ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
v.20, n.9, p.777-782, 2016
Campina Grande, PB, UAEA/UFCG – http://www.agriambi.com.br

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v20n9p777-782

Daily and seasonal patterns of CO_2 fluxes and evapotranspiration in maize-grass intercropping

Cássia B. Machado[1], José R. de S. Lima[2], Antonio C. D. Antonino[3],
Eduardo S. de Souza[4], Rodolfo M. S. Souza[3] & Edevaldo M. Alves[5]

[1] Universidade Federal de Pernambuco/Centro de Tecnologia e Geociências/Programa de Pós-Graduação em Engenharia Civil. Recife, PE. E-mail: cassiabmachado@gmail.com
[2] Universidade Federal Rural de Pernambuco/Unidade Acadêmica de Garanhuns/Programa de Pós-Graduação em Produção Agrícola. Garanhuns, PE. E-mail: romualdo.lima@ufrpe.br (Corresponding author)
[3] Universidade Federal de Pernambuco/Centro de Tecnologia e Geociências/Programa de Pós-Graduação em Tecnologias Energéticas e Nucleares. Recife, PE. E-mail: acda@ufpe.br, rodolfomssouza@gmail.com
[4] Universidade Federal Rural de Pernambuco/Unidade Acadêmica de Serra Talhada/Programa de Pós-Graduação em Produção Vegetal. Serra Talhada, PE. E-mail: edu_souza_pe@yahoo.com.br
[5] Universidade Federal de Pernambuco/Centro Acadêmico do Agreste. Caruaru, PE. E-mail: edevaldofisica@gmail.com

---

Key words:
eddy covariance
carbon
climate change

ABSTRACT

Studies that investigate the relationships between CO_2 fluxes and evapotranspiration (ET) are important for predicting how agricultural ecosystems will respond to climate changes. However, none was made on the maize-grass intercropping system in Brazil. The aim of this study was to determine the ET and CO_2 fluxes in a signal grass pasture intercropped with maize, in São João, Pernambuco, Brazil, in a drought year. Furthermore, the soil water storage (SWS) and leaf area index (LAI) were determined. The latent heat flux was the main consumer of the available energy and the daily and seasonal ET and CO_2 variations were mainly controlled by rainfall, through the changes in soil water content and consequently in SWS. The agroecosystem acted as an atmospheric carbon source, during drier periods and lower LAI, and as an atmospheric carbon sink, during wetter periods and higher LAI values. In a dry year, the intercropping sequestered 2.9 t C ha^{-1}, which was equivalent to 8.0 kg C ha^{-1} d^{-1}. This study showed strong seasonal fluctuations in maize-grass intercropping CO_2 fluxes, due to seasonality of rainfall, and that this agroecosystem is vulnerable to low SWS, with significant reduction in CO_2 uptake during these periods.

Palavras-chave:
correlação dos turbilhões
carbono
mudança climática

Variação diária e sazonal dos fluxos de CO_2 e evapotranspiração no consórcio milho-pastagem

RESUMO

Estudos que investiguem a relação entre os fluxos de CO_2 e a evapotranspiração (ET) são importantes para predizer como os agroecossistemas responderão às mudanças climáticas globais porém até o momento nenhum foi realizado no consórcio milho-pastagem no Nordeste do Brasil razão por que o objetivo desta pesquisa foi determinar a ET e os fluxos de CO_2 no consórcio milho-braquiária em São João, PE, em um ano de seca. Também foram medidos o armazenamento de água no solo (AAS) e o índice de área foliar (IAF). O fluxo de calor latente foi o principal consumidor da energia disponível e as variações da ET e dos fluxos de CO_2 foram controladas pela precipitação pluvial, por meio das mudanças na umidade do solo e, consequentemente, no AAS. O consórcio atuou como fonte de CO_2 atmosférico durante os períodos mais secos e de menor IAF e atuou como sumidouro de CO_2 atmosférico durante os períodos mais úmidos e de maior IAF. Em um ano seco o consórcio sequestrou 2,9 t C ha^{-1} o equivalente a 8,0 kg C ha^{-1} d^{-1}. Esta pesquisa constatou que há fortes flutuações sazonais nos fluxos de CO_2 do consórcio devido à sazonalidade da precipitação pluvial demonstrando que este agroecossistema é vulnerável aos baixos AAS com redução significante do sequestro de CO_2 atmosférico, durante esses períodos.

