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Carbon balance of an intensively grazed permanent grassland in southern Belgium

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ABSTRACT

Grasslands are an important component of the global carbon balance, but their carbon storage potential is still highly uncertain. In particular, the impact of weather variability and management practices on grassland carbon budgets need to be assessed. This study investigated the carbon balance of an intensively managed permanent grassland and its uncertainties by drawing together 5 years of eddy covariance measurements and other organic carbon exchanges estimates. The results showed that, despite the high stocking rate and the old age of the pasture, the site acted as a relatively stable carbon sink from year to year, with a 5-year average net biome productivity of −161 [−134 −180] g C m^{-2} yr^{-1}. Lateral organic carbon fluxes were found to increase the carbon sink because of high carbon imports (organic fertilization, feed complements) and low carbon exports in form of meat compared to dairy pastures. The cattle stocking density was adapted to grass production, which itself depends on weather conditions and photosynthesizing area, in order to maintain a steady meat production. This resulted in a coupling between grazing management and weather conditions. As a consequence, both weather and grazing impacts on net ecosystem exchange were difficult to distinguish. Indeed, no correlation was found between weather variables anomalies and net ecosystem exchange anomalies. This coupling could also partly explain the low C budget inter-annual variability. The findings in this study are in agreement with those reported by other studies that have shown that well-managed grasslands could act as carbon sinks.

1. Introduction

Grasslands cover 40% of the Earth's ice-free land surface (Steinfeld et al., 2006) and are characterized by soils with a high soil carbon (C) content (Conant et al., 2001). They therefore constitute an important component of the global C balance (IPCC, 2007). Studies assessing the C balance under grasslands are relevant because grassland C sequestration can play an important role in mitigating the total greenhouse gas emissions from livestock production systems (Lal, 2004; Soussana et al., 2010). There is a strong need, therefore, to accurately evaluate grassland C sequestration (Herrero et al., 2011).

Grassland C sequestration can be determined directly by measuring changes in soil organic carbon (SOC) stocks or indirectly by measuring the balance of C fluxes at the system boundaries. Contrary to studies based on SOC change measurements (Goidts and van Wesemael, 2007; Lettens et al., 2005a,b; Meersmans et al., 2011, 2009), studies assessing the total C grassland budget by combining eddy covariance measurements with measurements of other C fluxes enable investigations to be made of seasonal, annual and inter-annual C flux dynamics and budgets (Byrne et al., 2007; Gilmanov et al., 2010; Klumpp et al., 2011; Mudge et al., 2011; Peichl et al., 2012, 2011; Soussana et al., 2010; Zeeman et al., 2010). They also enable the impact of specific management practices or weather conditions to be analyzed (Aires et al., 2008; Allard et al., 2007; Ammann et al., 2007; Ciais et al., 2005; Harper et al., 2005; Heimann and Reichstein, 2008; Hussain et al., 2011; Jaksic et al., 2006; Jongen et al., 2011; Klumpp et al., 2011; Peichl et al., 2012; Suyker et al., 2003; Teuling et al., 2010).

The results of these studies reveal strong site-to-site variability because of differences in pedoclimatic conditions and management

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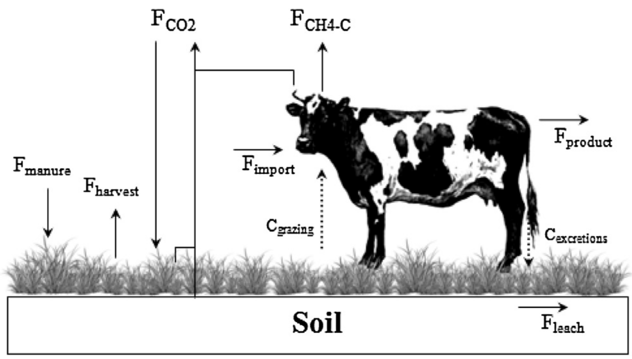

Fig. 1. Carbon (C) cycle of the grazing animal. Solid arrows represent C components of the net biome productivity (see Eq. (1)). Dashed arrows represent internal C fluxes.

practices: they report increases as losses or no change in soil C balances (Soussana et al., 2010). Grassland C balance and the impact of environmental conditions and management practices on this balance are still not well understood (Mudge et al., 2011; Soussana et al., 2010). Grazing is known to directly affect the carbon dioxide (CO_2) net ecosystem exchange (NEE) via livestock respiration and indirectly via biomass consumption, natural fertilization through excreta and soil compaction (Jérôme et al., 2014). A high stocking rate could impact the carbon budget by either reducing growth primary productivity (GPP) through defoliation (Jérôme et al., 2014) but also by stimulating GPP by removing less productive plant material before withering. The land use and the management prior to the study could also affect the carbon budget. Indeed, interventions such as ploughing, reseeding, land use change from a crop field to a grassland and improved management could still increase the CO_2 accumulation many years later before reaching an eventual equilibrium (Smith, 2014).

