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Short communication

Modelling short-term temporal changes of bare soil CO_2 emissions in a tropical agrosystem by using meteorological data

N. La Scala, Jr.*, A.R. Panosso, G.T. Pereira

FCAV-UNESP, Via de Acesso Prof. Paulo Donato Castellane s/n., 14884-900 Jaboticabal, SP, Brazil

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Abstract

Determining the variability of carbon dioxide emission from soils is an important task as soils are among the largest sources of carbon in biosphere. In this work the temporal variability of bare soil CO_2 emissions was measured over a 3-week period. Temporal changes in soil CO_2 emission were modelled in terms of the changes that occurred in solar radiation (SR), air temperature (T_{air}), air humidity (AR), evaporation (EVAP) and atmospheric pressure (ATM) registered during the time period that the experiment was conducted. The multiple regression analysis (backward elimination procedure) includes almost all the meteorological variables and their interactions into the final model ($R^2 = 0.98$), but solar radiation showed to be the one of the most relevant variables. The present study indicates that meteorological data could be taken into account as the main forces driving the temporal variability of carbon dioxide emission from bare soils, where microbial activity is the sole source of carbon dioxide emitted.

Keywords: Carbon balance; Carbon dioxide emission; Soil respiration; Greenhouse gases

1. Introduction

One of the main aspects of soil CO_2 emission that accounts for understanding the global carbon cycle is the temporal variability of such emission in several ecosystems. The most frequent variables that have shown to affect CO_2 evolution from soil are soil temperature and soil moisture (Edwards, 1975; Singh and Gupta, 1977; Howard and Howard, 1993). A large variety of models based on the power law (Brunnell et al., 1977), logarithmic and exponential (Howard and Howard, 1993; Davidson et al., 2000) and polynomial functions (Buyanovsky et al., 1986) have been proposed, including those two variables as the main factors governing temporal variability of soil CO_2 emissions throughout annual and shorter time periods. But the changes in time that occurred in soil temperature and moisture conditions are directly and indirectly associated with meteorological events. Some papers have proposed factors such as solar radiation and atmospheric pressure as the main variables turning control of the soil CO_2 production rates and transport and thereby the CO_2 flux into the atmosphere (Massmann and Ferrier, 1992; Ouyang and Zheng, 2000). Notwithstanding, temporal variability of soil CO_2 emission as a function of meteorological data has rarely been reported, especially for tropical bare soils, where microbial activity is the sole source of the carbon dioxide emission.

The objective of the present paper is modelling the short-term temporal variability of CO_2 emissions in a

* Corresponding author. Fax: +55-16-3202-4275.
E-mail address: lascala@fcav.unesp.br (N. La Scala Jr.).

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tropical bare soil in terms of environmental variables. Changes in the CO_2 emission are described as a function of the changes that occurred in air temperature (T_{air}), evaporation (EVAP), solar radiation (SR), atmospheric pressure (ATM), relative air humidity and some of the first-order interactions.

2. Materials and methods

The study was conducted on a completely bare dark red latossol (oxisol) at FCAV-UNESP (21°15′22″S, 48°18′58″W), São Paulo, Brazil. The climate of the area is subtropical, with average annual temperature of 21 °C. The mean annual precipitation is around 1380 mm, with rain distribution concentrated in the period from October to March, and a relatively dry period between April and September.

A 65-point grid was established on the experimental site (80 m × 80 m) with points spaced from 1 to 10 m. The experimental site had previously been cultivated with soybean (*Glycine max* L. Merr.) using conventional tillage practices, and was mechanically harvested 2 months before the experiment started.

CO_2 emissions were measured at each grid point during a 3-week study. The observations were done on 12 different days, by morning: 10th, 11th, 13th, 18th, 20th and 22nd days, and afternoon: 12th, 16th, 25th, 26th, 27th and 28th days, in July 2001, considering contrasting soil temperatures and soil moisture conditions. Morning observations started at around 7 a.m. and the afternoon ones around 3 p.m. Soil temperatures were measured at 0–20 cm depth in each grid point, using LI-6400 Soil Temperature Probe (built by LI-COR, NE, USA) at the same moment that measurements of CO_2 emissions were taken.

The CO_2 emissions were measured using a CO_2 flux chamber (LI-6400-09, LI-COR, NE, USA) according to Healy et al. (1996). The chamber is a closed system with an internal volume of 991 cm^3 and exposed area to soil of 71.6 cm^2 and is coupled to a LI-6400 photosynthesis system that analyzes the CO_2 concentration by infrared gas absorption. The chamber was placed on the top of PVC soil collars installed in the field 3 days before the measurements in each grid point. Prior to each measurement the CO_2 concentration inside the chamber was reduced to 370 $\mu mol\,mol^{-1}$ by driving the air sampled through soda lime for a few seconds. The increase in CO_2 concentration was measured every 2.5 s, and the soil CO_2 emissions were computed during approximately 90 s, while CO_2 concentration increases up to 390 $\mu mol\,mol^{-1}$. At the end of the logging period, a linear regression is calculated between the soil CO_2 emissions and CO_2 concentration inside the chamber, and the emission on that point is determined for the chamber CO_2 concentration equal to that at the soil surface in the open (380 $\mu mol\,mol^{-1}$). A short sampling period of 1.5 min at each grid point was used, throughout the period of measurement, in order to complete the sampling from the whole 65 points as quickly as possible, avoiding soil temperature variation in the grid during this period. Deviations of daily soil temperature were smaller than 1 °C, when temperatures at different points in the grid were compared.