Ref. 114-2015 – Received 28 Jul, 2015 • Accepted 14 Jul, 2016 • Published 3 Aug, 2016

Introduction

Long-term flux measurements of different crop species are necessary to improve our understanding of management and climate effects on carbon flux variability as well as cropland potential in terrestrial carbon sequestration (Béziat et al., 2009). Quantifying carbon dioxide (CO_2) fluxes in terrestrial ecosystems is critical for better understanding of global carbon cycling and observed changes in climate (Hernandez-Ramirez et al., 2011).

Many studies have been conducted in various global ecosystems, which have measured CO_2, water and energy fluxes. However, most studies have focused on forest ecosystems and grasslands (Aires et al., 2008; Merbold et al., 2009; Otieno et al., 2010; Wolf et al., 2011; Krishnan et al., 2012; Zhang et al., 2014) and only a minority has concentrated on croplands, as example maize and soybean (Béziat et al., 2009; Hernandez-Ramirez et al., 2011; Moreira et al., 2015).

In Brazil, these studies focus mainly on rain forest and grass (Randow et al., 2004; Meirelles et al., 2011) and none measured these fluxes in maize-grass intercropping system using the eddy covariance method in semiarid lands of Brazil. Thus, it is not clear how much carbon could be captured by the maize-grass intercropping system in semiarid regions of Brazil.

Here, a micrometeorological experiment over maize-grass intercropping system was conducted in the northeastern region of Brazil from January to December 2013 to improve the current understanding of CO_2, water and energy exchanges over this ecosystem. Therefore, the main objectives of the present work are: (1) to quantify the seasonal and diurnal variations in the CO_2, energy and water fluxes over the maize-grass intercropping and (2) to understand the biotic and abiotic factors controlling these fluxes in this agroecosystem in a drought year.

Material and Methods

The water, energy and CO_2 fluxes were measured in an area cultivated with signal grass (*Brachiaria decumbens* Stapf) intercropped with maize (*Zea mays* L.). The area of study was in São João, Pernambuco, Brazil (8° 52' S; 36° 22' W; 705 m).The climate is hot and humid, with average annual rainfall of 782 mm, and the wettest trimester consists of the months of May, June and July and the soil is classified as Regolithic Neosol (Gondim et al., 2015).

In 2012, one of the worst droughts recorded in the last 50 years occurred in this region. Consequently, the grassland that was planted in 2000 was destroyed. To recover these grasslands for grazing, the producer planted maize intercropped with signal grass on June12, 2013. Maize was sown with a spacing of 1.0 m between rows, with seven seeds per meter. Between the rows of maize, two rows of signal grass were sown. Maize emergence occurred on June 27, 2013, and harvested on September 14, 2013. Maize was planted with signal grass to recover the pasture in the system known as "Santa Fé". This system is one of the most frequently used cultivation systems for recovering pastures in this region.

This study was conducted throughout the year of 2013, considering three sub-periods: the no cropped period (from January 1 to June 27); the intercropping period (from June 28 to September 14) and the grass alone period (from September 15 to December 31).

Soil water content was measured at depths of 0.10, 0.20, 0.30, 0.40 and 0.50 m using a water content reflectometer (model CS 615, Campbell Scientific Inc., Logan, UT, USA) and then the soil water storage (SWS) was calculated for the layer of 0-0.50 m, according to Lima et al. (2013).

The leaf area index (LAI) was determined seven times for maize and eight times for grass, at approximately fifteen-day intervals from June to December 2013 in five 1 m^2 plots. The LAI was obtained using an automatic leaf area meter (model LI-300, LI-COR Inc., Lincoln, NE, USA).

Meteorological and eddy covariance measurements were made at a height of 1.5 m above the maize/grass layer by a tower installed in the center of an area (420 x 400 m) that had a flat topography. The height of the sensors increased as the maize/grassland grew taller over the study period, such that the distance between the sensors and the crops did not change.

