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Study of CO2 flux and soil carbon in northern Pantanal, Brazil

The determination of greenhouse gas emissions from wetlands are of great interest given the biogeochemistry these areas exhibit. We measure soil CO2 concentration and monthly fluxes on a tree island of the Northern Pantanal of Mato Grosso, Brazil, and estimate the role of soil as a carbon source or sink during high tide, low tide, flooding, and drought seasons. The average value of the CO2 fluxes in the wetland soil was 0.54 ± 0.30 g (CO2)·m- 2·h- 1 with the soil acting as a carbon source at -9.11 ton.·ha-1 over the one year cycle. Soil CO2 fluxes were significantly correlated with soil moisture and temperature at 5 cm depth. Soil CO2 concentrations reached more than 100 ppm. Soil carbon stocks did not correlate significantly with variables in this study, suggesting that non-measured variables can influence soil carbon dynamics.

Keywords: Ecosystem Dynamics; Tropical Soils; Wetland.

Estudo do fluxo de CO2 e carbono do solo no norte do Pantanal, Brasil

A determinação das emissões de gases de efeito estufa das áreas úmidas é de grande interesse, dada a biogeoquímica que essas áreas exibem. Medimos a concentração de CO2 no solo e os fluxos mensais em uma ilha arbórea do Pantanal Norte do Mato Grosso, e estimamos o papel do solo como fonte ou sumidouro de carbono durante as estações de maré alta, baixa maré, inundação e seca. O valor médio dos fluxos de CO2 no solo úmido foi de 0,54 ± 0,30 g (CO2) · m-2 · h-1, com o solo atuando como fonte de carbono a -9,11 ton.ha-1 ao longo do ciclo de um ano. Os fluxos de CO2 no solo foram significativamente correlacionados com a umidade e temperatura do solo a 5 cm de profundidade. As concentrações de CO2 no solo atingiram mais de 100 ppm. Os estoques de carbono no solo não se correlacionaram significativamente com as variáveis deste estudo, sugerindo que variáveis não medidas podem influenciar a dinâmica do carbono do solo.

Palavras-chave: Dinâmica do Ecossistema; Solos Tropicais; Wetland.

Topic: **Ciências do Solo**

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INTRODUCTION

The Pantanal wetland on the upper Paraguay River, located mostly within Brazil, is one of the largest floodplains in the world and is a good example of the hydrological complexity of floodplains. Covering 160,000 km^2, the Pantanal is among the world's largest wetlands, and is a major priority for conservation (SILVA, 2000; GIRARD et al., 2003; SILVA et al., 2004; JUNK et al., 2006; FANTIN-CRUZ et al., 2008; KEDDY et al., 2009; LEADY et al., 2001). The Pantanal has been of interest in the scientific community due to its system of rain and flooding affecting the seasonal distribution of energy and carbon in this region.

Forests are both sources and sinks of atmospheric carbon (C). Sources of CO_2 include respiration, biomass burning, and decomposition. Sinks include biomass growth and photosynthesis (HOEN et al., 1994; FOODY et al., 1996). The global carbon cycle is very much dependent on tropical ecosystems that both emit and absorb atmospheric CO_2. Thus, any change in these ecosystems, due to natural and anthropogenic disturbances, will entail changes in carbon fluxes to the atmosphere at levels that will vary with the intensity of the disturbance (PAIVA et al., 2011).

Brazil is home to a diversity of ecosystems defined by climatic characteristics, soil, topography, and biodiversity. For the Pantanal, savanna (locally known as cerrado) and Amazon forest are considered important regulatory systems of the environment. Soil CO_2 flux dynamics are key to understanding the soil's role in the carbon balance. Another important factor is how the different ecosystems such as the Pantanal emit or sequester carbon. As soil CO_2 fluxes are a significant component of the dynamics of carbon (C) in terrestrial ecosystems, their quantification and mechanism are important when studying ecosystems. Quantification of *in situ* soil carbon flux provides accurate measurements of CO_2 emissions from the soil of the Pantanal, which can be used in estimates of carbon sequestration by the ecosystem. Our study aims to quantify several parameters that we hypothesize influence soil CO_2 flux on a tree island of the Northern Pantanal in Mato Grosso, Brazil. The soil of tree islands in this region can be identified as a carbon source or sink through the temporal analysis of the CO_2 stream and the carbon stock.

