Science of the Total Environment 613–614 (2018) 810–819

Contents lists available at ScienceDirect

Science of the Total Environment

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

Effects of long-term grassland management on the carbon and nitrogen pools of different soil aggregate fractions

Gary Egan [a,*], Michael J. Crawley [b], Dario A. Fornara [c]

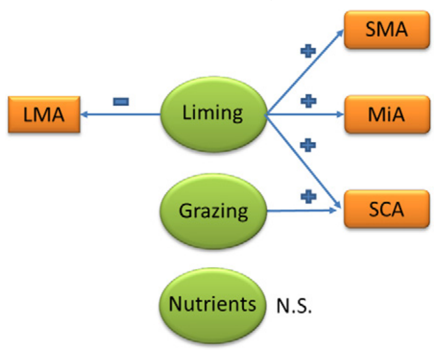
[a] Ulster University, Cromore Road, Coleraine, Co. Londonderry BT52 1SA, Northern Ireland, UK
[b] Department of Biological Sciences, Imperial College, Silwood Park, Ascot, Berkshire SL5 7PY, England, UK
[c] Agri-Food and Biosciences Institute, 18A Newforge Lane, Co. Antrim, Belfast BT9 5PX, Northern Ireland, UK

HIGHLIGHTS

- Long-term grazing, liming and nutrient fertilization effects on soil aggregates
- Liming significantly increased C and N pools of small soil aggregate fractions
- Liming effects were significantly explained by increases in soil pH.
- Evidence of positive liming effects on the C balance of managed grasslands

GRAPHICAL ABSTRACT

Significant negative (−) and positive (+) effects of 23 years of grassland management on the carbon pool of different soil aggregate fractions: Large Macro Aggregate (LMA >2 mm), Small Macro Aggregate (SMA 250 μm–2 mm), Micro Aggregates (MiA 53–250 μm), Silt Clay Aggregates (SCA <53 μm). Note: N.S. = Not significant.



ARTICLE INFO

Article history:
Received 5 July 2017
Received in revised form 14 September 2017
Accepted 16 September 2017
Available online 20 September 2017

Editor: D. Barcelo

Keywords:
Soil aggregates
CO_2 efflux
C sequestration
Liming
Grazing
Inorganic nutrient treatment

ABSTRACT

Common grassland management practices include animal grazing and the repeated addition of lime and nutrient fertilizers to soils. These practices can greatly influence the size and distribution of different soil aggregate fractions, thus altering the cycling and storage of carbon (C) and nitrogen (N) in grassland soils. So far, very few studies have simultaneously addressed the potential long-term effect that multiple management practices might have on soil physical aggregation. Here we specifically ask whether and how grazing, liming and nutrient fertilization might influence C and N content (%) as well as C and N pools of different soil aggregate fractions in a long-term grassland experiment established in 1991 at Silwood Park, Berkshire, UK.

We found that repeated liming applications over 23 years significantly decreased the C pool (i.e. g C Kg^{-1} soil) of Large Macro Aggregate (LMA > 2 mm) fractions and increased C pools within three smaller soil aggregate fractions: Small Macro Aggregate (SMA, 250 μm–2 mm), Micro Aggregate (MiA, 53–250 μm), and Silt Clay Aggregate (SCA < 53 μm). Soil C (and N) accrual in smaller fractions was mainly caused by positive liming effects on aggregate fraction mass rather than on changes in soil C (and N) content (%). Liming effects could be explained by increases in soil pH, as this factor was significantly positively related to greater soil C and N pools of smaller aggregate fractions. Long-term grazing and inorganic nutrient fertilization had much weaker effects on both soil aggregate-fraction mass and on soil C and N concentrations, however, our evidence is that these practices could also contribute to greater C and N pools of smaller soil fractions.

* Corresponding author at: Ulster University, Cromore Road, Coleraine, Co. Londonderry BT52 1SA, Northern Ireland, UK.
E-mail addresses: gartle@outlook.com (G. Egan), dario.fornara@afbini.gov.uk (D.A. Fornara).

http://dx.doi.org/10.1016/j.scitotenv.2017.09.165
0048-9697/

Overall our study demonstrates how agricultural liming can contribute to increase C pools of small (more stable) soil fractions with potential significant benefits for the long-term C balance of human-managed grassland soils.

1. Introduction

The agriculture sector strongly contributes to the production of greenhouse gases (GHGs) including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions (Johnson et al., 2007). Soil ecosystems partly offset GHG emissions by sequestering carbon (C) in different soil organo-mineral pools, some of which could keep C 'locked' for decades or even for centuries (Sollins et al., 2009). The long-term fate of C in different soil pools is determined by complex interactions between multiple agricultural practices, climate and intrinsic soil biogeochemical properties. Common management practices, such as animal grazing, liming (e.g. the addition of $CaCO_3$ to soils) and nutrient fertilization can strongly affect rates of soil aggregation and of soil CO_2 respiration thus affecting the net C balance of managed-grassland soils.

