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Review

Long term observations of carbon dioxide exchange over cultivated savanna under a Sudanian climate in Benin (West Africa)

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ABSTRACT

Turbulent CO_2 exchanges between a cultivated Sudanian savanna and the atmosphere were measured during 29 months (August 2007–December 2009) by an eddy-covariance system in North-Western Benin, West Africa. The site (Lat 9.74° N, Long 1.60° E, Alt: 449 m) is the one of three sites fitted out by the international AMMA-CATCH program. The flux station footprint area is mainly composed of herbs and crops with some sparse trees and shrubs. Fluxes data were completed by an inventory of dominating species around the tower and the meteorological measurements. Flux response to climatic and edaphic factors was studied. Water was found the main controlling factor of ecosystem dynamics: much larger uptake was found in wet than dry season. During wet season, a very clear answer of net CO_2 fluxes to photosynthetic photon fluxes density (PPFD) was observed. A low limitation in response to saturation deficit and soil water variability was however observed. The total ecosystem respiration (TER) was found highly dependent on soil moisture below 0.1 $m^3\,m^{-3}$, but saturates above this threshold. The average annual carbon sequestration was 232 ± 27 $gC\,m^{-2}$ with its inter-annual variability mainly controlled by TER. Finally, the ecosystem appeared more efficient during morning and wet season than during afternoon and dry period.

Contents

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1. Introduction

Although estimates of net carbon sequestration by terrestrial ecosystems have flourished these 15 last years (Baldocchi et al., 2005; Valentini et al., 2000; Scholess et al., 1999) thanks to the development of the eddy-covariance method, studies focusing on African ecosystems remain rare. In the last decade, however, the role of African terrestrial ecosystems in global carbon cycle, and thus in global climate change, was increasingly recognized (Bombelli et al., 2009; Ciais et al., 2009; Williams et al., 2007; Houghton and Hackler, 2006). Despite this, the terrestrial ecosystem impact on the global carbon cycle remains less known in Africa than in other continents.

In addition, the role of land-use changes in controlling CO_2 emissions and annual carbon budgets in Africa remains more critical than in any other regions (Houghton and Hackler, 2006). Finally, Africa is found to be a major source of inter-annual variability of atmospheric CO_2 (Ciais et al., 2011; Williams et al., 2007). More than half of this continent is covered by tropical savanna ecosystems (Menaut et al., 1985), which are expected to store enough carbon to play a significant role in the global carbon balance (Ciais et al., 2011; Bombelli et al., 2009; Grace et al., 2006). The African biogenic carbon balance was reported to be a sink of 0.15–1 Pg C yr^{-1} by (Ciais et al., 2009; Bombelli et al., 2009) whereas other authors like Williams et al. (2007) reported a neutral carbon balance for these same ecosystems. These great differences in results, were due fundamentally to methodologies and processes used by each author which were generally proven unsuitable to African sites (Weber et al., 2009; Ciais et al., 2009; Chevallier et al., 2009; Williams et al., 2007). Also, the lack of adequate data contributes to high uncertainties of numerical models, those being developed and validated on other types of ecosystems which are not necessarily representative of African's. Finally, it appears difficult to conclude about Africa carbon budget and thus to specify if Africa acts as a net carbon source or sink. It is therefore desirable to calibrate and validate these models on African ecosystems in order to improve their carbon budget, especially for savanna sites because of their important coverage. In West Africa, there is still a lack of studies on carbon cycle and global climate change, although this region appears particularly to be vulnerable in climate change context (IPCC, 2007). However, only a few studies of carbon dioxide fluxes over the Sudano-Sahelian savannas were reported in this region of Africa, especially in Benin (Mulindabigwi, 2005), in Burkina Faso (Brümmer et al., 2008), in Mali (Merbold et al., 2009) and in Niger (Boulain et al., 2009; Hanan et al., 1998; Moncrieff et al., 1997b; Monteny et al., 1997; Friborg et al., 1997; Verhoef et al., 1996). This context triggered the development of a few projects or programs of green house gas especially CO_2 in West Africa region. Mainly, CarboAfrica network was developed to assess carbon fluxes over a diversity of ecosystems in Africa and centralized dioxide carbon fluxes measurements from independents initiatives. Among them, the AMMA-CATCH[1] program "African Monsoon Multidisciplinary Analysis", initially designed for Hydrological and monsoon studies on West Africa (Lebel et al., 2009; Redelsperger et al., 2006), contributes to CarboAfrica network database. Our study analyzes data acquired during the latter project at a Sudanian savanna in northern Benin. Energy and water vapor fluxes at this site have already been analyzed by Mamadou et al. (2014) and Guyot et al. (2012, 2009).

