Agriculture, Ecosystems and Environment 158 (2012) 132–146

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

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

Management and climate effects on carbon dioxide and energy exchanges in a maritime grassland

Matthias Peichl[a,b,*], Owen Carton[c], Gerard Kiely[a]

[a] Center for Hydrology, Micrometeorology & Climate Change, Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland
[b] Department of Forest Ecology & Management, Swedish University of Agricultural Sciences, Umeå, Sweden
[c] Teagasc, Johnstown Castle, Ireland

ARTICLE INFO

Article history:
Received 4 February 2012
Received in revised form 14 May 2012
Accepted 4 June 2012
Available online 2 July 2012

Keywords:
Albedo
Bowen ratio
Eddy-covariance
Evapotranspiration
Grazing
Harvest
Grass re-seeding
Kale planting
Sensible/latent heat flux

ABSTRACT

This study investigated the effects of grassland management and climate on the exchanges of carbon dioxide (CO_2) (i.e. net ecosystem CO_2 exchange, NEE; gross ecosystem production, GEP; and ecosystem respiration, ER) and energy (i.e. latent heat flux, LE; sensible heat flux, H; and Bowen ratio, β) in an intensively managed grassland in the maritime climate of southeast Ireland using six years (2004–2009) of eddy-covariance data. The observed effects on CO_2 (reduction of net CO_2 uptake (i.e. NEE), GEP and ER) and energy exchanges (LE decreased while H and β increased) were more pronounced following harvest compared to grazing practices and were further dependent on their seasonal timing. Most importantly, a net loss of CO_2 occurred for 2–3 weeks following harvest whereas net uptake continued during grazing periods. Whereas the environmental conditions were in general non-constraining and similar among years, the predominant annual management regime varied widely among years including cattle grazing, grass harvesting, kale planting, and grass re-seeding. For the years 2004–2009, the NEE was −385, −202, −109, +134, −101, and −201 $\mathrm{g\,C\,m^{-2}\,year^{-1}}$ (negative sign indicating uptake) and the mean growing season midday β was 0.97, 0.66, 0.82, 1.07, 0.78 and 0.79. During similar environmental conditions, about twice as much annual CO_2 uptake and greater H flux occurred under the cattle grazing regime in 2004 compared to the grass harvesting regime in 2005. Kale planting and re-seeding during the early summer likely caused the reduced annual CO_2 uptake in 2006 and net emission combined with a greater β in 2007. A 2-week drought period in summer 2006 further affected GEP, ER and energy fluxes, while its impact on NEE was limited. Recognizing additional effects from climate, this study finds that the choice of grassland management regime is a key control on grassland ecosystem carbon, water, and energy exchanges in this maritime climate region.

1. Introduction

Managed grasslands constitute a considerable fraction of landscapes and agricultural production in temperate regions (e.g. ~60% of Irish lands; Eaton et al., 2008), and affect local and regional dynamics in climate, carbon (C) and water cycling through processes related to plant photosynthesis, respiration and energy partitioning (Ryszkowski and Kędziora, 1987; White et al., 2000; Rosset et al., 2001; Pielke et al., 2002; Janssens et al., 2005; Gilmanov et al., 2010). A distinct feature of intensively managed grassland ecosystems is the disruption of natural vegetation growth patterns as well as high external C and nitrogen (N) input/output through grazing, harvesting, and N fertilizer application events (Snaydon, 1987). Altogether, the type, frequency, intensity and timing of these management practices may, in addition to environmental controls, considerably modify the seasonal and inter-annual dynamics of carbon dioxide (CO_2) and energy fluxes (i.e. latent heat, LE; sensible heat, H) (Rogiers et al., 2005; Allard et al., 2007; Hammerle et al., 2008; Wohlfahrt et al., 2008a,b; Schmitt et al., 2010; Zeeman et al., 2010). Thus, understanding the response and restoration behaviour of these fluxes following such management events, is essential to improve our understanding of the implications from current and future management regimes on regional carbon, water and energy exchanges.