The tower was equipped with sensors to measure wind speed and direction (model 034B Windset, Campbell Scientific Inc., Logan, UT, USA), relative humidity and air temperature (model HMP45C, Vaisala, Campbell Scientific Inc., Logan, UT, USA) and rainfall (model TE 525WS-L, Texas Electronics, Dallas, TX, USA).The solar global radiation (Rs) was measured with a pyranometer (model LI-200X, LI-COR Inc., Lincoln, NE, USA) and net radiation (Rn) was measured with a net radiometer (model NR-Lite, Kipp & Zonen, Campbell Scientific Inc., Logan, UT, USA). Soil heat flux (G) was measured at depth of 0.02 m by using one soil heat flux plate (model HFT3, REBS, Seattle, WA, USA). The measurements from all of the sensors were recorded by a data logger (model CR1000, Campbell Scientific Inc., Logan, UT, USA) every 60 s. The mean/sum data were logged every 1800 s. The tower also was equipped with a measurement system of eddy covariance, which consisted of a three-dimensional sonic anemometer (model CSAT3, Campbell Scientific Inc., Logan, UT, USA) and a fast response CO_2/H_2O infrared gas analyzer anemometer (model EC-150, Campbell Scientific Inc., Logan, UT, USA). These data were recorded at a rate of 10.0 Hz.

The latent heat (LE W m^{-2}), sensible heat (H, W m^{-2}) and carbon dioxide (CO_2, μmol m^{-2} s^{-1}) fluxes were calculated using the eddy covariance method. The CO_2, LE and H were obtained from Eqs. 1, 2 and 3, respectively.

$$CO_2 = \rho \overline{w'c'} \tag{1}$$

$$H = \rho c_p \overline{w'T'} \tag{2}$$

$$LE = \rho \lambda \overline{w'q'} \tag{3}$$

where:

ρ - air density, kg m^{-3};
w' - vertical wind velocity, m s^{-1};
c' - carbon dioxide concentration, μmol m^{-2} s^{-1};
c_p - the specific heat of air at constant pressure, J kg^{-1} K^{-1};
T' - air temperature, °C; and,
λ - latent heat of vaporization, MJ kg^{-1}.

Turbulent fluxes were corrected for inadequate sensor frequency response following standard methods (Aubinet et al., 2000; Moreira et al., 2015).

The evapotranspiration (ET, mm d^{-1}) was calculated by dividing the latent heat flux (MJ m^{-2} d^{-1}) by the latent heat of vaporization (MJ kg^{-1}), according to Lima et al. (2013). The reference evapotranspiration (ETo, mm d^{-1}) was determined by the Penman-Monteith model (Allen et al., 1998).

RESULTS AND DISCUSSION

The daily average of air temperature and vapor pressure deficit and daily total of rainfall and soil water storage are shown in Figure 1. The maximum air temperature was 26.3 °C, minimum air temperature was 17.4 °C and an average air temperature was 21.4 °C. Little variation in air temperature was observed during the study period (Figure 1A).

The vapor pressure deficit (VPD) was associated with the air temperature and rainfall. During periods of lower temperature and higher rainfall, the VPD was lower, and vice versa. Krishnan et al. (2012) examined the seasonal and interannual variability of the energy balance of the two grasses in Arizona (a semiarid region) and found that the VPD varied from 1.47 to 1.98 kPa, with the highest values occurring during the periods with higher temperatures.

A total rainfall of 416.8 mm (Figure 1B) occurred during the study period, which corresponded to 65% of the normal climatologic precipitation in this region during the studied months, showing that 2013 also was a dry year. The maximum rainfall of 28.0 mm occurred on April 28, 2013. The month of July had the highest amount of precipitation (76.2 mm), followed by April (58.5 mm) and June (54.7 mm). The soil water storage (SWS) was higher in June and July 2013 and lower between January and March and from September to December 2013. This result corresponded with the rainfall (Figure 1B).