Agricultural liming has been shown to increase mean weight and diameter of soil aggregates and increase both total organic C and particulate organic C content within large macro aggregate and mineral associated soil fractions (Briedis et al., 2012). Aggregate stability may increase in response to positive soil pH-induced effects on new plant organic matter inputs, which include polysaccharides (Haynes and Naidu, 1998). Soil pH may also alter the surface charge of clay particles, determining whether they repel each other or flocculate (Bronick and Lal, 2005). Liming may increase aggregation because of increased potential for molecular interactions, which include the role of calcium (Ca^{++}) acting as cationic bridge between organic and inorganic substances (Six et al., 2004). Soil organo-mineral pools contain both positively and negatively charged ions (cations and anions), therefore the addition of Ca^{++} may increase binding to sites of anions and increase soil aggregation. The stabilising effect of Ca^{++} is most prevalent within soil micro-aggregates as this is the scale of organo-mineral complexation (Six et al., 2004). Liming-induced increases in large macro-aggregates (LMAs) can also occur due to increases in the C flow to soils resulting from enhanced plant growth (Briedis et al., 2012).

Animal grazing can also influence soil aggregation either directly by increasing organic matter returns to soils or indirectly by stimulating plant root exudates, which benefit soil aggregation through valency or glue-like properties causing particles to adhere together (Amézketa, 1999; Graf and Frei, 2013; Rillig et al., 2015). Several studies report that grazing can affect soil aggregate stability in different size classes, for example Li et al. (2007) found that larger aggregates >5 mm decreased under intensive grazing, whereas smaller soil aggregates above 0.25 mm all increased. Dormaar and Willms (1998) found that the mean weight diameter of water stable aggregates was reduced under heavy grazing, which increased soil compaction and reduced soil structural stability. The above-mentioned studies report effects from sheep and cattle grazing respectively, whereas in this current study grazing animals are primarily rabbits together with occasional deer. It is worth noting that different grazing animals may have varied effects on soil aggregate formation. For example, the compaction pressure of a standing cow is roughly twice that of a sheep (Greenwood and McKenzie, 2001). Furthermore, the nutrient content and volume of waste material can vary widely for example, a cow produces on average 25 kg of faeces/day (2.7 kg solids; Petersen et al., 1956) whereas a rabbit produces on average about 9.5 g of dry matter/day (Eden, 1940).

Long-term inorganic nutrient applications may also affect soil stability, aggregate formation and soil C and N content of different organo-mineral fractions. For example, a study by Aoyama et al. (1999) found that the application of inorganic NPK increased mineral and particulate related C and N encased in larger macro aggregates. Nutrient N fertilization alone was also shown to increase both the stability and C and N content of soil macro aggregates, which was related to increases in soil arbuscular mycorrhizal fungal hyphae and associated glomalin content within the soil (Wilson et al., 2009). AMF abundance is potentially increasing within repeated N-only fertilization treatments as a mechanism to increase P uptake by plants (Smith and Read, 1997). Nutrient additions to the soil may also increase aggregate stability (particularly Silt Clay Aggregates (SCAs)) due to an increase of microbial biomass entering the soil in response to nutrient fertilization (Li et al., 2014; Luo et al., 2015).

Despite evidence that liming, grazing and nutrient fertilization can significantly alter soil physical aggregation, very few studies have simultaneously addressed how long-term liming, grazing and nutrient fertilization management might influence the C and N content of different soil organo-mineral pools. Here we measure aggregate mass and the C and N content (%) of different soil fractions in a long-term grassland experiment established at Silwood Park, Berkshire (UK) where animal grazing, liming and five different combinations of inorganic nutrient were applied for 23 years. We particularly focused on the response of large macro-aggregates (LMA > 2 mm), small macro-aggregates (SMA, >250 μm–2 mm), micro-aggregates (MiA, 53–250 μm) and particle sized silt + clay fractions (SCA, <53 μm) to long-term grassland management. We also measured CO_2 efflux rates during the plant peak-growing season to address whether soil respiration might be influenced by the same agricultural practices and whether changes in CO_2 efflux rates might be potentially related to the C content of different soil fractions.

We first, hypothesize ($\mathbf{H_1}$) that long-term liming applications to our grassland soils will increase the mass size of all soil aggregate fractions. This is because of greater C inputs to the soil as a result of increased plant growth and because of increased chemical bonds between soil minerals and humic substances. We expect that increases in aggregate size mass (i.e. more LMAs) will be related to reductions in soil respiration (i.e. CO_2 efflux) due to increased physical protection of contained soil organic matter (SOM).

Our second hypothesis ($\mathbf{H_2}$) is that repeated grazing by rabbits (*Oryctolagus cuniculus* L.) has contributed to increase soil aggregate stabilisation, particularly for large macro aggregates because of grazing-induced increases in humic substances entering the soil.

Our third hypothesis ($\mathbf{H_3}$) is that long-term N fertilization will cause an increase in soil macro-aggregate stability especially under chronic N-only applications where grassland soils tend to become deficient in nutrient P and thus might rely more on plant-microbial symbioses (e.g. roots colonized by arbuscular mycorrhizal fungi). We also expect smaller aggregates (i.e. MiA and SCA) to increase due to increased inputs of microbially derived organic matter.

2. Methods

2.1. Study site

Plant and soil samples were collected from the Nash's Field experimental grassland, which was established at Silwood Park, Berkshire, UK in 1991. This grassland is classified as a MG5, *Lolio-Cynosuretum cristati* grassland, *Anthoxanthum odoratum* sub-community (Rodwell, 1992). Nash's Field was managed as a hay meadow from 1947, prior to being set up as an experimental grassland. The site is surrounded by Oak (*Quercus robur*) and birch (*Betula pendula*) woodlands. The abundance of grazing rabbits (*Oryctolagus cuniculus* L.), as the primary herbivores, increased markedly in the 1950s. Occasional grazers include muntjuc (*Muntiacus reevesi* Ogilby) and roe deer (*Capreolus capreolus* L.). Nash's