Grass harvesting (i.e. silage cutting) affects the net ecosystem exchange (NEE) of CO_2 and energy partitioning in grasslands primarily through its step change reduction of plant biomass and leaf area index (LAI) as well as through alterations of the surface resistance and albedo (Dugas et al., 1999; Novick et al., 2004; Hammerle et al., 2008; Harding and Lloyd, 2008; Schmitt et al., 2010; Zheng et al., 2010). In contrast, grazing effects may be more variable depending on the stocking density and length of the

---

* Corresponding author. Current address: Department of Forest Ecology & Management, Swedish University of Agricultural Sciences, 901 83 Umeå, Sweden. Tel.: +46 90 786 8463.
E-mail address: Matthias.Peichl@slu.se (M. Peichl).

0167-8809/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agee.2012.06.001

grazing period. Some studies reported considerable impacts of grazing on the annual energy balance due to reduced evapotranspiration (ET) (Li et al., 2000; Frank, 2003), while others found no difference in energy partitioning between grazed and non-grazed grasslands (e.g. Chen et al., 2009). Furthermore, variations in form and rates of nitrogen input from fertilizer or cattle excreta may also affect grassland CO_2 exchange (Jones et al., 2006; Allard et al., 2007; Ammann et al., 2007; Shimizu et al., 2009).

On a multi-annual scale, the cycle of periodic re-seeding, fallow periods and intermittent forage crop cultivation among individual paddock fields is a common practice of grassland cultivation systems (Barnes et al., 2007). Grass re-seeding and planting of kale (for winter cattle grazing) during spring or early summer is associated with initial soil disturbance through ploughing and rotavating and results in a severe reduction of plant biomass and subsequent modifications in the seasonal development of vegetation growth and land surface cover (Harper and Compton, 1980). Therefore, such activities may alter grassland CO_2 and energy exchanges over a multi-year time frame (e.g. Vellinga et al., 2004; Willems et al., 2011).

During the past decades, many experimental studies have investigated grazing and harvest effects on plant growth and C dynamics on the plot or plant level (e.g. through clipping experiments) (Snaydon, 1987; Ferraro and Oesterheld, 2002). With the introduction of the eddy covariance (EC) technique, it has become feasible to explore these effects at the ecosystem scale (Baldocchi et al., 2001). To date, a considerable number of studies have investigated seasonal dynamics and annual budgets of CO_2 and energy exchanges in managed grasslands using the EC technique (Li et al., 2005; Byrne et al., 2007; Jacobs et al., 2007; Ryu et al., 2008; Chen et al., 2009; Ciais et al., 2010; Gilmanov et al., 2010). However, in-depth studies assessing the impacts of specific management events on grassland CO_2 and energy fluxes are less abundant and mostly conducted in mountainous or summer-dry regions with primarily extensive management (Dugas et al., 1999; Novick et al., 2004; Hammerle et al., 2008; Harding and Lloyd, 2008; Schmitt et al., 2010; Zheng et al., 2010). By comparison, knowledge is still limited for intensively managed grasslands in the maritime region (but see Jaksic et al., 2006; Harding and Lloyd, 2008; Peichl et al., 2011). Moreover, management effects in previous studies often tend to be masked by environmental constraints (e.g. through seasonal soil water deficits). Meanwhile, investigating grassland management implications in the maritime region that is less prone to temperature or water stress, may allow for more clearly segregating the effects of management practices given the potentially reduced additional impact from environmental constraints.

The aim of this study was to investigate the effects of climate and management practices on short-term flux patterns and annual exchanges of CO_2, latent heat (LE) and sensible heat (H), using six years (2004–2009) of EC data collected in intensively managed grassland in southeast Ireland. In detail, the study aimed at assessing: (i) the absolute changes and recovery times of CO_2 and energy fluxes related to harvest and grazing events and (ii) the effect of climate and annual management regime (i.e. harvest, cattle grazing, kale planting, re-seeding) on the inter-annual variability in annual CO_2 and energy exchanges for an intensively managed grassland that is representative of Irish grassland management practices.