MATERIALS AND METHODS

Study Site

The study was conducted on a tree island (16º 29' 52" S 56º 24' 47" W), locally known as *cordilheira*, located in the Private Natural Heritage Reserve of the Brazil Social Service of Commerce (PRNP SESC Pantanal) in the municipality of Poconé, Mato Grosso, about 130 km South of Cuiaba. The vegetation type is savanna scrub forest, with soils classified as Eutrophic Haplic Planossolo. The climate is Aw, according to the Köppen classification, with seasonal characteristics of pronounced wet (October to April) and dry seasons (May to September) (CUNHA et al., 2004). The average annual air temperature in the PRNP SESC Pantanal ranges between 22 ºC and 32ºC, and the average annual rainfall ranges between 1100mm/y and 1200 mm/y, with the driest month having less than 40 mm/month of rain (HASENACK et al., 2003).

Data collection

Monthly Soil CO_2 flux and soil temperature were measured between January and December 2012. Soil was collected after each measurement campaign to determine soil moisture content and total organic carbon. Micrometeorology measurements of accumulated precipitation, average air temperature, relative humidity, wind direction, wind speed, and atmospheric pressure were obtained from a WXT520 station (Vaisala Inc., Helsinki, Finland) every thirty minutes. In this study, the year was divided into 4 seasons: Warm Wet (February, March, and April), Cool Dry (May, June, and July), Warm Dry (August, September, and October), and Warm Wet (December and January).

Soil CO_2 Flux Measurements

Monthly soil CO_2 fluxes were obtained at five distinct locations delimited by 25 cm diameter plastic rings installed in the soil one month prior to the start of measurements. Polyvinyl chloride (PVC) was chosen for the rings because the white color prevents heating and PVC shows adequate durability in the field (**Costa** et al., 2006). CO_2 flux measurements were performed using portable infrared gas analyzer (EGM- 4, PP Systems, UK) connected to a CO_2 soil flow chamber (SRC-1, PP Systems, UK). The EGM-4 chamber was positioned inside the PVC ring described. Litter was not removed during measurements. The soil CO_2 flux was quantified by placing the EGM closed chamber (volume = 1170 cm^3) over a known soil surface area (78 cm^2) and by measuring the rate of increase of the CO_2 concentration within the chamber (Equation 1).

$$Rs = \frac{DC}{DT} \times \frac{V}{A}, \qquad \text{Equation 1}$$

where *Rs* is the Efflux rate of soil CO_2 (CO_2 flux/unit area/unit time), *DT* is the time of measurement, *DC* is the difference in CO_2 concentration on elapsed time, *V* is the system volume (1170 cm^3), and A is the soil area exposed to the measurement (78 cm^2). Measurements were made on an hourly basis between 8 am and 4 pm over the months of collection.

Soil Temperature

Soil temperature was measured with a conventional digital thermometer (model TE 400, Instrutherm, São Paulo, Brazil) installed next to the PVC rings. Measurements were taken at 5 cm depth at the same locations as soil CO_2 fluxes.

Soil Moisture

Soil moisture was determined between March and December 2012 using the gravimetric method. Samples were collected monthly from a depth of 5 cm near the soil CO_2 flux measurement points and then packed in aluminum capsules. Samples were weighed and placed in an unventilated 105°C oven for 24 h until they reached constant weight. Water content was then determined by subtraction. Soil moisture (UG) was calculated as the percent change between wet mass (m_u) and dry mass (m_s) (Equation 2).

$$UG = \frac{m_u - m_s}{m_s} x\ 100 \qquad \text{Equation 2}$$

Soil bulk density

Soil bulk density was determined using volumetric ring samples. Undisturbed soil was collected by a steel ring of known internal volume before being placed in an unventilated 105 °C oven for 24 h, or until a constant mass was measured. Bulk density was then calculated using Equation 3.

$$D = \frac{m}{V}, \quad \text{Equation 3}$$

where *D* is the bulk density ($g \cdot cm^{-3}$), *m* soil mass contained in the ring (g) after drying and *V* is the ring volume of the ring (cm^3).

