Agricultural and Forest Meteorology 226–227 (2016) 108–118

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Spatiotemporal variability in carbon exchange fluxes across the Sahel

Torbern Tagesson[a,*], Rasmus Fensholt[a], Bernard Cappelaere[b], Eric Mougin[c], Stéphanie Horion[a], Laurent Kergoat[c], Héctor Nieto[d], Cheikh Mbow[e], Andrea Ehammer[a], Jérôme Demarty[b], Jonas Ardö[f]

[a] Department of Geosciences and Natural Resource Management, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen, Denmark
[b] Institut de Recherche pour le Développement, HydroSciences Montpellier (CNRS, IRD, UM), BP 64501, 34394 Montpellier Cedex 5, France
[c] Géosciences Environnement Toulouse (GET), UMR 5563 CNRS – UR 234 IRD – UPS, Observatoire Midi-Pyrénées, 14 avenue Edouard Belin, 31400 Toulouse Cedex 4, France
[d] Institute for Sustainable Agriculture (IAS), Spanish National Research Council (CSIC) Campus Alameda del Obispo, Avda. Menendez Pidal s/n 14001 Córdoba, Spain
[e] World Agroforestry Centre, Research Unit SD6, PO Box 30677-00100, Nairobi, Kenya
[f] Department of Physical Geography and Ecosystem Science, Lund University, Sölvegatan 12, SE- 223 62 Lund, Sweden

ARTICLE INFO

Article history:
Received 14 July 2015
Received in revised form 16 May 2016
Accepted 19 May 2016

Keywords:
Carbon dioxide
Climate change
Dryland
Net ecosystem exchange
Photosynthesis
Respiration

ABSTRACT

Semi-arid regions play an increasingly important role as a sink within the global carbon (C) cycle and is the main biome driving inter-annual variability in carbon dioxide (CO_2) uptake by terrestrial ecosystems. This indicates the need for detailed studies of spatiotemporal variability in C cycling for semi-arid ecosystems. We have synthesized data on the land-atmosphere exchange of CO_2 measured with the eddy covariance technique from the six existing sites across the Sahel, one of the largest semi-arid regions in the world. The overall aim of the study is to analyse and quantify the spatiotemporal variability in these fluxes and to analyse to which degree spatiotemporal variation can be explained by hydrological, climatic, edaphic and vegetation variables. All ecosystems were C sinks (average ± total error $-162 \pm 48\,g\,C\,m^{-2}\,y^{-1}$), but were smaller when strongly impacted by anthropogenic influences. Spatial and inter-annual variability in the C flux processes indicated a strong resilience to dry conditions, and were correlated with phenological metrics. Gross primary productivity (GPP) was the most important flux process affecting the sink strength, and diurnal variability in GPP was regulated by incoming radiation, whereas seasonal dynamics was closely coupled with phenology, and soil water content. Diurnal variability in ecosystem respiration was regulated by GPP, whereas seasonal variability was strongly coupled to phenology and GPP. A budget for the entire Sahel indicated a strong C sink mitigating the global anthropogenic C emissions. Global circulation models project an increase in temperature, whereas rainfall is projected to decrease for western Sahel and increase for the eastern part, indicating that the C sink will possibly decrease and increase for the western and eastern Sahel, respectively.

1. Introduction

Vegetation growth in semi-arid regions plays an increasingly important role as a sink within the global carbon (C) cycle, and it is the main biome driving inter-annual variability and long-term trends in carbon dioxide (CO_2) uptake by terrestrial ecosystems (Ahlström et al., 2015; Poulter et al., 2014). It has recently been shown that the net ecosystem exchange (NEE) of CO_2 at the peak of the growing season of semiarid savanna ecosystems can potentially reach very high levels (up to $-40\,\mu mol\ CO_2\ m^{-2}\,s^{-1}$) (Tagesson et al., 2015a), indicating the importance of improving our understanding of the spatiotemporal variability of C cycling for semi-arid savanna regions across the world.

