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# Spatial and temporal variability of soil $CO_2$ emission in a sugarcane area under green and slash-and-burn managements

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ABSTRACT

Soil management causes changes in physical, chemical, and biological properties that consequently affect soil $CO_2$ emission (FCO2). Here, we studied the soil carbon dynamics in areas with sugarcane production in southern Brazil under two different sugarcane management systems: green (G), consisting of mechanized harvesting that produces a large amount of crop residues left on the soil surface, and slash-and-burn (SB), in which the residues are burned before manual harvest, leaving no residues on the soil surface. The study was conducted during the period after harvest in two side-by-side grids installed in adjacent areas, having 60 points each. The aim was to characterize the temporal and spatial variability of FCO2, and its relation to soil temperature and soil moisture, in a red latosol (Oxisol) where G and SB management systems have been recently used. Mean FCO2 emission was 39% higher in the SB plot (2.87 $\mu$mol $m^{-2}$ $s^{-1}$) when compared to the G plot (2.06 $\mu$mol $m^{-2}$ $s^{-1}$) throughout the 70-day period after harvest. A quadratic equation of emissions versus soil moisture was able to explain 73% and 50% of temporal variability of FCO2 in SB and G, respectively. This seems to relate to the sensitivity of FCO2 to precipitation events, which caused a significant increase in SB emissions but not in G-managed area emissions. FCO2 semivariogram models were mostly exponential in both areas, ranging from 72.6 to 73.8 m and 63.0 to 64.7 m for G and SB, respectively. These results indicate that the G management system results in more homogeneous FCO2 when spatial and temporal variability are considered. The spatial variability analysis of soil temperature and soil moisture indicates that those parameters do not adequately explain the changes in spatial variability of FCO2, but emission maps are clearly more homogeneous after a drought period when no rain has occurred, in both sites.

## 1. Introduction

Fluxes of carbon (C) from soil affected by land use or management can impact the existing pool of $CO_2$ in the atmosphere (Epron et al., 2004; Sartori et al., 2006). Also, it has been argued that the capacity of agricultural soils worldwide to restore atmospheric C as soil organic matter (SOM) could be increased in 60 Pg C, back to the original level of soil C pool (240 Pg C) (Harrison et al., 1993).

It is estimated that in Brazil the C stored in the 0–30 cm soil depth is around 36.4 ± 3.4 Pg C. Additionally, changes in land use and agricultural practices are responsible for more than two thirds of total greenhouse gases emission (Bernoux et al., 2002).

Presently, Brazil is the world's main sugarcane (*Saccharum* spp.) producer with 7.0 million ha planted; the state of São Paulo is the major producer and responsible for 3.7 million ha. Considering that the total area cropped with sugarcane increased around 13% in São Paulo state in 2008 (National Supply Company – CONAB, 2008), the study of the spatial and temporal changes of soil $CO_2$ emission (FCO2) in sugarcane agrosystems in the state of São Paulo is of great interest.

However, in Southern Brazil, more important than the agricultural expansion are the changes in management practices occurring in sugarcane areas, where this crop is associated with food, biofuel, and energy production, being considered as an important alternative when the problem of climate change is addressed (Cerri et al., 2007). In sugarcane plantations, large areas have been converted from one production system (slash-and-burn) to another (green). In slash-and-burn (SB) areas, sugarcane is burned in the field a few days before harvesting to facilitate manual slashing by removing leaves and insects. Slash-and-burn management has an immediate and direct effect on the physical and hydrological properties of the soil (Are et al., 2009). On the other hand, in green (G) management the mechanical harvesting provides the return of crop residues to the soil surface favoring soil organic matter accumulation and gas emission reduction, when compared to the burning system (Razafimbelo et al., 2006; Cerri et al., 2007). It has been argued that soil management practices

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would result in modifications of the soil's physical and chemical properties, affecting microbial activity and consequently soil $CO_2$ emission (Sartori et al., 2006; Cerri et al., 2007). Still, little is known about the changes in soil properties when conversion from SB to G agrosystem is considered, and how this may affect the loss of soil $CO_2$.

The magnitude of FCO2 varies in time and space depending on the environmental conditions, soil characteristics, and agricultural management adopted. The value of the coefficient of variation (CV) of FCO2 is the first indicative of spatial variability of the FCO2; however, this is not enough to compare $CO_2$ emissions from different studies, especially because no information on the points of the spatial distribution is available (Fang et al., 1998). Geostatistics provide the basis for describing quantitative spatial variations in soil that can be used for estimating soil properties (Webster, 1985; Webster and Oliver, 1990). Indeed, geostatistical analysis has been used to study several soil properties, most of them physical and chemical (Cambardella et al., 1994; Wang et al., 2002), but also biological properties such as FCO2 in various ecosystems, from forests to bare soils (La Scala Jr. et al., 2000; Ishizuka et al., 2005; Ohashi and Gyokusen, 2007; Konda et al., 2008). However, only few studies using geostatistic analysis have been conducted in order to examine the spatial structure of soil $CO_2$ emission in sugarcane areas (Panosso et al., 2008). Understanding the spatial variability of soil $CO_2$ emission in agricultural areas in Brazil is important for conducting a controlled and sustained management of cropping. This may help preserving the carbon in the soil and reducing the greenhouse effects.