The main objective of the present study is to analyze CO_2 fluxes by providing an assessment of net carbon exchange at this site. Especially, we aim to: (i) quantify the CO_2 net fluxes exchanged by the ecosystem and its partition between GPP and TER (ii) describe functional responses of nighttime and daytime fluxes to climatic or environmental driving variables, and (iii) estimate finally for the site the annual carbon sequestration together with its uncertainty.

2. Materials and methods

2.1. Site description

The site is located at Nalohou in the Ara watershed (12 km^2 basin), part of Djougou district of Donga catchment (586 km^2) in the Northern Benin (9.74° N, 1.60° E, 449 m). It has been already described by Mamadou et al. (2014), Guyot et al. (2012, 2009) and Blanchard et al. (2007). The site is a cultivated savanna ecosystem (Fig. 1a) submitted to a Sudanian climate at 450 km NW of Cotonou, the Capital of Benin and located in the "*Northern savanna belt*" region as defined according to bioclimatic conditions by Weber et al. (2009). Average precipitation on the 1950–2009 period was 1190 mm (Le Lay and Galle, 2005), 60% of which occurring from July to September, wet season extending generally from April to October (Lawin, 2007).

Nalohou is one of the sites installed in the frame of AMMA-CATCH program. This site is slightly sloping (3%) in S-N direction. The soil at the site is a Luvisol skeleta chromic (FAO classification) (Youssouf and Lawani, 2000). It is composed of 5–13% clay, 77–85% sand and 7–9% silt on surface horizon (0–50 cm depth) and 28–32% clay, 50–56% sand and 12–18% silt in root zone. Nevertheless Loamy-sandy soils are observed in the Ara River bed (Blanchard et al., 2007). The original landscape has been modified by the historic agricultural practices over the past decades in the region. Most of them are undergoing hydric erosion (Seghieri et al., 2009). The floristic inventory shows that the vegetation is heterogeneous and composed particularly during wet season by some woody species (*Parkia biglobosa*, *Dialium guineense*, *Vitellaria paradoxa*, *Isoberlinia doka)*, annual and, in a lesser extent, perennial herbs (*Andropogon guayanus*, *Panicum maximum*, *Hyparrhenia involucrate*, *Andropogon fastigiatus*, *Imperata cylindrica*), crops (*Pennisetum spp*, *Arachis hypogaea*, *Voandzeia subterranea*, *Sorghum bicolor*, *Zea mays*, *Dioscorea spp*, *Manihot esculenta*) and sparse plantations (*Anacardium occidentale*, *Bligia sapida, Tectona grandis*, *Mangifera indica*). On the basis of LANDSAT TM scenes in 2006 (Fig. 1b), the studied zone, i.e., area of 1 km^2 around the measuring point, was considered as constituted by Crops and/or bare soil (42%), Shrubland (51%) and Riparian woodland (7%). Fig. 1b shows the land-use and vegetation distribution around the tower. There are two main wind directions at the site: SW in wet season and NE mainly in dry season. During the wet season, the vegetation was very developed (Fig. 2b) and

[1] http://www.amma-catch.org/.