UW, UK
[c] Department of Botany, School of Natural Sciences, Trinity College Dublin, Dublin 2, Ireland
[d] Scotland's Rural College (SRUC) Edinburgh, West Mains Road, Edinburgh, EH93JG, UK

ARTICLE INFO

Keywords:
Grazing
Soil organic carbon
Grassland
Grazing intensity
Total nitrogen

ABSTRACT

Livestock grazing intensity (GI) is thought to have a major impact on soil organic carbon (SOC) storage and soil quality indicators in grassland agroecosystems. To critically investigate this, we conducted a global review and meta-analysis of 83 studies of extensive grazing, covering 164 sites across different countries and climatic zones. Unlike previous published reviews we normalized the SOC and total nitrogen (TN) data to a 30 cm depth to be compatible with IPCC guidelines. We also calculated a normalized GI and divided the data into four main groups depending on the regional climate (dry warm, DW; dry cool, DC; moist warm, MW; moist cool, MC). Our results show that taken across all climatic zones and GIs, grazing (below the carrying capacity of the systems) results in a decrease in SOC storage, although its impact on SOC is climate-dependent. When assessed for different regional climates, all GI levels increased SOC stocks under the MW climate (+7.6%) whilst there were reductions under the MC climate (−19%). Under the DW and DC climates, only the low (+5.8%) and low to medium (+16.1%) grazing intensities, respectively, were associated with increased SOC stocks. High GI significantly increased SOC for C4-dominated grassland compared to C3-dominated grassland and C3-C4 mixed grasslands. It was also associated with significant increases in TN and bulk density but had no effect on soil pH. To protect grassland soils from degradation, we recommend that GI and management practices should be optimized according to climate region and grassland type (C3, C4 or C3-C4 mixed).

1. Introduction

Grasslands cover approximately 40% of the earth's land surface (Wang and Fang, 2009) and represent about 70% of the agricultural area (Conant, 2012). They contain about 10% of terrestrial biomass and make a contribution of about 20–30% to the global pool of soil organic carbon (SOC) (Scurlock and Hall, 1998; Conant et al., 2001). Grasslands have some potential to sequester atmospheric CO_2 as stable carbon (C) in the soil (Reid et al., 2004) and hence could contribute to mitigation of climate change (Allard et al., 2007). However, the accumulation and storage of C in grasslands is influenced by many factors, especially biotic factors e.g. grazing intensity (GI), animal type and grass species (Conant et al., 2001; Olff et al., 2002; Jones and Donnelly, 2004; McSherry and Ritchie, 2013). Nevertheless, although grasslands have high SOC contents, recent studies have suggested that intensive livestock management has led to C losses from many grasslands around the world and thereby, grassland soils could become a source rather than a sink for greenhouse gas (GHG) emissions (Janzen, 2006; Ciais et al., 2010; Powlson et al., 2011). Grazing intensity has the potential to modify soil structure, function and capacity to store organic carbon (OC) (Cui et al., 2005) and could significantly change grassland C stocks (Cui et al., 2005). As SOC has a major influence on soil physical structure and a range of ecosystem services (e.g. nutrient retention, water storage, pollutant attenuation), its reduction could lead to reduced soil fertility and consequently, land degradation (Rounsevell et al., 1999). These effects may also be magnified if SOC loss rates are magnified by climate change (Lal, 2009). However, investigating the effects of GI on SOC is hampered by the heterogeneity in grassland types and variations in environmental factors among sites. This is exacerbated by the fact that all previous published meta-analyses studies on this topic (e.g. McSherry and Ritchie, 2013; Lu et al., 2017; Zhou et al., 2017) pooled the data of different studies together without considering the differences in soil depth at which the SOC and TN were measured, thus producing highly uncertain/contradictory results.

---

* Corresponding author at: Institute of Biological and Environmental Sciences, School of Biological, Sciences, University of Aberdeen, 23 St. Machar Drive, Aberdeen, AB24 3UU, UK.
E-mail address: mabdalla@abdn.ac.uk (M. Abdalla).

http://dx.doi.org/10.1016/j.agee.2017.10.023
Received 22 May 2017; Received in revised form 24 October 2017; Accepted 25 October 2017

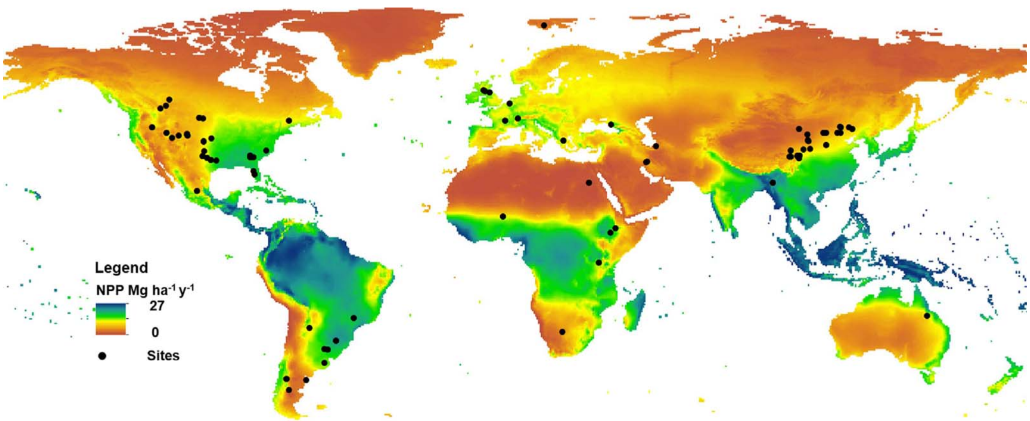

Fig. 1. Map of mean Net Primary Production (NPP) in mg C ha^{-1} y^{-1} derived from the mean annual temperature and mean annual precipitation using the Miami model with the locations of experimental sites considered in this paper.