Total organic carbon (TOC) and carbon stock

TOC was obtained from monthly soil samples collected at 10 cm depth, near the points of measurement of CO_2 flux. Samples of 300 mg were replicated by Combustion Method Dry in specific equipment for analysis (Analytkjena- Model HT1300). The stock of organic carbon (SOC) in the soil layer studied was then calculated using Equation 4 (VELDKAMP, 1994).

$$SOC = \frac{C \times D \times e}{10}, \quad \text{Equation 4}$$

where *SOC* is the stock of organic carbon in the layer studied ($ton. \cdot ha^{-1}$), *C* is the carbon content in the layer ($g \cdot kg^{-1}$), *D* is the bulk density of the soil layer studied ($g \cdot cm^{-3}$) and *e* is studied layer thickness (cm). Additionally, the carbon balance was determined by taking the difference between the initial stock estimated for January 2012 and each subsequent monthly estimated stock.

RESULTS

Microclimate measurements

The average air temperature during the study period was 24.59 ± 2.34 °C, ranging from 20 °C in July 2012 to 26.86 °C in December 2012. The mean relative humidity was 79.21 ± 7.44%, ranging from 63.20% in September 2012 to 85.07% in January 2012. The annual accumulated rainfall was 1638 mm.

Temperature and soil moisture.

Soil temperature ranged from 21.88 ± 1.77 °C in June 2012 to 31.36 ± 0.88 °C in October 2012, with an average of 27.02 ± 2.45 °C. The annual mean soil moisture was 14.42 ± 1.55%, ranging from 2.06% in August 2012 to 32.85% in December 2012.

Variation of CO_2 soil flux

Between January and December 2012, the average soil CO_2 flux was 0.54 ± 0.30 g $(CO_2) \cdot m^{-2} \cdot h^{-1}$ (coefficient of variation 0.55).The average soil CO_2 flux was 0.37 ± 0.08 g $(CO_2) \cdot m^{-2} \cdot h^{-1}$ during high tide, 0.30 ± 0.02 g $(CO_2) \cdot m^{-2} \cdot h^{-1}$ during low tide, 0.61 ± 0.03 g $(CO_2) \cdot m^{-2} \cdot h^{-1}$ during the dry season, and 0.92 ± 0.13 g $(CO_2) \cdot m^{-2} \cdot h^{-1}$ during the flood season.

3.4 Soil organic carbon stocks

The annual soil carbon stock was 57.27 ± 9.77 ton.·ha^{-1}, ranging from 41.48 ± 8.00 ton.·ha^{-1} in September 2012 to 80.47 ± 24.38 ton.·ha^{-1} in February 2012. The soil density was 1.63 g·cm^{-3}. The balance of the stock of soil carbon to 10 cm depth from January to December 2012 was negative, with an estimated value of -9.10 ton.·ha^{-1}.

DISCUSSION

Flood dynamics at the tree island

During high tide and flood, the values of air temperature and relative humidity remained constant, which we explain by the presence of high relative humidity during the period, which improves the thermal conductivity of air. The greater accumulation of rainfall occurred in the high tide and flood seasons, with 400 and 906 mm respectively, and in low tide and dry seasons the rainfall readings were 179 and 153 mm respectively. On another tree island of the Pantanal, Brandão (2012) measured higher accumulation of rainfall during periods of high tide and flood. The annual rainfall was 1489 mm in their study in an area of savanna vegetation type in the Pantanal biome, between November 2010 October 2011.

Temperature and soil moisture

We observed that the variation of soil moisture correlated to precipitation at the tree island site, which is consistent with previous observations by Johnson et al. (2013) and Bruno (2004). Soil temperature was higher than air temperature over almost the entire period studied, which is the opposite of the results shown by Valentini (2008) and Nunes (2003). The difference could be due to a lower quantity of litter on the ground in the current study, thus leaving the soil more exposed to ambient temperature variations. In addition, the forest studied by Valentini et al. (2008) are denser than the forests in the current study.

