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The relationship between soil microbial activity and microbial biomass, soil structure and grassland management

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ABSTRACT

The question of how soil structure interacts with microbial biomass is poorly understood. Most research on soil structure and soil microbial activity has been based on laboratory measurements of soil properties that are indirectly indicative of soil structure, and very few have used direct field data. This study assessed soil structural quality in situ by visual evaluation of soil structure method (VESS) and measured microbial activity related to soil carbon (C) and nitrogen (N) cycles under various grassland management to assess whether soil structure is correlated with microbial activity, both of which are regulated by agricultural management. Soil structure (indicated by Sq score) was strongly negatively correlated with both soil respiration and enzyme activity, indicating a decline in microbial activity with poorer soil structural quality. Both frequent reseeding and N fertilizer application were positively correlated with enzyme activity indicating that these management activities, planned to improve yield can have positive impacts on C input to the soil as well. The increase in enzyme activity under higher stocking rate was perhaps driven by soil C re-location to depth by animal trampling. The strong correlation between soil structure and C and microbial activity and C indicated a two-way 'bridge' function of soil C regulated by management. Good structure is supportive of soil organic matter decomposition by supplying optimal physical conditions, which supply food source for soil microbes and the soil processes of soil C dominated by microbial activity are beneficial for soil structure formation. However, further research is required to better understand this two-way C 'bridge' function.

1. Introduction

Grasslands are a globally significant carbon store (Mannetje, 2007), and are also a major platform for agricultural production (Knaus, 2013). Grassland in Europe represents about 45% of the agricultural area (Eurostat, 2013a), and in Ireland occupies about 93% of the agricultural area (Eurostat, 2013b). Grasslands are typically used for production of beef, milk and sheep products, which account for over 60% of agricultural output from Ireland (Teagasc, 2011). Grassland management plays an important role in soil C and N turnover, aggregate formation and microbial abundance (Lagomarsino et al., 2009). Ploughing and reseeding increase aeration (Nikièma et al., 2012) and leads to the development of a new balance between soil organisms in a micro-environment that is dominated by accelerated biochemical processes (Fontaine et al., 2007). Fertilizer management is now focused on use efficiency targeting to improve soil production with low environmental cost (Ussiri and Lal, 2013), which increases litter yield return to the soil and ultimately regulates soil quality by increasing soil organic matter (SOM) and improving soil structural quality. Grazing or harvesting reduces input to the SOM pool with consequent impacts on microbial biomass (Laird and Chang, 2013) and the carbon pool (Maia et al., 2009). Intensive grazing modulates key ecosystem processes by controlling the availability and distribution of essential resources (water and nutrients) to other organisms (Fontaine, 2007) at least partly through the impact on soil structure (Hiltbrunner et al., 2012) and soil nutrient re-location to depth (Jones et al., 1997). The interaction of all these management decisions is ultimately seen in the processes that are reflected by soil structure and soil quality (Ball et al., 2007b). The evaluations of soil structure and soil quality are common approaches to studying soil productivity and sustainability as regulated by agricultural management.

Visual soil structure assessment methods (Ball and Douglas, 2003; Guimarães et al., 2011; Peerlkamp, 1959) have been developed to allow rapid field assessment of structural quality

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in order to identify when agricultural management has an adverse impact on soil structure. Ball et al. (2007a) interpreted the visual evaluation of soil structure (VESS) method to define management interventions required based on Sq score. Compared to single soil property measurement, visual assessment methods reflect a whole picture of the soil by using knowledge of color, porosity, aggregates, roots, and macro-faunal activity. VESS has been shown to be of practical used for assessment of soil response to both arable (Askari et al., 2013; Guimarães et al., 2013) and grassland (Newell-Price et al., 2013; Cui et al., 2014) management. The consistent relationship between soil physical properties and Sq score demonstrates that it can be used as a predictor of soil quality for sustainable production.

Soil enzyme activity is a 'sensor' of soil microbial status and physic-chemical conditions (Sardans et al., 2008). Specific enzymes act as catalysts for biochemical processes that decompose SOM and release nutrients for plant uptake (Dorodnikov et al., 2009). Enzyme activity can be used to help understand the interaction of soil management and fertility and is thus a valid soil quality indicator (Alster et al., 2013; Šrursová and Baldrian, 2011). Inorganic N fertilization has been reported to accelerate (Keeler et al., 2009) and inhibit (Olander and Vitousek, 2000) soil enzyme activity. Ploughing and grazing have also been shown to have positive (Roux et al., 2003) and negative (Holt, 1997) impacts on enzyme activity. Most of these studies were conducted under a limited range of short-term management, but fields are normally managed by a number of different practices simultaneously over the long-term.

Besides the knowledge gap about the influence of management on enzyme activity, the question of how soil structure interacts with microbial biomass and enzyme activity is poorly understood. Previous research has tended to use laboratory measurement of soil properties that are used as surrogates for soil structure, and very few have been based on field data. The objective of this study was to better understand how soil structure, indicated by Sq score and soil enzyme activity are influenced by grassland management. This was achieved by sampling fields with known long-term grassland management history.