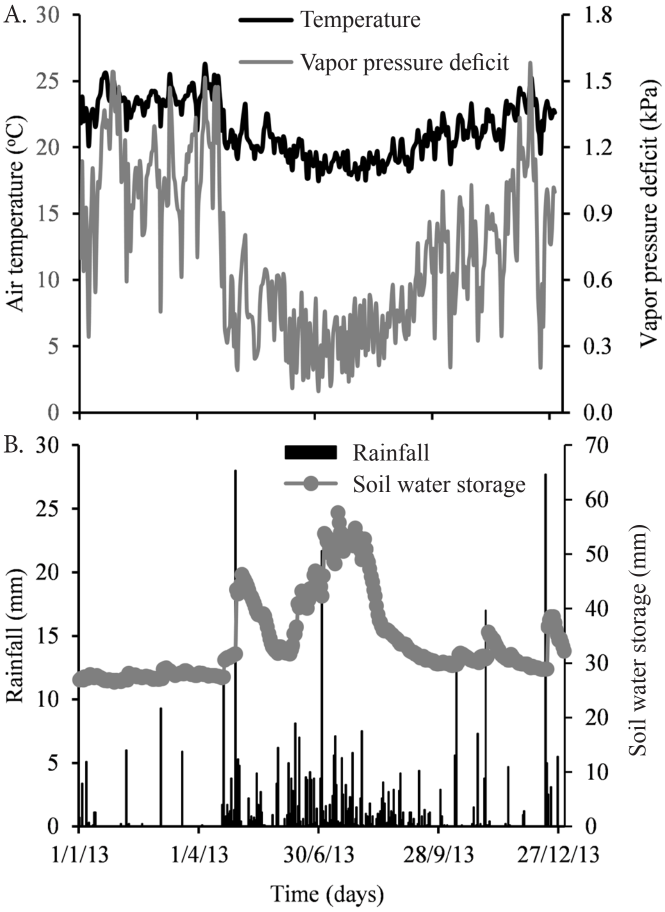

Figure 1. (A) Average air temperature (°C) and vapor pressure deficit (kPa), (B)rainfall (mm) and soil water storage (mm) during the period from January 1 to December 31, 2013, in the maize-grass intercropping

All of the above-mentioned factors (air temperature, VPD, rainfall and SWS) followed a seasonal cycle. In wettest months (April, May, June, July and August) with lower air temperatures, the VPD was lower and the SWS was higher due to the more frequent rainfall events. The opposite trend occurred from January to March and from September to December. These seasonal meteorological and soil variations have been observed by many authors (Aires et al., 2008; Meirelles et al., 2011), who have studied water and energy fluxes on pastures across many regions around the world.

Regarding LAI, the highest value (2.59 m^2 m^{-2}) was obtained for maize 48 days after planting (July 30, 2013). For the period of intercropping system, the highest LAI occurred on September 13, 2013 (0.63 m^2 m^{-2}). For grass alone, the highest LAI occurred December 12, 2013 and was 0.68 m^2 m^{-2} (Table 1). Gondim et al. (2015) studied LAI in grass in the same region and found similar results.

Seasonal variations of energy balance components, i.e., net radiation (Rn), latent heat (LE), sensible heat (H) and soil heat (G) fluxes are shown in Figure 2. The data in Figure 2 represent daily averaged values.

The Rn showed greater variation and lower values in July due to the higher rainfall and greater cloud cover. The highest Rn values occurred from January to March and from September to December. The daily average Rn value was 137 W m^{-2}. Aires et al. (2008) observed the same pattern of seasonality in Rn when measuring energy fluxes in a pasture comprised of C3/C4 plants in southeastern Portugal. Regarding G, the daily values varied from -11.6 to 9.7 W m^{-2} (-1.0 to 0.84 MJ m^{-2} d^{-1}) with an average value of 0.18 W m^{-2} (0.02 MJ m^{-2} d^{-1}). Gondim et al. (2015) determined the energy fluxes of pasture (*Brachiaria decumbens* L.) and observed a mean G value of 0.61 MJ m^{-2} d^{-1}.

The variations of LE and H can be due to the variations of rainfall and SWS (Figure 1B) because LE was greater than H during periods of greater water availability (higher rainfall and SWS). The opposite trend occurred at the start (January to March) and end (September to December) of the experiment when the amount of rainfall and SWS decreased.

Table 1. Leaf area index (LAI) of maize and signal grass during the period from July 6 to December 12, 2013, in the maize-grass intercropping

Date	LAI (m^2 m^{-2})	
	Maize	Brachiaria
July 06 2013	0.27	
July 25 2013	1.81	
July 30 2013	2.59	0.06
Aug 06 2013	2.24	0.05
Aug 23 2013	1.40	0.15
Sept 06 2013	0.62	0.51
Sept 13 2013	0.57	0.63
Nov 02 2013		0.39
Nov 22 2013		0.60
Dec 12 2013		0.68

