Geoderma 314 (2018) 175–183

Contents lists available at ScienceDirect

Geoderma

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

Soil organic carbon stock and fractional distribution in upland grasslands

Samuel Eze*, Sheila M. Palmer, Pippa J. Chapman

School of Geography, Faculty of Environment, University of Leeds, LS2 9JT Leeds, UK

ARTICLE INFO

Editor: Bernd Marschner

Keywords:
Soil carbon dynamics
Carbon fractions
Grassland management
Upland soils
Soil carbon stock

ABSTRACT

Upland grassland soils are an important terrestrial carbon (C) store and provide vital ecosystem services such as climate regulation. The C stocks in these soils are subject to changes due to management activities. In this study, we compared soil organic C (SOC) stocks and fractions under traditional hay meadow and conventional (silage or permanent) pasture management regimes at two upland grassland locations within the Yorkshire Dales, northern England, United Kingdom. Stocks of SOC in the top 15 cm of the grassland soils were determined from bulk soil samples and in soil fractions after a combination of physical and chemical fractionation. Results showed that these upland grasslands stored significant amounts of organic C in the top 15 cm of their soils, ranging from 58.93 ± 3.50 to 100.69 ± 8.64 Mg ha^{-1}. Overall, there was little contrast between the sites except that soil C stock was significantly higher under the Nidderdale silage pasture that received the highest nitrogen (N) inputs, possibly due to enhanced vegetation growth and subsequent litter return to the soil. No effect of soil parent material was observed on soil C stock due to liming-induced increase in the pH of Nidderdale soils and neither management activities nor soil parent materials affected the distribution of soil C into different fractions. In all sites, about 70% of the SOC stock was protected in stable soil fractions, specifically in the mineral soil mass, indicating a potential for the grasslands to contribute in climate change mitigation. However, due to the rapid turnover of the labile C pool and especially in a changing climate, it is recommended that further research be carried out in order to understand the turnover rates of labile C pools and whether management activities alter the distribution between the decomposition products. This will help to better understand whether rapid turnover of labile C will negate the likely benefits of stable C pools to climate change mitigation.

1. Introduction

Grasslands store a significant amount (~90%) of its sequestered carbon (C) in the soil (Ajtay et al., 1979), and often have higher soil C stock relative to other vegetation types in a given climate regime (IPCC, 2003). Management of grasslands can range from extensive practices such as no/minimal chemical inputs and occasional grazing to intensive practices such as regular chemical additions including lime, nitrogen (N), phosphorus (P) and potassium (K) containing fertilizers, and year-round grazing (Tiemeyer et al., 2016). Generally, these management activities have been shown to influence soil C dynamics (Soussana et al., 2007) but the exact effects of each management practice on C stock are not fully understood. For example, variable results have been reported in a number of studies that investigated how soil C respond to different management activities such as grazing intensity (Burrows et al., 2012; Han et al., 2008; Schuman et al., 1999), liming (Mijangos et al., 2010; Sochorová et al., 2016; Wang et al., 2016), and fertilizer application (Fornara et al., 2013; He et al., 2013; Neff et al., 2002). These studies reported either an increase, a decrease or no change in soil C stock due to management activities. The inconsistencies in these results may be due to differences in soil types, specific management activities and duration of management regimes as they change over time, for example, in response to financial incentives such as agri-environmental schemes.