To be able to estimate the amount of soil respiration it is also imperative to describe its temporal variability and the relationship between soil respiration and environmental variables that can be continuously monitored, such as temperature and soil moisture content. In tropical regions where seasonal variation in soil temperature is small, soil moisture should be tested and considered as the most effective index to estimate the seasonal variation of soil respiration rate (Kosugi et al., 2007).

Here we raised the hypothesis that different harvest practices would result in different soil carbon dynamics in each plot, which in turn could be expressed in terms of spatial and temporal variability, and relations with the main controlling factors: soil temperature and soil moisture. In this study we focused on the spatial and temporal characterization of soil $CO_2$ emission in sugarcane areas cropped with two contrasting harvest systems: slash-and-burn and green.

## 2. Materials and methods

This study was done on São Bento farm, which belongs to the São Martinho ethanol plant, in an area that has been devoted to sugarcane production for the last 35 years, located in Guariba city, São Paulo, Brazil (Fig. 1). The geographical coordinates are 21° 24′ S and 48° 09′ W, with mean elevation around 550 m above sea level. Regional climate is classified as Aw (according to Köepen), tropical with rainy summer and dry winter. Mean rain precipitation is around 1425 mm, concentrated mostly between October and March. The mean annual temperature registered in the region during the last 30 years is 22.2 °C.

The studied area has a soil type that is classified as high clay, Oxisol (Eutrustox, USDA Soil Taxonomy). Located in an area with low slope (3–4%), two side-by-side plots were installed. Each plot had its own management system. One was green (G), with a history of mechanized harvest in the last 7 years, resulting in a huge amount of sugarcane crop residues left on the ground after the harvest (12 tons/ha), which occurred on 16 May 2007 (Julian day 136). The other was slash-and-burn (SB) management with a history of sugarcane cropped since 1970; this plot was harvested on 9 June 2007 (Julian day 160). Two identical 190 m × 50 m grids presenting 60 points each were installed in the studied plots, with a minimum distance of 13.3 m between points (Fig. 1).

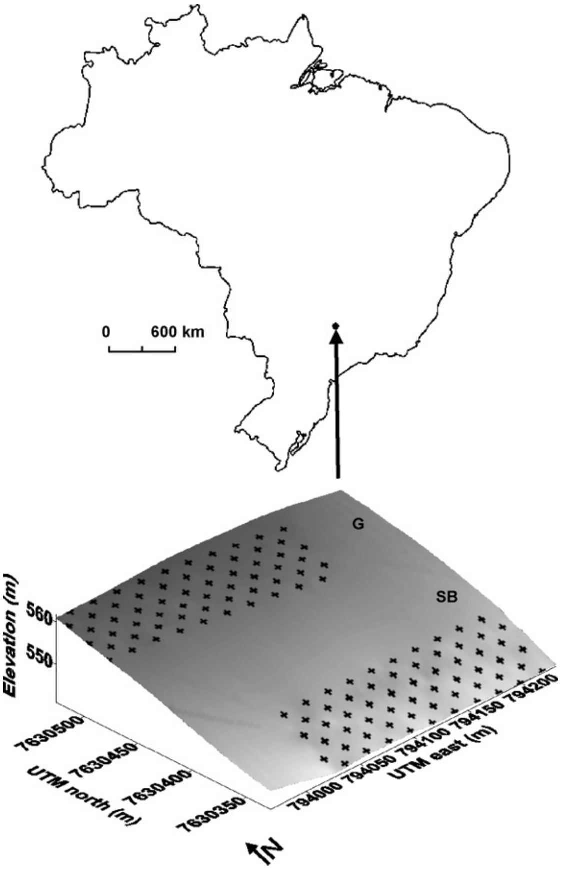

**Fig. 1.** Map showing the site location and the two grids installed on the green (G) and slash-and-burn (SB) areas.

FCO2 was registered with a portable LI-COR system (LI-8100, Lincoln, NE, USA), during the stage where the crop ratoon was on its initial growth phase. In the measurement mode the LI-8100 system monitors the changes in $CO_2$ concentration inside the chamber by using an infrared gas analyzer (IRGA). The soil chamber has an internal volume of 854.2 $cm^3$ with a circular contact area to soil of 83.7 $cm^2$, and was placed on PVC soil collars previously inserted at a depth of 3 cm into soil grid points. Soil temperature ($T_{soil}$) was monitored by using a 20 cm depth probe (thermistor based) inserted into the soil close to the collars. Soil moisture ($M_{soil}$), with its % in volume, was registered with a portable hydrosense system (TDR probe, Campbell, USA). Twenty points were chosen in each grid in order to conduct the temporal variability studies, which occurred up to 70 days after harvest. Those measurements were taken on the following Julian days of the year 2007: 190, 192, 195, 200, 201, 204, 208, 209, 215, 227, 234, 241, 255, and 260. They were done once a day, in the mornings (7–9 am). For the spatial variability studies, measurements were taken in each one of the grids on days 191, 200, and 248 (G) and 192, 201, and 246 (SB), in the mornings (7–10 am).

Descriptive statistics (mean, standard deviation, standard error, minimum, maximum, and coefficient of variation) was used to classify the variability of FCO2, $T_{soil}$, and $M_{soil}$. Additionally, variance and non-linear regression analysis was applied to the temporal variability data. The spatial variability dependence was analyzed by applying geostatistic techniques (Webster and Oliver, 1990) to all of the variables studied. We considered that when