High GI could indirectly alter grass species composition (Cingolani et al., 2005) by decreasing water availability (Pineiro et al., 2010). This decreases plant community composition, aboveground biomass, leaf area and light interception and thereby, net primary production (NPP) (Manley et al., 1995; Pineiro et al., 2010). However, according to Derner and Schuman (2007), Pineiro et al. (2010) and McSherry and Ritchie (2013), high GI can increase soil C sequestration but only when mean annual precipitation is 600 mm or less, and with different responses observed in different soil types. Grazing intensity has also been shown to increase root C contents (a primary control of SOC formation) at the driest and wettest sites, but decrease root C contents at intermediate precipitation levels (400 mm–850 mm) (Pineiro et al., 2010). Wang et al. (2017) reported that the compositions of plant species and soil condition in the Tibetan pastures were not only affected by GI but also by the local environmental factors. Moreover, Russell et al. (2013) suggest that grazing at high intensity for a short period of time was effective at increasing soil organic matter and diversity in forage species composition. On the other hand, overgrazing to the point of stripping surface vegetation can result in soil-degradation and loss of the fertile topsoil, especially where precipitation is low and evaporation is high (Xie and Wittig, 2004).

Furthermore, high GI can alter SOC by changing the competitive abilities of different microbial phyla because of the link between GI, SOC availability and ecosystem functions (Eldridge et al., 2017). However, Eldridge and Delgado-Baquerizo (2017) suggest that, the relationship between GI and SOC is generally non-linear. Previous studies have found mixed results (Derner et al., 2006; McSherry and Ritchie, 2013; Zhou et al., 2017), with some showing increases (Reeder and Schuman, 2002; Li et al., 2011; Silveira et al., 2014), while others show no effect (Frank et al., 2002; Shrestha and Stahl, 2008; Cao et al., 2013) or decreases (Zuo et al., 2008; Golluscio et al., 2009; Reszkowska et al., 2011; Qiu et al., 2013) in SOC stocks. The review by McSherry and Ritchie (2013) showed that GI effects on SOC are highly context-specific where higher GI increased SOC on C4-dominated and C4-C3 mixed grasslands, but decreased SOC in C3-dominated grasslands. Other recent reviews by Lu et al. (2017) and Zhou et al. (2017) found that high GI significantly decreased belowground C and N pools. They found that GI interacts with elevation and mean annual temperature (Lu et al., 2017) or with soil depth, livestock type and climatic conditions (Zhou et al., 2017).

Understanding the impacts of GI on SOC accumulation and storage in grasslands is crucial to provide the most effective soil C management options. However, although all of these previous reviews are valuable, scientific understanding would be improved by normalizing the sampling depth and GI. In this study, to be compatible with the IPCC guidelines, reduce these errors and make a comprehensive evaluation for GI we have normalized the soil depth for all studies to 30 cm using a quadratic density function based on Smith et al. (2000) and calculated a normalized GI. The major objective of this meta-analysis was to investigate the impacts of GI on SOC in extensively grazed grassland soils at a global scale. Additionally, and because of its importance for C biogeochemistry, we considered the impacts of GI on total nitrogen (TN) and other soil properties (mainly pH and bulk density) in grasslands. We also investigated whether spatial variations in climate determine the ecological effects of grazing practices on SOC in grasslands. The specific hypotheses we critically evaluated are as follows: 1) higher GI decreases SOC and TN in soils; 2) the impacts of GI on SOC are modified by environmental and biotic factors; and 3) the effects of GI on SOC stocks depends on climatic zone and soil texture.

2. Materials and methods

2.1. Data collection

To collect published studies that have investigated the impacts of GI on SOC and other selected soil properties (TN, pH and BD) under grassland, we performed a comprehensive search on the Web of Science database (accessed between January 2015 and July 2017) using the following keywords: grazing; soil organic carbon; grassland; GI; total nitrogen and carbon sequestration. In an attempt to have the best possible coverage; we also checked all references in the papers found in the Web of Science search. Only studies which were longer than one year and measured SOC or TN were selected. We also accounted for the differences in grass growing seasons at each experimental site. Our searches resulted in 83 studies that investigated the impacts of grazing on SOC and other selected soil properties; carried out at 164 sites covering different countries; climatic zones and management systems (Fig. 1). The studies were segregated into four groups depending on the regional climatic zones (dry cool (DC); dry warm (DW); moist cool (MC) and moist warm (MW)).

We defined the climatic zones based on thermal and moisture regimes: cool, warm, dry, and moist zone according to Smith et al. (2008). The cool zone covers the temperate (oceanic, sub-continental, and continental) and boreal (oceanic, sub-continental and continental) areas, whilst the warm zone covers the tropics (lowland and highland) and subtropics (summer rainfall, winter rainfall, and low rainfall) areas. The dry zone includes the areas where the annual precipitation is equal or below 500 mm, whilst the moist zone includes areas where the annual precipitation is above 500 mm. Coordinates, grass type (i.e. shrubby, woody, steppe, and prairie), annual mean climatic conditions as well as grazing details, soil texture, original depth (OD), initial and final BD and pH, changes in SOC and TN (kg m^{-2}); values were added where available or were designated plus (+) for increased and minus (−) for decreased, as shown in Tables 1–4.

2.2. Estimation methods applied

In some studies SOC and TN values are given as concentrations. To