The African Sahel is a semi-arid savanna region with shrubs and low tree coverage located south of the Sahara desert. The region is characterized by a long dry season and a rainy season of 2–3 months. The livelihood of the Sahelian population is strongly dependent on local ecosystems services providing food, feed, fuel

* Corresponding author.
E-mail addresses: torbern.tagesson@ign.ku.dk (T. Tagesson), rf@ign.ku.dk (R. Fensholt), bernard.cappelaere@um2.fr (B. Cappelaere), eric.mougin@get.obs-mip.fr (E. Mougin), stephanie.horion@ign.ku.dk (S. Horion), laurent.kergoat@get.obs-mip.fr (L. Kergoat), hnieto@ias.csic.es (H. Nieto), C.mbow@cgiar.org (C. Mbow), andrea.ehammer@ign.ku.dk (A. Ehammer), jerome.demarty@univ-montp2.fr (J. Demarty), jonas.ardo@nateko.lu.se (J. Ardö).

http://dx.doi.org/10.1016/j.agrformet.2016.05.013
0168-1923/

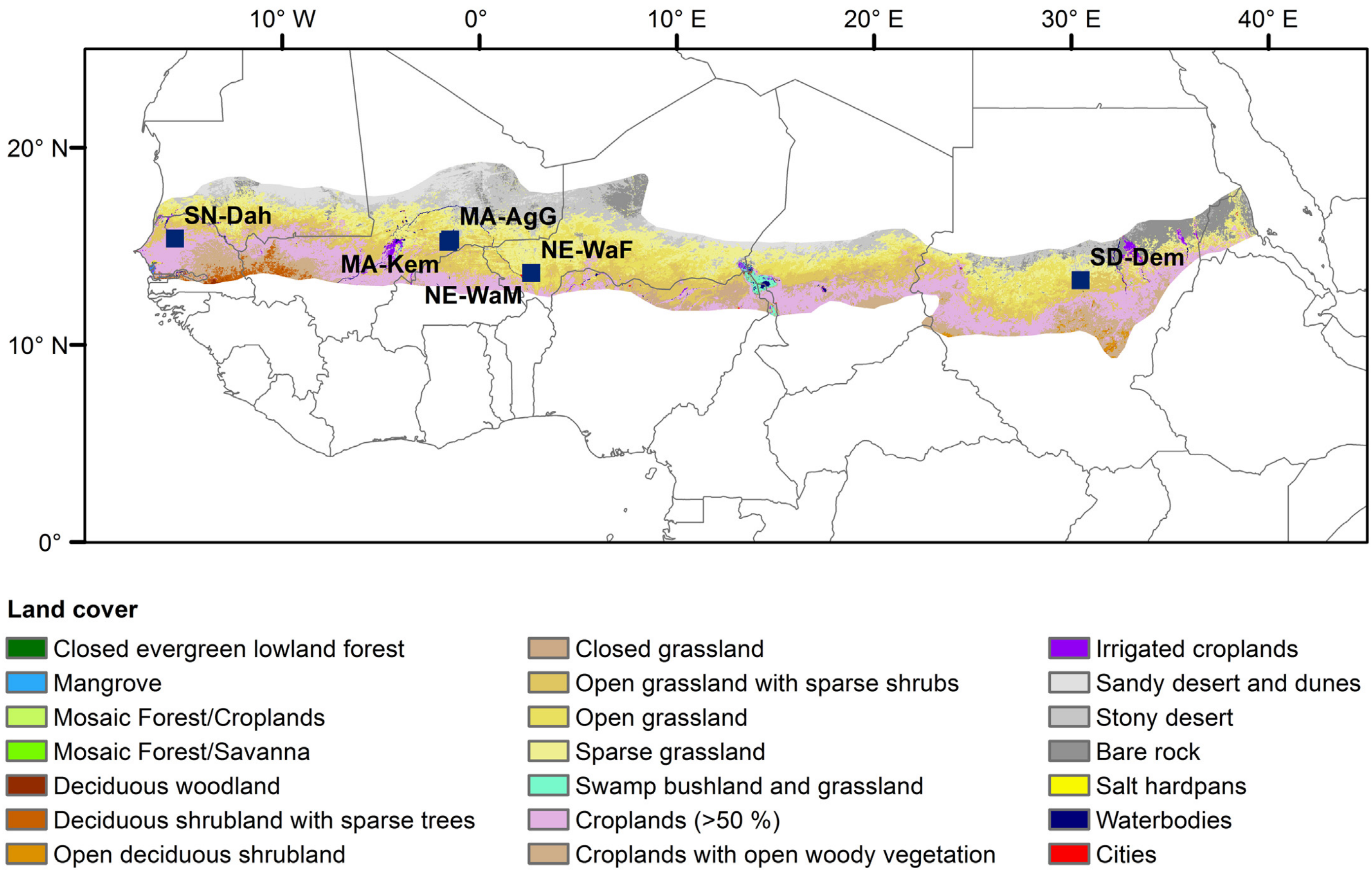

Fig. 1. Location of the different sites in the Sahel. Land cover for the Sahel (based on multi-sensor satellite observations (Mayaux et al., 2003)) and location of the different sites included in the study. The sites are Demokeya (SD-Dem), Agoufou (ML-AgG), Kelma (ML-Kem), Dahra (SN-Dah), Wankama Fallow (NE-WaF), and Wankama Millet (NE-WaM). The delineation of the Sahel is based on isohyets 150 and 700 mm.

and fibre, but Sahelian ecosystems are currently under great pressure from rapidly increasing population, changes in land-use and climatic forcing (Abdi et al., 2014; Sarr, 2012). In the future, it is projected that the Sahel will have shorter rainy seasons, increased temperature and increased or decreased rainfall, depending on location within the Sahel (Roehrig et al., 2013; Sarr, 2012). This will affect the ecosystem productivity with consequences for Sahelian livelihood strategies (OECD, 2009; Sarr, 2012). An improved understanding of resilience and responses of these ecosystems to climatic and environmental changes are therefore essential to better understand, quantify, and predict the effects of current and future climate change.

The NEE is the balance between CO_2 assimilated through gross primary productivity (GPP) by the vegetation and the C decomposed and released as ecosystem respiration (R_{eco}). There is great spatiotemporal variability in climatic, hydrological, edaphic, and vegetation factors across the Sahel, and the NEE and the C exchange processes (GPP and R_{eco}) are known to vary considerably both spatially and temporally for semi-arid savanna areas (e.g. Merbold et