Agricultural and Forest Meteorology 247 (2017) 520–532

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Research Paper

Patterns and controls of carbon dioxide and water vapor fluxes in a dry forest of central Argentina

Alfredo G. García[a], Carlos M. Di Bella[a,b], Javier Houspanossian[c], Patricio N. Magliano[c], Esteban G. Jobbágy[c], Gabriela Posse[a], Roberto J. Fernández[d], Marcelo D. Nosetto[c,e,*]

[a] Instituto de Clima y Agua, Instituto Nacional de Tecnología Agropecuaria (CIRN-INTA Castelar), Hurlingham, Buenos Aires, Argentina
[b] Departamento de Métodos Cuantitativos, Universidad de Buenos Aires, Facultad de Agronomía, Buenos Aires, Argentina
[c] Grupo de Estudios Ambientales (GEA), IMASL, CONICET & UNSL, San Luis, Argentina
[d] Instituto de investigación Fisiológicas y Ecológicas Vinculado a la Agricultura, IFEVA, CONICET & Univ. Buenos Aires, Argentina
[e] Cátedra de Climatología, Facultad de Ciencias Agropecuarias, Universidad Nacional de Entre Ríos,, Entre Ríos, Argentina

ARTICLE INFO

Keywords:
Eddy covariance
Deforestation
Chaco
Net ecosystem exchange
Carbon balance

ABSTRACT

Covering 16% of global land surface, dry forests play a key role in the global carbon budget. The Southern Hemisphere still preserves a high proportion of its native dry forest cover, but deforestation rates have increased dramatically in the last decades. In this paper, we quantified for the first time the magnitude and temporal variability of carbon dioxide and water vapor fluxes and their environmental controls based on eddy covariance measurements in a dry forest site of central Argentina. Continuous measurements of CO_2 and water vapor exchanges spanning a 15-month period (Dec. 2009 – March 2011) showed that the studied dry forest was a net sink of carbon, with an overall integrated net ecosystem exchange (NEE) of -172 g C m^{-2} (-132.8 g C m^{-2} for year 2010). The cool dry season (May–Sept.) accounted for a quarter of the total annual NEE of year 2010 with low but steady CO_2 uptake rates (1 g C m^{-2} d^{-1} on average) that were more strongly associated with temperature than with soil moisture. By contrast, in the warm wet season (Oct.–April), almost three times greater CO_2 uptake rates (2.7 g C m^{-2} d^{-1} on average) resulted from a highly pulsed behavior in which CO_2 uptake showed sharp increases followed by rapid declines after rainfall events. Cumulative evapotranspiration (ET) during the whole study (595 mm) accounted for most of the rainfall inputs (674 mm), with daily water vapor fluxes during the wet season being four times greater compared to those observed during the dry season (1.7 mm d^{-1} vs. 0.45 mm d^{-1}). Modeling of the partition of all evaporative water losses suggested that transpiration was the dominant vapor flux (67% of ET), followed by interception (20%) and soil evaporation (13%). The influence of air temperature on half-hourly CO_2 fluxes was notably different for the dry and wet seasons. In the 11–34 °C air temperature range, CO_2 uptake rates were higher in the warm wet rather than the cool dry season, yet this difference narrowed with temperatures > 26 °C. The dry forest became a net CO_2 source at 40 °C. Our study provides new insights about the functioning of dry forests and the likely response of their CO_2 and water vapor exchange with the atmosphere under future climate and land use/cover changes.

1. Introduction

Dry forests cover ~16% of global land surface (Olson et al., 2001) and because of land-use changes, fires and climate regime shifts (Fischer et al., 2012; Houspanossian et al., 2016; Smith et al., 2000) are one of the most threatened ecosystems worldwide (Hoekstra et al., 2005). The South American dry forests of Chaco and Espinal, extending over 1.4 million km^2, are no exception to these trends. This region encompass the second forest extension in South America after Amazonia, still preserving most of their area (~70%) covered by native vegetation (Houspanossian et al., 2016). However, deforestation rates have sped up dramatically in the last two decades, achieving record rates worldwide (Hansen et al., 2013; Vallejos et al., 2015). The region is also experiencing noticeable climatic changes which interact with technological and socioeconomic factors to drive land use changes (Zak et al., 2008). The understanding of carbon dioxide and water vapor fluxes patterns and their controls over such vast forests, is particularly important given the size of the carbon stocks that they host and the significance of their water fluxes shaping landscape hydrology and continental climate (Marchesini et al., 2016; Saulo et al., 2007).

