Agriculture, Ecosystems and Environment 215 (2016) 1–19

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Modelling of grassland fluxes in Europe: Evaluation of two biogeochemical models

R. Sándor[a,b], Z. Barcza[c], D. Hidy[d], E. Lellei-Kovács[e], S. Ma[a,1], G. Bellocchi[a,*]

[a] Grassland Ecosystem Research Unit, French National Institute for Agricultural Research, Clermont-Ferrand, France
[b] MTA Centre for Agricultural Research, Institute for Soil Sciences and Agricultural Chemistry, Budapest, Hungary
[c] Eötvös Loránd University, Department of Meteorology, Budapest, Hungary
[d] Szent István University, MTA-SZIE Plant Ecology Research Group, Gödöllő, Hungary
[e] MTA Centre for Ecological Research, Institute of Ecology and Botany, Vácrátót, Hungary

ARTICLE INFO

Article history:
Received 17 December 2014
Received in revised form 31 August 2015
Accepted 2 September 2015
Available online 22 September 2015

Keywords:
Carbon-water fluxes
Climate change
Grasslands
Model comparison

ABSTRACT

Two independently developed simulation models – the grassland-specific PaSim and the biome-generic Biome-BGC MuSo (BBGC MuSo) – linking climate, soil, vegetation and management to ecosystem biogeochemical cycles were compared in a simulation of carbon (C) and water fluxes. The results were assessed against eddy-covariance flux data from five observational grassland sites representing a range of conditions in Europe: Grillenburg in Germany, Laqueuille in France with both extensive and intensive management, Monte Bondone in Italy and Oensingen in Switzerland. Model comparison (after calibration) gave substantial agreement, the performances being marginal to acceptable for weekly-aggregated gross primary production and ecosystem respiration ($R^2 \sim 0.66-0.91$), weekly evapotranspiration ($R^2 \sim 0.78-0.94$), soil water content in the topsoil ($R^2 \sim 0.1-0.7$) and soil temperature ($R^2 \sim 0.88-0.96$). The bias was limited to the range −13 to 9 g C m^{-2} week^{-1} for C fluxes (−11 to 8 g C m^{-2} week^{-1} in case of BBGC MuSo, and −13 to 9 g C m^{-2} week^{-1} in case of PaSim) and −4 to 6 mm week^{-1} for water fluxes (with BBGC MuSo providing somewhat higher estimates than PaSim), but some higher relative root mean square errors indicate low accuracy for prediction, especially for net ecosystem exchange The sensitivity of simulated outputs to changes in atmospheric carbon dioxide concentration ([CO_2]), temperature and precipitation indicate, with certain agreement between the two models, that C outcomes are dominated by [CO_2] and temperature gradients, and are less due to precipitation. ET rates decrease with increasing [CO_2] in PaSim (consistent with experimental knowledge), while lack of appropriate stomatal response could be a limit in BBGC MuSo responsiveness. Results of the study indicate that some of the errors might be related to the improper representation of soil water content and soil temperature. Improvement is needed in the model representations of soil processes (especially soil water balance) that strongly influence the biogeochemical cycles of managed and unmanaged grasslands.

1. Introduction

Accurate quantification of ecosystem carbon (C) and water fluxes over sites and regions is essential for understanding the feedbacks between the terrestrial biosphere and the atmosphere in the context of global change and climate policy-making (Xiao et al., 2012; Ciais et al., 2013). This is especially true for grassland ecosystems worldwide and also in Europe (the focus of this study), which are known to be uncertain components of the C balance (Scurlock and Hall, 1998; Schulze et al., 2009). Grassland ecosystems are permanent for about 85% of the EU-27 (the 27 member states of the European Union as at the end of 2013) and play an important role in land use, with 67 million ha (i.e. about 40% of agricultural surface), run by about 5.4 millions of farmers to provide the feed basis of 78 million herbivores producing about 25% of European milk and meat (Peyraud, 2013).

In the last decades, considerable progress has been made in modelling C and water fluxes by soil–crop systems, including grassland ecosystems (e.g. Churkina et al., 1999; Jung et al., 2007; Huntzinger et al., 2012; Warszawski et al., 2014). Some of these models provide an integrated perspective by taking into account

* Corresponding author. Fax.: +33 473624457.
E-mail address: gianni.bellocchi@clermont.inra.fr (G. Bellocchi).
[1] Present address: The University of New South Wales, Climate Change Research Center, Australia.

http://dx.doi.org/10.1016/j.agee.2015.09.001
0167-8809/

the various vegetation, soil and weather processes (and the management factors) regulating energy and matter exchanges in agro-ecosystems. By their implicit or explicit representation of key plant processes (such as photosynthesis, respiration and evapotranspiration), they represent dynamically the agro-ecosystems and are considered useful tools for optimizing the usage of water resources and estimating C emissions at different levels, from individual fields to whole regions (Laniak et al., 2013). One of the main advantages of the models based on biophysical equations is the fact that the parameters of the model can be related to physical quantities. Thus, one must have only in situ measured inputs to run them, and no calibration of their parameters, in theory, is needed. However, several process-based models are available to simulate a given agro-ecosystem, which differ in the way they represent dynamic processes, set parameters and use input variables. Large differences in simulation results from different crop models have been reported (e.g. Palosuo et al., 2011), which can be attributed to differences in the structures of the models used and how model parameters are set. The variations among models, in particular, can be a great proportion of the uncertainty in the simulated climate change impacts (Asseng et al., 2013; Bassu et al., 2014; Li et al., 2015). This is also true for grassland models (Ma et al., 2014) and a thorough assessment of the variation in the response of different models is necessary before grassland models are used to project what the future realizations may be under changed climate.