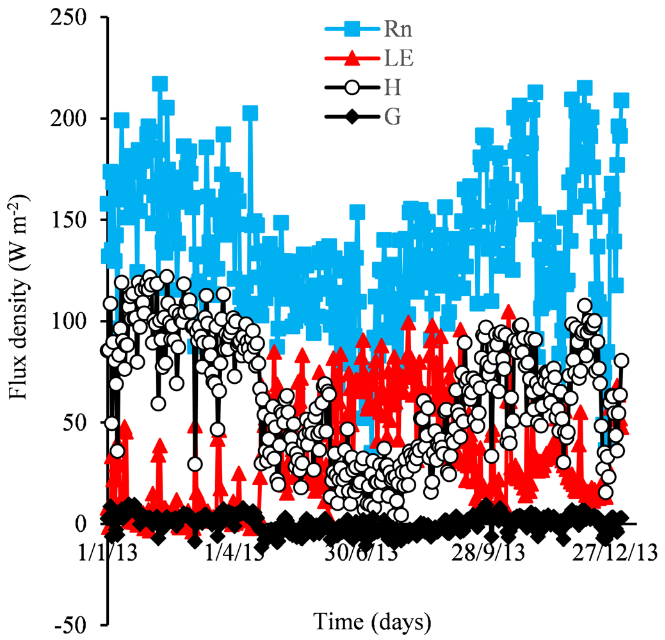

Figure 2. Energy fluxes of maize-grass intercropping during the period from January 1 to December 31, 2013

Randow et al. (2004) studied the components of the energy balance of *Brachiaria brizantha* in the Amazon and observed that the highest values of H occurred during the dry season and highest values of LE occurred during the wet season, which corresponded with our results, in spite of great climate differences between semiarid and Amazon regions.

Higher values of LE correspond with more energy being directed to the process of soil evaporation and plant transpiration (ET). In contrast, higher H correspond to the use of more energy for heating air. Therefore, from January to March and from September to December, most of the available energy in the maize-grass intercropping system was used to heat the air (H). This result can be explained by the decreased rainfall and SWS at the beginning of the dry season (Figure 1B). Krishnan et al. (2012) also observed higher H values in grasslands during the dry season.

Actual (ET) and reference (ETo) evapotranspiration in maize-grass intercropping during the period from January to December 2013 are represented in Figure 3.

The ETo varied from 1.6 to 7.0 mm d^{-1}, with a mean of 4.0 mm d^{-1}. The maximum ETo (above 3.5 mm d^{-1}) values occurred from January to March and from September to December, most likely due to the higher air temperature, VPD (Figure 1A) and Rn (Figure 2). However, in the late autumn and winter, due to the low atmospheric demand, the minimum values of ETo (1.5 to 3.0 mm d^{-1}) occurred. These results are according to Gondim et al. (2015), who measured the ETo values for same region of this research.

The ET varied from 0.1 to 4.0 mm d^{-1} with an average value of 1.2 mm d^{-1}. The maximum ET values (3.0 to 4.0 mm d^{-1}) occurred during the periods of higher SWS (June, July and August). Meirelles et al. (2011) measured the ET of *Brachiaria brizantha* using the same methodology of this research (eddy covariance). These authors found that the ET varied from 1.6 to 4.3 mm d^{-1}, with an average value of 2.6 mm d^{-1}. In addition, these authors found that the maximum ET values occurred during the periods of higher soil moisture. Krishnan et al. (2012) studied two grassland areas in a semiarid climate over four years and observed ET values of 2.8 to 3.6 mm d^{-1}.

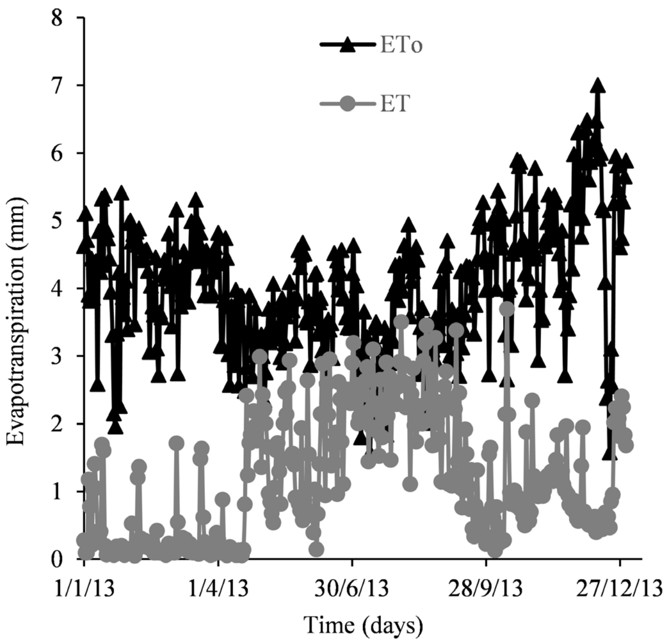

Figure 3. Actual (ET) and reference (ETo) evapotranspiration in maize-grass intercropping during the period from January 1 to December 31, 2013

The seasonal variation of CO_2 fluxes and SWS are shown in Figure 4.