The main objective of this research was to assess the total C balance of a grazed grassland located in Wallonia (southern Belgium) by measuring all C fluxes exchanged at the system boundaries, using the eddy covariance method, direct measurements made in the field, estimates by the farmer and literature data when no measurements were available. The study site has been a permanent grassland since it was used for grazing (probably more than a century). It has been intensively managed with high stocking rates (around 2 Livestock units (LU) per hectare per year) and the application of mineral and organic fertilization for more than 40 years.

This paper also attempts to answer a few specific questions: (i) is a grassland established for more than a century and intensively managed for more than 40 years with a stocking rate exceeding 2 LU per hectare a C sink or a source? (ii) How do management practices and weather conditions affect the C budget? (iii)What are the main sources of uncertainties and how robust is the methodology used to establish the C budget? The research covered 5 years of measurements, providing an opportunity to assess the grassland C budget on monthly and annual scales, evaluate its uncertainties and identify some drivers linked with weather or grassland management.

2. Material and method

2.1. Carbon balance of the pasture

The net balance of C fluxes exchanged at the system boundaries, commonly known as net biome productivity (NBP, $g\,C\,m^{-2}\,yr^{-1}$), was defined by Soussana et al. (2010) for temperate grazed grassland as (Fig. 1):

$$NBP = F_{CO2} + F_{CH4} + F_{manure} + F_{import} + F_{harvest} + F_{product} + F_{leach} \quad (1)$$

where F_{CO2} is the net ecosystem carbon dioxide (CO_2) exchange, corresponding to the difference between gross CO_2 uptake via photosynthesis (gross primary productivity, GPP) and CO_2 loss via respiration (total ecosystem respiration, TER, including cattle respiration); F_{CH4} is the C lost through methane (CH_4) emissions by grazing cattle (the CH_4 fluxes from the soil were considered as negligible as their magnitude was only 2.5% of the cattle fluxes according to (Dumortier et al., submitted); F_{manure} and F_{import} are the lateral organic C fluxes imported into the system through manure and/or slurry application and supplementary feed, respectively; $F_{harvest}$ and $F_{product}$ are the lateral organic C fluxes exported from the system through mowing and animal products (meat), respectively and F_{leach} represents organic and/or inorganic C losses through leaching. Throughout this paper, we adopt the micrometeorological convention that fluxes from the ecosystem are positive and that fluxes to the ecosystem are negative. A negative NBP therefore corresponds to C uptake.

2.2. Site description

The research was carried out at the Dorinne terrestrial observatory (DTO) (50° 18′ 44″ N; 4° 58′ 07″ E). Dorinne is 18 km south/south-east of Namur, in the Condroz region in Belgium. The Condroz region is characterized by a succession of depressions and crests with soils suitable for arable land use (mainly cereals and sugar beet) and pastures for cattle breeding (Goidts and van Wesemael, 2007). The climate is temperate oceanic. The mean annual air temperature is 10 °C, the annual precipitation is 847 mm and the main wind directions are south-west (IRM, 2011) and north-east. The field is bordered on the south-west by a cultivated field and by pastures on the north-east. The research site is a permanent grassland covering 4.22 ha and dominated by a large colluvial depression exposed south-west/north-east. This depression is situated on a loamy plateau with a calcareous and/or clay substrate. The altitude varies from 240 m (north-east) to 272 m (south). So far as we know, the field has never been cultivated and has been permanent grassland since it started being used for grazing (probably for more than a century). It has been intensively used for cattle grazing, with the application of organic (cattle slurry and manure) and inorganic fertilizers, for about 40 years. The grassland species composition is: 66% grasses, 16% legumes and 18% other species. The dominant species are perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). There has been no renovation of the grass vegetation (ploughing – resowing) for more than 50 years. Flux measurements have been taken since spring 2010. The data given in this study cover 5 full years of measurements from 12 May 2010, when the eddy covariance measurements began, to 12 May 2015.

2.3. Grassland management

The field was intensively managed and grazed during the growing season by Belgian Blue cattle (heifers, suckler cows, breeding bulls, calves). The rotation between stocking (periods with cattle) and recovery periods without cattle (rest periods) depended on herbage growth and its consumption by cattle. In this context, weather conditions limited the grazing pressure, which was adjusted when necessary. Feed (corn silage, hay and a mixture of straw and ProtiWanze®, a by-product of bio-ethanol production) was distributed when necessary to supplement grass shortage (drought or beginning/end of the grazing season). Fertilizers, including mineral and organic fertilizers, were applied at various times to the field throughout the growing season (Table 1). The reference unit used for calculating LU is the grazing equivalent of one 600 kg liveweight (LW) adult dairy cow producing 3000 kg of milk annually, without additional concentrated feed (Eurostat, 2013).