Simulations of grassland C and water–energy fluxes are inherently uncertain because grasslands are highly complex ecosystems and their behaviour is affected by multifaceted interactions of climate drivers with water availability, nutrients, soil, vegetation and management conditions (Soussana et al., 2013). Grassland-specific, process-based models can simulate measured grassland outputs accurately under a range of environments, particularly if the input information is sufficiently detailed (e.g. Graux et al., 2013). They deal with vegetation and major soil processes on a plot-scale configuration, and are generally suited to perform analysis of alternative management options, thanks to the control of actions such as fertilization, irrigation, cutting and grazing. Biome models also comprise an important class of models. Traditionally, they are based on the plant function types (PFTs) logic such as the dynamic global vegetation models (DGVMs) developed since the 1990s (Foley et al., 1996; Brovkin et al., 1997) that can deal with a variety of spatially-distributed systems (including grassland ecosystems). Biome models use time series of climate data to describe dynamics of ecosystem processes (biogeochemical and hydrological cycles, and energy fluxes), given constraints of latitude, topography, and soil characteristics. They are often used to simulate the effects of future climate changes on natural vegetation and C and water cycles, while also including feedbacks from the biosphere to the atmosphere (so that vegetation shifts and changes in the C and hydrological cycles affect the climate). Biome models divide vegetation into few PFTs (i.e. grassland, croplands, different forest types, etc.) that share the same set of equations and parameters, and can yield satisfactory performance to simulate grassland ecosystems (e.g. Chang et al., 2013). However, these models commonly treat grasslands as being unmanaged, or include simplified schemes of human or livestock disturbance by prescribed amounts of biomass removed by mowing or grazing (e.g. Bondeau et al., 2007).

The main goal of this work is to compare the multi-year estimation accuracy of two modelling approaches that differ in the way they address basic physiological mechanisms and management. To estimate the C and water fluxes by grassland systems in Europe, we applied Biome-BGC MuSo v2.2 (BBGC MuSo, hereafter; Hidy et al., 2012) that is a generic biome model, and PaSim grassland-specific model (Ben Touhami et al., 2013; Ma et al., 2015). They both are process-based biogeochemical models simulating plant dynamics (e.g. photosynthesis, biomass allocation and tissue turnover) and C and water fluxes of ecosystems, while PaSim focuses on grassland ecosystems only. Both models account for animal processes and management options (including cutting, grazing and fertilization options). Data from five eddy covariance measurements (performed at four European sites) were used to quantify the accuracy of the two models. As we plan to use the models to predict the evolution of future C cycles under climate change, an important aspect of the present work is also the documentation of the sensitivity of the two models to changing environmental conditions, i.e. precipitation, temperature, and ambient CO_2 mixing ratio (one-at-a-time approach).

Table 1
List of permanent grassland sites.

Site	Latitude	Longitude	Elevation (m a.s.l.)	Years of available data	Notes	Source
Laqueuille (LAQ1, LAQ2), France	45°38′N	02°44′E	1040	2004–2010	Flux-tower grazed site, either intensively (LAQ1) or extensively (LAQ2) managed. Since spring 2002, the field (6.65 ha) is divided into two adjacent paddocks, continuously grazed by heifers from May to October. One paddock (2.81 ha), referred to as intensive, is adjusted to mean stocking rate of about 1 LSU ha^{-1} yr^{-1}. The second paddock (3.4 ha, extensive) is maintained at about half the stocking rate of the intensive paddock. The intensively grazed paddock receives about 200 kg N ha^{-1} in the form of ammonium nitrate, while the extensive paddock is not fertilized.	Klumpp et al. (2011)
Oensingen (OEN), Switzerland	47°17′N	07°44′E	450	2002–2008	Flux-tower mowed site, established on a ley-arable rotation. In November 2000 the field was ploughed for the last time, and then the area divided into two equal parts (0.77 ha each). They were sown on May 2001 with two grass–clover mixtures typical for permanent grassland under intensive and extensive management, respectively. We refer to the intensively managed field, which was sown with a grass–clover mixture of seven species. It is cut typically four times per year and fertilized with solid ammonium nitrate or liquid cattle manure at the beginning of each growing cycle (after the previous cut). It receives in total about 200 kg N ha^{-1} yr^{-1}.	Ammann et al. (2007)
Monte Bondone (MBO), Italy	46°00′N	11°02′E	1500	2003–2007	Flux tower Alpine hay meadow with occasional grazing in late autumn. It experiences typical Alpine climatic conditions with precipitation peaking in summer. The site is managed as hay meadow, being cut between one and three times per year with occasional grazing in late autumn	Wohlfahrt et al. (2008)
Grillenburg (GRI), Germany	50°57′N	13°30′E	380	2004–2008[a]	Flux-tower mowed, extensively managed site. The grassland is managed by regular cutting two to four times a year. Neither mineral nor organic fertilizers are applied at this site to fulfil criteria of a support programme.	Prescher et al. (2010)

[a] At Grillenburg, soil water content data were only available for 2007 and 2008.