CO_2 flux variations

The highest and lowest monthly average soil CO_2 fluxes were measured in December and August, respectively, at the beginning of the wet and dry seasons. Monthly average values of soil CO_2 flux through the year showed a maximum value of 1.02 ± 0.14 g (CO_2)·m^{-2}·h^{-1} (December), which can be explained by the beginning of the wet season when precipitation contributes to soil moisture. Higher soil moisture speeds up soil microbial activity, which increases CO_2 emission from the soil. The minimum value of soil CO_2 flux was 0.16 ± 0.01 g (CO_2)·m^{-2}·h^{-1} (August), resulting from low soil moisture due to the dry season (Fig. 1).

Average CO_2 flux from the soil was 0.37 ± 0.08 g (CO_2)·m^{-2}·h^{-1} during high tide, 0.30 ± 0.02 g (CO_2) m^{-2} h^{-1} during low tide, 0.61 ± 0.03 g (CO_2)·m^{-2}·h^{-1} during the dry season, and 0.92 ± 0.13 g (CO_2)·m^{-2}·h^{-1} during the flood season. We observed a statistically significant difference ($F_{3;32}$= 50.94) between soil CO_2 flux and the four seasons. Soil CO_2 fluxes were greater during high tide, which was also observed by Brandao (2012), but lower during low tide, which differs from Brandao results of the lowest value in the dry season. The difference can be explained by the increase of soil moisture in September in the present study. Davidson et al. (1998) and Savage et al. (2003) also found this pulse in CO_2 emissions after the fast wetting of dry soil, similar to our study.

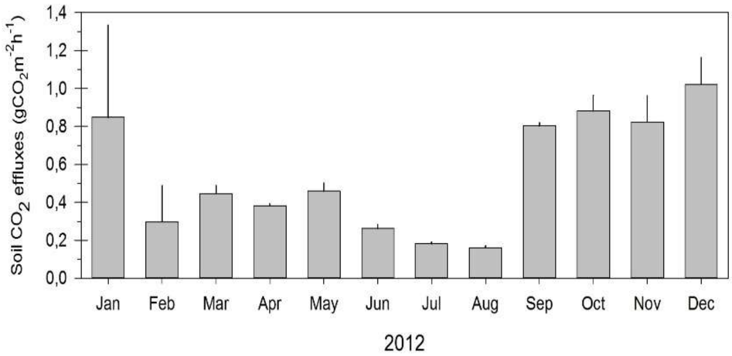

Figure 1: Flow of CO_2 in soil interfluvial area of the Pantanal in Poconé.

CO_2 flux and soil temperature

During dry and flood periods in the Pantanal, when there was an increase in soil temperature, there was also an increase of soil CO_2 flux and vice versa. Soil moisture was therefore not the limiting factor for microbial activity; rather, CO_2 emissions were limited by soil temperature. The soil CO_2 flux correlated positively and significantly with soil temperature ($r = 0.67$, $p = 0.01$) (Fig. 2) which differs from previous results in a primary rainforest (Nunes 2003) where a negative relationship between the average soil temperature and soil CO_2 flux was found. Costa et al. (2008) and Escobar (2007) also found positive correlation with temperature. Brandão (2012) also found a positive correlation, although not significant (r =0.42, p =0.20) between CO_2 flux and soil temperature.