2. Materials and methods

2.1. Study site description

The study was conducted at the Wexford grassland research station which is located near the city of Wexford, in southeast Ireland (52°30′N; 6°40′W; 57 m above sea level). The grassland is owned and managed by the Johnstown Castle Agriculture Research Institute (Teagasc).

2.1.1. Climate

The 30-year annual mean air temperature and total precipitation in this region is 10.1 °C and 877 mm, respectively (Met Eireann, 1961–1990 climate norms at Rosslare Meteorological Station). However the six-year (2004–2009) mean annual precipitation measured at our study site was 1207 mm. The seasonal range in daily mean temperatures is limited, with a mean daily minimum of 3.8 °C in February and a mean daily maximum of 17.9 °C in July/August. Days with pronounced heat or freezing temperatures are uncommon in this region. Precipitation occurs evenly distributed over the year. The prevailing wind direction is from the southwest.

2.1.2. Vegetation and soil characteristics

The grassland is used as pasture and meadow, with perennial ryegrass (*Lolium perenne* L.) being the dominant plant species. Vegetation height reaches a maximum height of about 40 cm in the summer prior to harvesting. However, more detailed data of vegetation height and leaf area index (LAI) were not available. The soil in the proximity (<150 m) of the EC flux tower is a moderately to imperfectly drained Gley (FAO classification: Gleyic Cambisol), with a transition to moderately or well drained Brown Earth (Cambisol) towards the far edge of the footprint of interest (i.e. fields A–F, Fig. 1). The soil texture is loam with 18% coarse sand, 26% fine sand, 38% silt, 18% clay. The permanent wilting point, field capacity and saturated water content were estimated using the SPAW Model (http://hydrolab.arsusda.gov/SPAW/Index.htm) as 0.15, 0.30 and 0.54 $m^3 m^{-3}$, respectively. Bulk density is 1.23 $g cm^{-3}$, soil C and nitrogen (N) concentrations are 3.2 and 0.28%, respectively (Hyde et al., 2006).

2.1.3. Footprint of interest

In this study, we focused our analysis on six evenly sized fields of about 0.7–0.9 ha surrounding the flux tower (fields A–F, Fig. 1) for

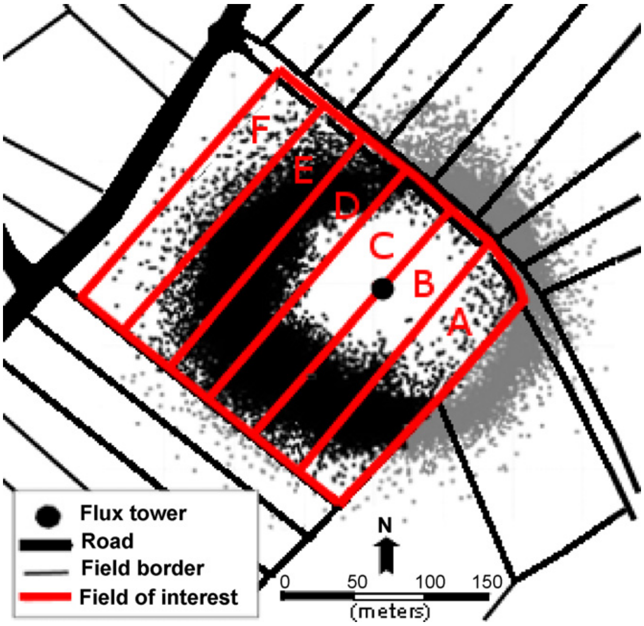

Fig. 1. Map of the Wexford Grassland Research Station outlining tower location, the footprint of interest consisting of the fields A–F (red outlines), and 90% fetch distances for accepted (black dots) and rejected (grey dots) half hourly fluxes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)