An important area of current research interest is understanding the factors controlling soil C stock and its stability in response to grassland management (e.g. Ward et al., 2016). This is because storage of soil C in long-term pools is necessary for climate change mitigation and requires stabilization in forms that are less susceptible to loss (Adkins et al., 2016; Lal and Kimble, 1997; O'Brien and Jastrow, 2013). The stabilization mechanisms may be through: 1) biochemical formation of organic C (OC) compounds with molecular structures that make them relatively more resistant to decomposition, 2) interaction of OC with soil mineral particles particularly clay and silt, and 3) occlusion of OC within soil aggregates (Breulmann et al., 2016; Sollins et al., 1996). In recent years, the idea of soil OC (SOC) possessing recalcitrant properties which make it stable in the soil has been challenged (Amelung et al., 2008; Lehmann and Kleber, 2015; Schmidt et al., 2011) and the key

---

* Corresponding author.
E-mail addresses: gyse@leeds.ac.uk (S. Eze), s.m.palmer@leeds.ac.uk (S.M. Palmer), p.j.chapman@leeds.ac.uk (P.J. Chapman).

https://doi.org/10.1016/j.geoderma.2017.11.017
Received 26 October 2016; Received in revised form 9 November 2017; Accepted 10 November 2017

mechanism of stabilization now favoured by researchers is physical protection of SOC from microbes regardless of its chemical structure (Dungait et al., 2012; Kleber et al., 2011). Also, the most important physical mechanism for stabilizing soil C is its association with reactive soil mineral particles because access by microbes and enzymes is limited (Conant et al., 2011; Mikutta et al., 2006). This has recently been corroborated by the results of a meta-analysis of 376 published laboratory incubation data, where clay content was found to be the most crucial regulator of SOC decomposition (Xu et al., 2016).

SOC is usually fractionated into functional pools such as labile (or active) and stable (or passive) pools, with different turnover rates or mean residence times (ranging from days to centuries and millennia), and this often serves as a relative measure of stability (Breulmann et al., 2016; Cambardella and Elliott, 1992; Roscoe and Machado, 2002; Von Lützow et al., 2007). The active C pools such as particulate OC (POC), dissolved OC (DOC) and microbial biomass C (MBC) have the fastest turnover and are more sensitive to land management than the stable pools (Alvarez and Alvarez, 2016; De Figueiredo et al., 2010; Van Leeuwen et al., 2015). It is therefore important to study not just the changes in total SOC in response to environmental change, which requires long term monitoring to be able to detect, but the partitioning and dynamics of the various soil C pools. This would improve understanding of land management effects on SOC even in the short term.

In the UK, the greater number of studies on the response of soil C to management activities have focused on lowland grasslands (e.g. Clegg, 2006; Clegg et al., 2003; Hopkins et al., 2009, 2011), with results showing either a decrease, an increase or no change in soil C stock. However, a recent report based on a study of 180 permanent grasslands (mostly lowlands) in the UK, revealed a decrease in soil C stock with increasing management intensity (Ward et al., 2016). This study also suggested that soil parent material might have influenced the response of soil C to management activities (Ward et al., 2016) but this has not fully been investigated for UK grasslands. The effect of soil parent material is possible because there is a likely interaction between inherent soil characteristics and management activities that subsequently influences soil C dynamics. For example, in northern Spain, Mijangos et al. (2010) studied the effects of liming on soil characteristics and plant productivity in calcareous and siliceous grasslands; they found that liming significantly increased soil pH and microbial activity in the siliceous grassland compared to the calcareous grassland. Soil acidity is important for C dynamics because C tends to accumulate in the soil under acidic conditions, due to the predominance of fungi with high biomass and restricted microbial decomposition of organic materials (Alexander, 1977; Bardgett et al., 1993). This is also evident in the report of the UK Countryside Survey of 2007, where acid grassland soils store 82 $t\,ha^{-1}$C compared to neutral grassland soils which contain 61 $t\,ha^{-1}$C within 15 cm of the soil surface (Carey et al., 2008). Leifeld et al. (2013) also found that a one pH unit of acidification resulted in 22 to 86% increase in mean residence times of organic C pools.