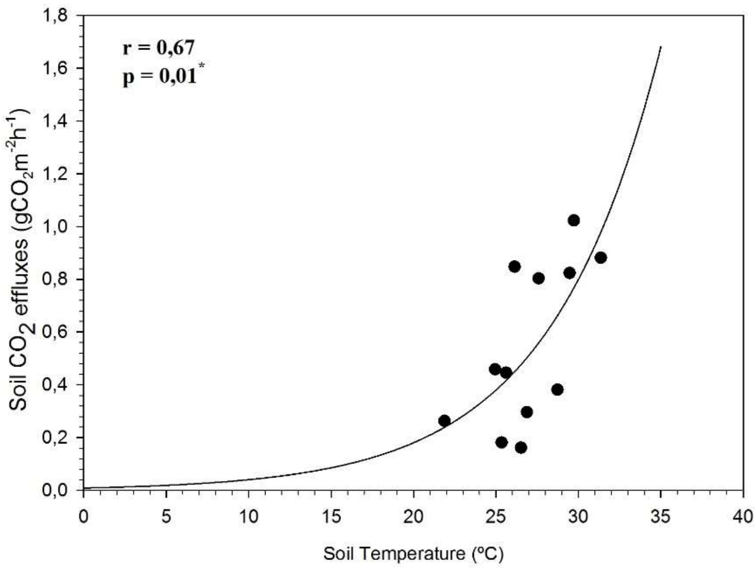

Figure 2: Response of soil CO_2 flux to temperature at 5 cm soil depth.

Soil CO_2 flux and soil moisture

Soil moisture exerts great influence on soil CO_2 emission by interfering in both physical and biological soil properties. According to Ross (1989), the high water content of the soil interferes with the flow of CO_2 from the soil in one of two ways. One way is through decreasing aerobic respiration, which is mainly responsible for the emission of CO_2 from the soil. The second way is through actual physical impediment of CO_2 passage through the pore space (Brandão, 2012). There was a positive and significant correlation (r = 0.72, p = 0.02) between the monthly averages of soil moisture and soil CO_2 flux (Fig. 3).

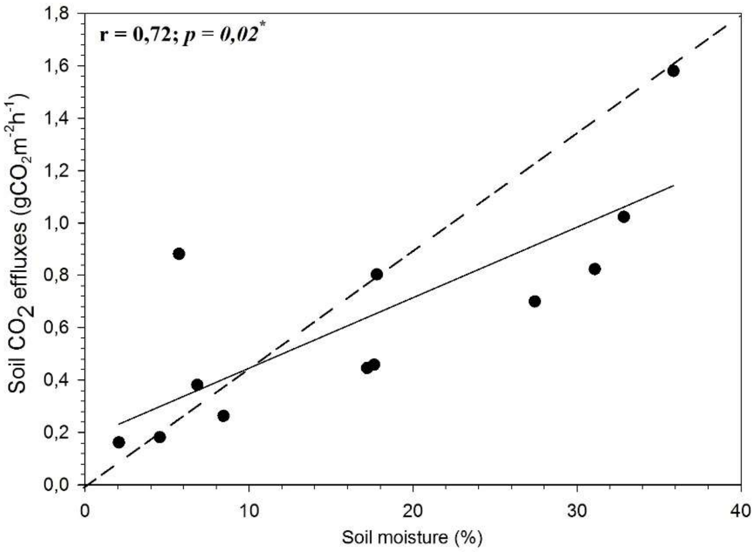

Figure 3:. Response of soil CO_2 flux to soil moisture.

During periods of flood, high tide, and low tide in the Pantanal, when there was a decrease in soil moisture, CO_2 flux also decreased, and vice versa. This indicates that soil moisture in these periods was a limiting factor for the emission of CO_2 from the soil. The dry season, exhibited the same dynamics observed in other periods. This response may be explained by the low soil moisture, which limits microbial activity and root respiration (YUSTE et al. 2003).

Soil organic carbon stocks

It was observed that the largest carbon stocks occurred in the flood and high tide seasons, with 63.56 ± 14.94 and 57.45 ± 6.93 ton.·ha^{-1} respectively, while the low tide and dry seasons had the smallest values of 52.95 ± 4.47 and 55.12 ± 11.83 ton.·ha^{-1} respectively (Fig. 4). Previous studies in areas of the Pantanal, in the region of Barão de Melgaço, estimated the average annual carbon stock in soil at 89.9 ± 25.1 ton.·ha^{-1} (MENDES, 2009), and 39.08 ± 16.62 ton.·ha^{-1} (MELLO, 2015). The current study shows similar results to Mello (2015), where the largest carbon stocks were found during the high tide and flood seasons in regions with similar annual variation in river stage. The lowest values of carbon stock during high tide and flood seasons are directly associated with water depth, which hinders the action of wind and the consequent movement of gases (SILVA et al., 1995). Similarly, Schongart et al. (2008) and Mendes (2009) show that during local flooding of the Pantanal, these areas function as a constant reservoir of carbon in the soil.