In the period from January 1 to June 12 2013, when the area was not cropped as well as in the period when maize emerged (from June 13 to 27, 2013), the major part of the CO_2 fluxes was positive, with an average of 0.37 µmol m^{-2} s^{-1}. Thus, the area served as a carbon source, emitting 0.69 t C ha^{-1} in a period of 179 days (January 1 to June 27, 2013).

At the beginning of the intercropping, when the SWS was low, maize was in its early growth stage with a low LAI, and the signal grass had not yet emerged (Table 1), the CO_2 fluxes were positive, reaching values of 0.58 µmol m^{-2} s^{-1}.However, when maize had a greater LAI, the signal grass had emerged and the SWS was greater than 40 mm, the CO_2 fluxes were lower.

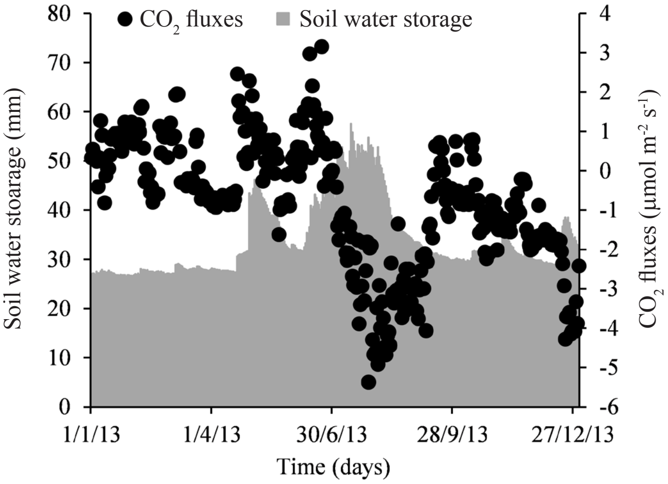

Figure 4. Soil water storage (SWS) and CO_2 fluxes in the maize-grass intercropping during the period from January 1 to December 31, 2013

The period from July 26 to September 14, 2013, had the lowest values of CO_2 (negative values), average of -3.08 μmol m^{-2} s^{-1}, indicating that the intercropping system acted as a carbon sink. In this same period, 1.63 t C ha^{-1} was sequestered, which was equivalent to 31.9 kg C ha^{-1} d^{-1}.

After the harvest of maize (from September15 to December 31, 2013), period of signal grass alone, the values of CO_2 showed a tendency of decrease, but still remained negative, with average of -1.33 μmol m^{-2} s^{-1}, which corresponds to 13.8 kg C ha^{-1} d^{-1}.

During the experimental period, the average value of CO_2 fluxes was -0.78 μmol m^{-2} s^{-1}, which corresponded to a carbon sequestration of 2.9 t C ha^{-1} and 8.0 kg C ha^{-1} d^{-1}. Several studies (Randow et al., 2004; Wolf et al., 2011; Zhang et al., 2014) have shown that the CO_2 flux values in pastures tend to be negative (i.e., pastures usually act as a sink for CO_2).

The results obtained in this study agree with those obtained by Randow et al. (2004), who measured CO_2 fluxes in pastures and forests in the Amazon region and found an average day time CO_2 flux of -11.2 μmol m^{-2} s^{-1} in the pastures during the wet season and -7.6 μmol m^{-2} s^{-1} during the dry season. On the other hand, Wolf et al. (2011), who measured the CO_2 fluxes in pastures in Panama, found values ranging from 5.6 (dry season) to -24.5 (wet season) μmol m^{-2} s^{-1}. Despite the great difference of climate between Amazon and Northeast regions, the data of our study showed results similar to those of Randow et al. (2004) and Wolf et al. (2011), once that CO_2 fluxes were also higher in the wet season compared with the dry season.