2. Materials and methods

2.1. Study site and sampling

Following a study in October 2012 of 20 sites in Ireland (located between latitude 52°8′12″N and 54°20′12″N and longitude 6°22′42″W and 8°16′05″W) that examined the impact of grassland management on soil structural quality (Cui et al., 2014), soil samples from 7 grassland fields with a range of management intensity defined by stocking rate, N fertilizer rate and reseeding frequency were chosen (Table 1). All soils were loam texture with clay content ranging from 18 to 27% to limit the effect of the known association between enzyme activity and clay content (Blagodatskaya and Kuzyakov, 2008). The climate is defined as temperate with mean daily winter temperatures from 4.0 °C to 7.6 °C, mean daily summer temperatures vary from 12.3 °C to 15.7 °C and mean annual rainfall from 750 mm to 1250 mm. An interview with each farmer was conducted prior to sampling to obtain detailed management information about reseeding, N fertilizer application and stocking rate.

In each field an area of 30 m plus 30 m land that was representative, homogenous and avoided gates, ditches and feeding areas was chosen. Five subplots were identified by walking a 'W' and sampling at the nodes. Samples from 0 to 10 cm and 10 to 20 cm depth were bulked from 10 augerings and 5 cores for bulk density. Each sample was split in two with one subsample air-dried, ground and sieved to 2 mm within 1 week for pH, C and N analysis, and the other subsample stored at 4 °C temperature for <2 weeks for microbiological and enzyme activity assessment.

2.2. VESS method and the rating of Sq score

At each subplot the VESS method was performed (Guimarães et al., 2011) and the each layer of soil was identified by scoring into one of five categories from Sq1 (good) to Sq5 (poor structure). Briefly, a soil block was extracted by spade, manually broken along fracture lines and gently crumbled to expose aggregate units. Soil layers were identified and depth of each layer was measured. The Sq score for each layer was carefully identified by observation and scoring of the visual key attributes including strength required to break up soil slice, porosity, size and shape of aggregates, color, mottling, roots and also the difficulty of soil block extraction according to the score card in VESS. A final Sq score for a single block was calculated by multiplying the score of each layer by its thickness and dividing the product by the overall depth (Ball et al., 2007a). Sq score for each field was determined as the average of the five subplots.

2.3. Soil chemical and physical properties

Soil pH was determined with a soil suspension to water (w/w) ratio of 1:2 and a standard pH meter. Total C and N were determined by dry combustion using a CHN analyzer (TruSpec CN, LECO Corporation). Soil inorganic carbon was measured by C analyzer (Primacs[SLC], SKALAR Co.). Soil organic C was estimated by difference between inorganic C and total C. Soil texture was determined by pipette method (Gee and Or, 2002). Soil C:N ratio was the ratio of total C to total N. Cold water extractable organic C

Table 1
Characteristics of field management and soil properties (top 20 cm soil) of the seven fields used in this study.

Soil	Sward age[a]	Stocking rate[b] (LSU ha^{-1})	N fertilizer input[c] (kg ha^{-1})	Moisture (g 100 g^{-1})	pH	Bulk density (0–10 cm) (g cm^{-3})	Porosity (0–10 cm) (g g^{-1})	Clay (g 100 g^{-1})	Sq score
1	3	3	3	21.5	6.2	0.85	56%	18	2.60
2	1	3	2	18.4	6.7	0.85	57%	19	1.07
3	1	2	2	72.9	6.1	0.75	65%	25	1.60
4	3	3	3	56.0	5.7	0.73	63%	24	2.70
5	1	1	3	61.9	5.6	0.84	65%	27	1.77
6	2	1	1	58.3	5.3	0.81	65%	25	1.44
7	1	2	3	56.4	4.9	0.72	65%	26	1.95

[a] Sward ages (years) means the number of years since last reseed: 0–9 years as class 1, 10–20 years as class 2, and >20 years as class 3.
[b] Stoking rate was defined as the livestock units per hecter, where a dairy cow is 1 LSU assumed to produce 85 kg N per year according to Irish Statutory Instruments (S.I. No. 610 of 2010), and the class threshold was: <1.5 LSU ha^{-1} as class 1, 1.5–2.5 LSU ha^{-1} class 2 and >2.5 LSU ha^{-1} class 3.
[c] According to the National fertilizer application survey (Lalor et al., 2010) , the average application rate of manufactured N fertilizer use on grassland in Ireland was 86 kg N ha^{-1}; manufactured N fertilizer use thresholds were set at 0.5 and 1.5 times this rate (i.e. 43 kg N ha^{-1}, 129 kg N ha^{-1}): <43 kg N ha^{-1} as class 1, 43–129 kg N ha^{-1} as class 2, and >129 kg N ha^{-1} as class 3.