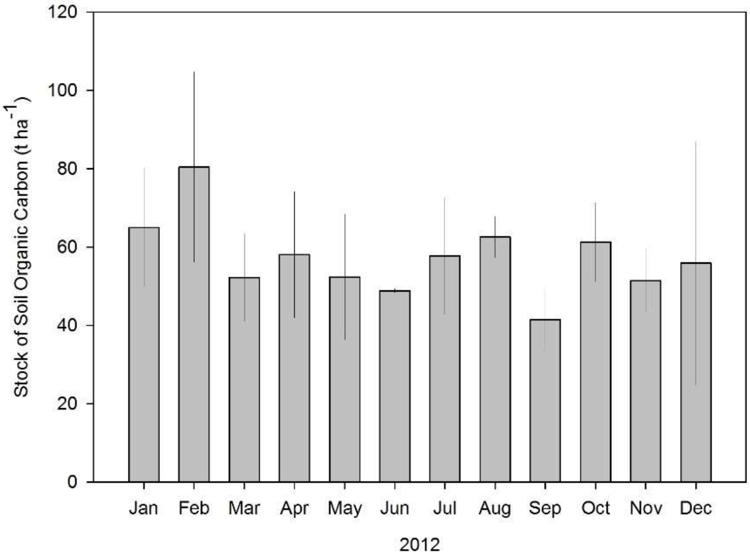

Figure 4: Monthly average (± SD) of the stock of soil organic carbon in the Pantanal.

The annual soil carbon balance at 10 cm depth was negative, with an estimated value of -9.10 ton.·ha^{-1} which suggests that soil acted as a likely source of CO_2 to the atmosphere (Fig. 5). These results differ from previous studies, where the soils were found to work as carbon sinks (MELO, 2015). Another study indicates that the total stock of soil carbon associated with seasonality in the Pantanal was positive, through incorporation of soil organic carbon (MENDES, 2009).

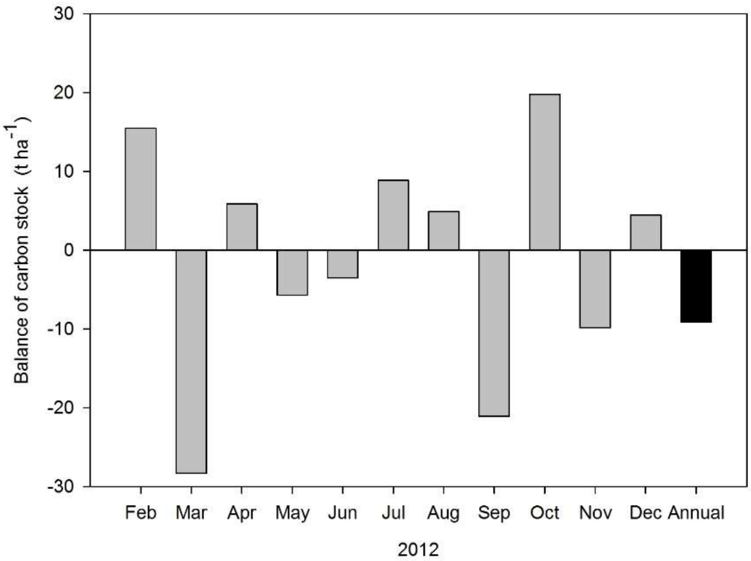

Figure 5: Balance of carbon stock in the soil.

The balance of carbon stock during the flood season decreased compared to the previous period (January, initial stock), with an estimated -6.96 ton.·ha^{-1}. Values were also negative for high tide and flood, with estimated values of -0.36 ton.·ha^{-1} and -5.38 ton.·ha^{-1} respectively (Fig. 5). The balance of carbon stock during the dry season increased from the previous period (low tide) with an estimated 3.39 ton·ha^{-1} value.

CONCLUSIONS

It was found that the soil acted as a likely source of CO_2 to the atmosphere in the Pantanal, suggesting that the ecosystem plays an important control for the discussion of global climate change.

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