This behavior of CO_2 fluxes can be explained by the higher SWS (Figures 1B and 4) and LAI for the signal grass and maize (Table 1), which probably promoted higher water absorption, increasing the LE and ET (Figures 2 and 3), due to increased photosynthesis. Consequently, the increased photosynthesis resulted in greater carbon absorption from the atmosphere (Figure 4).

Several authors have observed results similar to those our research. Merbold et al. (2009) compared ecosystem fluxes across a range of vegetation types and climate zones of Africa and found that maximum carbon assimilation rates were highly correlated with mean annual rainfall. On the other hand, Otieno et al. (2010) observed a strong correlation between the CO_2 fluxes and soil water content and concluded that the savanna grassland is vulnerable to low soil moisture, with significant reduction in CO_2 uptake during drought, as observed in this study.

The variation between the crops regarding their roles as a carbon source or sink will depend on several factors related to the weather (higher or lower rainfall, solar radiation, air temperature, etc.), the type of plant (C3 or C4 metabolism), pasture condition, soil water storage, among others. For example, Zhang et al. (2014) showed, in a study of 11 years in temperate grasslands in China, that carbon sequestration occurred, but the ability of the grassland to sequester carbon depended on the type of the pasture and the environmental conditions. In addition, an extreme climate event, such as drought, can significantly reduce carbon sequestration, as observed in periods of lower rainfall and soil water storage (Figures 1B and 4) in this research.

CONCLUSIONS

1. The daily and seasonal variations of ET and CO_2 fluxes were mainly controlled by rainfall, through the changes in soil water content and consequently in soil water storage.

2. There were strong seasonal fluctuations in CO_2 fluxes of maize-grass intercropping, with significant reduction in CO_2 uptake during periods of low rainfall and soil water storage.

3. In a drought year, the intercropping sequestered 2.9 t C ha^{-1}, which was equivalent to 8.0 kg C ha^{-1} d^{-1}.

ACKNOWLEDGMENTS

The authors thank CNPq (475094/2009-3; 307641/2013-9; 312218/2013-3), FACEPE (IBPG-0896-5.01/11; APQ-0077-5.01/09; APQ-1178-3.01/10) and FINEP (551922/2011-7). We thank Prof. A. P. F. Montenegro for the assignment of the experimental field.

LITERATURE CITED

Aires, L. M.; Pio, C. A.; Pereira, J. S. The effect of drought on energy and water vapour exchange above a mediterranean C3/C4 grassland in Southern Portugal. Agricultural and Forest Meteorology, v.148, p.565-579, 2008. http://dx.doi.org/10.1016/j.agrformet.2007.11.001

Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M. Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: FAO, 1998. 300p. FAO Irrigation and Drainage Paper, 56

Aubinet, M.; Grelle, M. A.; Ibrom, A.; Rannik, Ü.; Moncrieff, J.; Foken, T.; Kowalski, A. S.; Martin, P. H.; Berbigier, P.; Bernhofer, C. H.; Clement, R.; Elbers, J.; Granier, A.; Grünwald, T.; Morgenstern, K.; Pilegaard, K.; Rebmann, C.; Snijders, W.; Valentini, R.; Vesala, T. Estimates of the annual net carbon and water exchange of forests: The EUROFLUX methodology. Advances in Ecological Research, v.30, p.113-175, 2000. http://dx.doi.org/10.1016/S0065-2504(08)60018-5

Béziat, P.; Ceschia, E.; Dedieu, G. Carbon balance of a three crop succession over two cropland sites in South West France. Agricultural and Forest Meteorology, v.149, p.1628-1645, 2009. http://dx.doi.org/10.1016/j.agrformet.2009.05.004

Gondim, P. S. S.; Lima, J. R. S.; Antonino, A. C. D.; Hammecker, C.; Silva, R. A. B.; Gomes, C. A. Environmental control on water vapor and energy exchanges over grasslands in semiarid region of Brazil. Revista Brasileira de Engenharia Agrícola e Ambiental, v.19, p.3-8, 2015. http://dx.doi.org/10.1590/1807-1929/agriambi.v19n1p3-8

Hernandez-Ramirez, G.; Hatfield, J. L.; Parkin, T. B.; Sauer, T. J.; Prueger, J. H. Carbon dioxide fluxes in corn–soybean rotation in the midwestern U.S.: Inter- and intra-annual variations, and biophysical controls. Agricultural and Forest Meteorology, v.151, p.1831-1842, 2011. http://dx.doi.org/10.1016/j.agrformet.2011.07.017