* Corresponding author at: Grupo de Estudios Ambientales, Instituto de Matemática Aplicada San Luis, Italia 1556 – Ciudad de San Luis (5700), Argentina.
E-mail addresses: marcelo.nosetto@gmail.com, mnosetto@unsl.edu.ar (M.D. Nosetto).

http://dx.doi.org/10.1016/j.agrformet.2017.08.015
Received 19 February 2017; Received in revised form 10 August 2017; Accepted 14 August 2017
0168-1923/

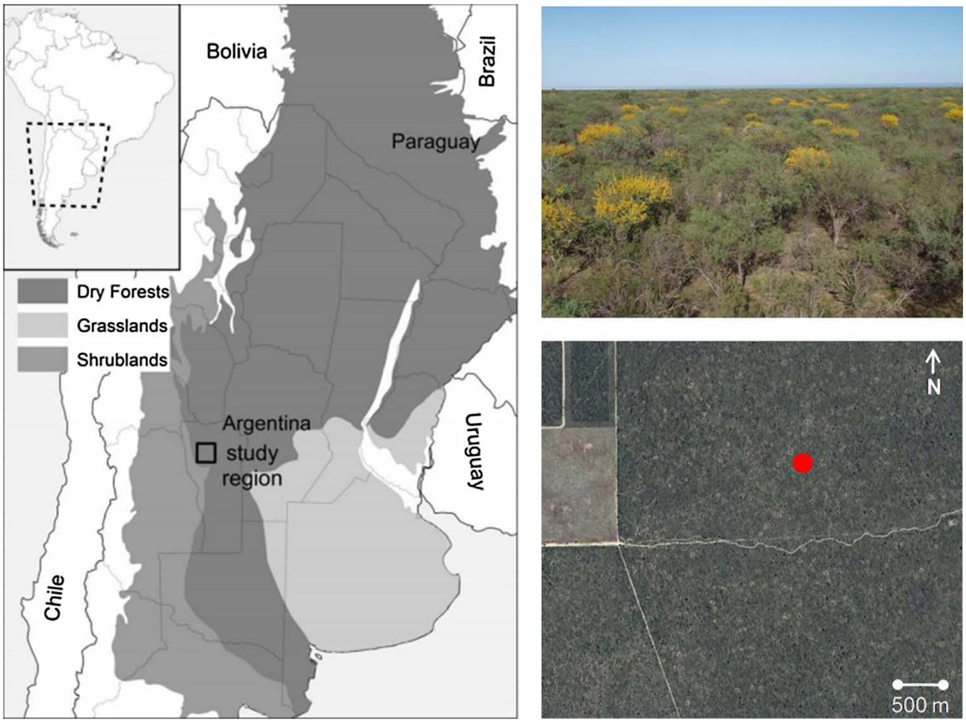

Fig. 1. Location of the study region in the dry forests of central Argentina. The original extension of the dominant biomes of the region is indicated on the map on the left. On the right, a Google Earth image (bottom) and a photograph taken at the field (top) show a typical dry forest stand. The red dot on the Google Earth image indicates the location of the measurement tower. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In the last decades, there has been much effort to understand carbon dioxide and water vapor fluxes and their controls based on eddy covariance towers (Baldocchi et al., 2001). However, the majority of these studies have investigated systems that were expected to be more productive and/or have greater potential for carbon sequestration, such as moist forests and crops (Running et al., 1999), while water-limited ecosystems, like dry forests, have been underrepresented (Buchmann and Schulze, 1999). Particularly in South America, CO_2 flux measurements are rather sparse and have been mostly devoted to the Amazonian forests. Recent studies have shown that dry forests, and particularly those from South America and Australia, can have a strong influence on the global carbon budget, even stronger than tropical rainforests (Poulter et al., 2014).