al., 2009; Moncrieff et al., 1997). Merbold et al. (2009) explained the variability in CO_2 exchange across the African biomes with annual sums of rainfall and Brümmer et al. (2008) have shown the importance of water availability and rainfall distribution for inter-annual variation in C budgets for a Soudanian savanna ecosystem. Moncrieff et al. (1997) showed that phenology was the main factor determining CO_2 flux variability, both in space and in time, which in turn was mainly determined by the timing of the start of the rainy season. Rockström and de Rouw (1997) on the other hand showed that short periods of intra-seasonal drought have a larger effect on spatiotemporal variability in grain yield than the annual sums of rainfall for a millet farm in the Sahel. Instead, it was nutrient availability increasing the capacity to compensate for damage caused by water shortage determining the size of grain yield (Rockström and de Rouw, 1997). The biomass accumulation and C exchange processes can also vary considerably depending on species composition, thus affecting both the spatial and inter-annual variation (Boulain et al., 2009; Mbow et al., 2013). Tagesson et al. (2016) explained findings of high CO_2 exchange fluxes at the peak of the rainy season for a grazed semi-arid savanna site in Senegal with alleviated water stress conditions, a low C3/C4 ratio and a grazing pressure resulting in compensatory growth and fertilization effects. Hence, there is a range of explanatory variables describing variability in the land-atmosphere C exchange processes for semi-arid savanna ecosystems, which indicates the importance of analysing and quantifying these relationships at different temporal and spatial scales.

A method that has received much attention during recent decades is the eddy covariance (EC) technique, which has become an important tool for measuring the CO_2 exchange between land and atmosphere. The EC method provides high resolution long term temporal data, making it suitable for assessing the diurnal, seasonal and inter-annual variation of net C exchange at the ecosystem level. Compared to boreal and temperate ecosystems, semi-arid savanna regions of Africa are underrepresented in the global EC flux networks (Ardö et al., 2008; Schwalm et al., 2010). However, a limited number of sites with conducted EC measurements does exist in the Sahel, and data from these sites are now available from the Fluxnet database, a global network of micrometeorological measurement