Acidic soil conditions prevail in the UK's upland grasslands (grasslands mostly above 300 m altitude) primarily due to base-poor geology and high leaching associated with cool and wet climate (Floate, 1977; Holden et al., 2006). Elevated C stocks in these wet, acidic upland soils is therefore to be expected. Yet, to the best of our knowledge, the dynamics of SOC in the mineral soils of the British upland grasslands remains poorly understood. These upland grasslands are mostly used for livestock production (Leifeld and Fuhrer, 2009; Medina-Roldán et al., 2012; Stevens et al., 2008) under management options that typically are influenced by environmental stewardship schemes, which aim to protect and enhance biodiversity. The interaction between parent material and management activity on soil C stock and stability has received relatively little research attention, and yet there are potentially important implications for development of new agri-environmental stewardship schemes and climate mitigation strategies. Therefore, the aim of this research is to assess the stock and fractions of SOC in the mineral soils of upland grasslands in northern England under: 1) traditional hay meadow and conventional pasture management regimes, and 2) soils of siliceous stone and limestone parent materials. We hypothesize that 1) SOC stock will be higher in soils under traditional hay meadow with intermittent grazing compared to soils under conventional pasture, 2) SOC stock will be lower in soils developed on limestone compared to soils that are poorly drained and developed on base-poor parent material due to likely effects of acidity and higher moisture content on organic matter decomposition, and 3) greater proportions of SOC stocks will be protected in stable forms due to high mineral contents of the soils at all the locations investigated.

2. Methodology

2.1. Study area

Two locations within the Yorkshire Dales, an upland area of the Pennines in Northern England, UK, were selected for this study; one in Nidderdale (54°09′N, 01°53′W) and the other in Ribblesdale (54°05′, 02°16′W). Both locations are at an elevation of approximately 300 m and a distance of about 20 km apart. These two locations were chosen because of their contrasting soil parent material (siliceous stones and limestone, respectively), which we expected to affect soil properties differently and how the soils would respond to management activities. The two locations are characterized by shallow soils, Stagnohumic gley at Nidderdale and Brown earth at Ribblesdale, with maximum depth to compacted layer being 20 cm. Mean annual temperature is 7.4 °C and mean annual rainfall is 1550 mm, based on 1981 to 2010 average. At each location, there are two contrasting grassland management regimes: traditional hay meadow managed under an agri-environment scheme and conventional pasture managed for silage (Nidderdale) or permanent grass (Ribblesdale), making a total of four sites. The traditional hay meadows under agri-environment schemes are managed with the aim of restoring, protecting and enhancing biodiversity. At the time of this study, hay meadow management typically involved avoiding inputs of inorganic fertilizer, no cutting before July, no grazing during spring and early summer, and re-seeding with a wildflower mix where necessary (Natural England, 2010). Hay meadow management was very similar at the two locations. In contrast to the hay meadows, the management regime of conventional pasture was quite different at the two locations, and at the Nidderdale site was very similar to the hay meadow except that the field managed for silage received inorganic N and additional inputs of P and K in poultry manure, and had recently been reseeded with ryegrass (Table 1). At the Ribblesdale location, the permanent pasture received no organic manure inputs or fertilizer and was not cut, but was continuously grazed by sheep (Table 1). The Nidderdale site had been limed to raise soil pH three years before sampling.

2.2. Experimental design, soil sampling and analysis

As multiple fields with the two contrasting management regimes and soil types could not be found at each location, we established five 25 m^2 replicate plots within single fields. The plots were part of an ongoing study to monitor gaseous land-atmosphere C fluxes. Soil samples were collected in May and June 2016. Within each plot, soil samples (0–15 cm depth) were randomly collected from five points with a soil auger (5 cm diameter) and bulked into a composite sample, giving five replicate samples per site at each location. One additional augered sample was collected from each 25 m^2 plot to determine bulk density of the 15 cm core depth ($N = 5$ per management). Samples were transported and stored at 4 °C prior to analysis at the School of Geography, University of Leeds, UK.

Soil samples were analyzed using standard laboratory techniques. A small proportion of each of the fresh soil samples was used for the determination of moisture content and available nitrogen (ammonium–nitrogen, NH_4-N; and nitrate-nitrogen, NO_3-N) within three days