As in most water-limited ecosystems, rainfall, and consequently soil moisture, is a key driver of biological activity of South America dry forests (Contreras et al., 2011; Ferrero et al., 2013). However, the individual responses of different CO_2 fluxes (i.e. Gross Ecosystem Productivity, GEP; Ecosystem Respiration, R_{eco}) to rainfall and soil moisture are unknown in this kind of ecosystems, as well as their relative responsiveness to water inputs during dry and more dormant vs. wet and more active seasons. It is generally believed that in water-limited ecosystems, the net ecosystem exchange (i.e. NEE = R_{eco} – GEP) is positive during the dry season (i.e. carbon source), which means that respiratory CO_2 losses are higher than CO_2 accumulation fluxes; while the opposite occurs during the wet season (i.e. carbon sink) (e.g. Hastings et al., 2005; Luo et al., 2007; Scott et al., 2006). However, some evergreen shrubs (e.g. *Larrea divaricata)* and deep-rooted tree species which can be very abundant in the dry forests of southern South America (e.g. *Aspidosperma quebracho blanco*) may use water stored deeply in the soil (Gimenez et al., 2016; Jobbágy et al., 2008) being able to sustain low photosynthesis rates during rainfall shortage periods. Moreover, although it is acknowledged that higher rainfall inputs translate into higher primary productivity rates, the responses of respiration and photosynthesis fluxes to discrete and infrequent rainfall events (i.e. pulses, Schwinning and Sala, 2004) are not completely understood when shorter timescales (e.g. days, weeks) are considered, as they are highly dependent on the timing and magnitude of precipitation events (Huxman et al., 2004; Scott et al., 2009). Such knowledge is critical to improve global carbon budgets and ecosystem modeling, to predict climatic change impacts and to design management strategies.

Dry forests play also a key role in regional hydrological balances. Several studies worldwide have shown that evaporation from dry forests almost balances precipitation inputs, resulting in negligible deep drainage fluxes, deep water-table levels and large salt stocks in the vadose zone (Santoni et al., 2010; Scanlon et al., 2005; Seyfried et al., 2005). When crops or pastures replace dry forests, declines of evaporation rates and increases of deep drainage flux are commonly observed. In the long term, this has triggered the onset of groundwater recharge, water-table rise and soil salinization over large extensions (George et al., 1997; Leduc et al., 2001; Scanlon et al., 2005). Recent studies in Argentina confirm the exhaustive use of rainfall inputs in the long term leading to the presence of dry soil profiles with large salt stocks under dry forests (Amdan et al., 2013; Gimenez et al., 2016; Jayawickreme et al., 2011; Santoni et al., 2010). Yet, the short term behavior of water vapor fluxes in these ecosystems, their response to rainfall and soil moisture pulses and their link with the ecosystem CO_2 exchange are still poorly understood.

The main goals of this study were: a) to quantify for the first time the magnitude and temporal variability of CO_2 and water vapor exchange with the atmosphere from eddy covariance measurements in a dry forest of central Argentina, and b) to analyze how CO_2 and water vapor fluxes respond to different environmental factors, with focus on soil moisture and temperature. Given the arid conditions of the studied dry forest (mean rainfall is less than a quarter of mean potential evapotranspiration, $PP/ET_o = 0.23$), we hypothesize that soil moisture is the main driver of CO_2 and water vapor fluxes and that this influence exacerbates during the dry season. We also expected the forest to switch from a carbon source under the extreme aridity of the dry season ($PP/ET_o = 0.09$) into a carbon sink during the wet season ($PP/ET_o = 0.34$). We performed continuous measurements of CO_2 and water vapor during a 15-month period (Dec. 2009 – March 2011) in a representative dry forest stand in central Argentina. These measurements were complemented with field and satellite observations in order to evaluate the main environmental drivers of CO_2 and water vapor fluxes and to assess the leaf area seasonality of the site.