Krishnan, P.; Meyers, T. P.; Scott, R. L.; Kennedy, L.; Heuer, M. Energy exchange and evapotranspiration over two temperate semi-arid grasslands in North America. Agricultural and Forest Meteorology, v.153, p.31-44, 2012. http://dx.doi.org/10.1016/j.agrformet.2011.09.017

Lima, J. R. S.; Antonino, A. C. D.; Souza, E. S.; Lira, C. A. B. O.; Silva, I. F. Seasonal and interannual variations of evapotranspiration, energy exchange, yield and water use efficiency of castor grown under rainfed conditions in northeastern Brazil. Industrial Crops and Products, v.50, p.203-211, 2013. http://dx.doi.org/10.1016/j.indcrop.2013.07.012

Meirelles, M. L.; Franco, A. C.; Farias, S. E. M.; Bracho, R. Evapotranspiration and plant–atmospheric coupling in a *Brachiaria brizantha* pasture in the Brazilian savannah region. Grass and Forage Science, v.66, p.206-213, 2011. http://dx.doi.org/10.1111/j.1365-2494.2010.00777.x

Merbold, L.; Ardo, J.; Arneth, A.; Scholes, R. J.; Nouvellon, Y.; Grandcourt, A. de; Archibald, S.; Bonnefond, J. M.; Boulain, N.; Bruemmer, C.; Brueggemann, N.; Cappelaere, B.; Ceschia, E.; El-Khidir, H. A. M.; El-Tahir, B. A.; Falk, U.; Lloyd, J.; Kergoat, L.; Ledantec, V.; Mougin, E.; Muchinda, M.; Mukelabai, M. M.; Ramier, D.; Roupsard, O.; Timouk, F.; Veenendaal, E. M.; Kutsch, W. L. Precipitation as driver of carbon fluxes in 11 African ecosystems. Biogeosciences, v.5, p.4071-4105, 2009. http://dx.doi.org/10.5194/bgd-5-4071-2008

Moreira, V. S.; Roberti, D. R.; Minella, J. P.; Gonçalves, L. G. G.; Candido, L. A.; Fiorin, J. E.; Moraes, O. L. L.; Timm, A. U.; Carlesso, R.; Degrazia, G. A. Seasonality of soil water exchange in the soybean growing season in southern Brazil. Scientia Agricola, v.72, p.103-113. 2015. http://dx.doi.org/10.1590/0103-9016-2014-0056

Otieno, D. O.; K'Otuto, G. O.; Maina, J. N.; Kuzyakov, Y.; Onyango, J. C. Responses of ecosystem carbon dioxide fluxes to soil moisture fluctuations in a moist Kenyan savanna. Journal of Tropical Ecology, v.26, p.605-618, 2010. http://dx.doi.org/10.1017/S0266467410000416

Randow, C. von; Manzi, A. O.; Kruijt, B.; Oliveira, P. J.; Zanchi, F. B.; Silva, R. L.; Hodnett, M. G.; Gash, J. H. C.; Elbers, J. A.; Waterloo, M. J.; Cardoso, F. L.; Kabat, P. Comparative measurements and seasonal variations in energy and carbon exchange over forest and pasture in South West Amazonia. Theoretical and Applied Climatology, v.78, p.5-26, 2004. http://dx.doi.org/10.1007/s00704-004-0041-z

Wolf, S.; Eugster, W.; Potvin, C.; Buchmann, N. Strong seasonal variations in net ecosystem CO_2 exchange of a tropical pasture and afforestation in Panama. Agricultural and Forest Meteorology, v.151, p.1139-1151, 2011. http://dx.doi.org/10.1016/j.agrformet.2011.04.002

Zhang, L.; Guo, H.; Ji, G.; Wylie, B.; Gilmanov, T.; Howard, D.; Ji, L.; Xiao, J.; Li, J.; Yuan, W.; Zhao, T.; Chen, S.; Zhou, G.; Kato, T. Net ecosystem productivity of temperate grasslands in northern China: An upscaling study. Agricultural and Forest Meteorology, v.184, p.71-81, 2014. http://dx.doi.org/10.1016/j.agrformet.2013.09.004