Other environmental characteristics used were daily evaporation, air temperature, air humidity (AR), solar radiation and atmospheric pressure recorded by a meteorological station located 2 km near the experimental site. Evaporation was determined by using an A-class tank at each end of the daily CO_2 measurement. Air temperature, air humidity, solar radiation and atmospheric pressure used in this work were recorded at 7 and 9 a.m. on mornings and 3 p.m. on afternoons, respectively. The CO_2 emission results on different days were submitted to descriptive statistics and multiple regression analysis (SAS, 1999).

3. Results and discussion

Table 1 presents the descriptive statistics of soil CO_2 emission (F_{CO_2}) and soil temperature (T_{soil}) observed in the 65 points studied in each of the 12 days. The average F_{CO_2} registered during the 3-week study was 1.18 $\mu mol\,m^{-2}\,s^{-1}$, with the minimum value of 0.94 $\mu mol\,m^{-2}\,s^{-1}$ observed on 16 July, in the driest afternoon, when air humidity was 29%. The maximum average F_{CO_2} of 1.41 $\mu mol\,m^{-2}\,s^{-1}$ was observed on 27 July, in an afternoon when soil temperature reached the highest value (24.1 °C). The increase of F_{CO_2} in this day could also be attributed to a rise in the soil moisture due to the 1.4 mm, occurred on days before. It already reported the control of organic matter decomposition by the increase of soil water content during dry periods, when soil water is likely to be the limiting factor (Buyanovsky et al., 1986).

Table 1
Descriptive statistics of average soil CO_2 emission, soil temperature at 65 points, and the environmental variables in 12 days

	Mean	Minimum	Maximum	S.D.	CV (%)
F_{CO_2} (μmol m^{-2} s^{-1})	1.18	0.94	1.41	0.15	12.7
T_{soil} (°C)	21.0	17.3	24.1	2.29	10.9
Solar radiation (W m^{-2})	417.0	108.7	513.3	109.5	26.3
Air humidity (%)	62.5	29.0	92.0	18.1	29.0
Atmospheric pressure (mbar)	951.1	948.2	954.3	2.0	1.8
Evaporation (mm)	5.11	0.92	7.72	2.07	40.5
Air temperature (°C)	21.0	11.7	29.6	5.7	27.1

No significant correlation was found between F_{CO_2} and T_{soil} indicating that soil temperature alone cannot respond for the changes that occurred on F_{CO_2} during the time that the experiment was conducted. Table 1 presents also the descriptive statistics of meteorological data, showing high variability of evaporation and air humidity values while atmospheric pressure showed the lowest variability during the experiment.

In order to examine the variability of F_{CO_2} in more detail, a multiple regression was applied taking into account the main meteorological variables and their first-order interaction. The results of a backward stepwise regression procedure applied to the 12 studied days are presented in Table 2, while the comparison of measured and predicted emissions is presented in Table 3. All the variables included into the model explained 97.8% of temporal variability of soil CO_2 emission during the period. The first variable removed by backward procedure was ATM, indicating that alone did not contribute so much to explain the variability. The parameter estimated for EVAP was negative and the ones estimated for T_{air}, AH, and SR were positive. Interactions involving almost all variables were included into the model, especially the ones associated with solar radiation. It is expected to have a relation of F_{CO_2} with some of these environmental variables and this relation has been described in the literature (Ouyang and Zheng, 2000; Massmann and Ferrier, 1992). Solar radiation has already been referred to as one of the most important processes governing the daily cycles of soil temperature and water evaporation controlling the soil CO_2 production rates, and thereby the CO_2 emission from soil to atmosphere (Ouyang and Zheng, 2000). The inclusion of atmospheric pressure as one of the variables related to F_{CO_2} was also pointed by Massmann and Ferrier (1992), who showed that daily trends in the atmospheric pressure may influence the efflux of CO_2

Table 2
Results of stepwise regression of F_{CO_2}

Soil CO_2 emission	Variables	Parameter estimate	P-value
F_{CO_2}	Intercept	−13.1573	0.0007
	AH	0.0990	0.0028
	EVAP	−68.3552	0.0001
	T_{air}	5.3740	0.0035
	SR	0.5709	0.0028
	SR × ATM	−0.0006	0.0044
	SR × AH	−0.0003	0.0003
	SR × EVAP	−0.0024	0.0001
	SR × T_{air}	−0.0008	0.0001
	ATM × EVAP	0.0727	0.0001
	ATM × T_{air}	−0.0054	0.0041
	AH × EVAP	0.0034	0.0026
	AH × T_{air}	0.0005	0.0136

$R^2 = 0.976$.

Table 3
Average values of F_{CO_2} measured and predicted (±S.E.) for each studied day

Day (July 2001)	Measured (μmol m^{-2} s^{-1})	Predicted (μmol m^{-2} s^{-1})
10	1.31 ± 0.04	1.29 ± 0.03
11	1.16 ± 0.04	1.17 ± 0.02
12	1.13 ± 0.04	1.13 ± 0.02
13	1.03 ± 0.03	1.03 ± 0.03
16	0.94 ± 0.03	0.94 ± 0.02
18	1.06 ± 0.03	1.08 ± 0.03
20	1.19 ± 0.03	1.17 ± 0.02
22	1.20 ± 0.03	1.19 ± 0.02
25	1.28 ± 0.03	1.29 ± 0.02
26	1.36 ± 0.04	1.36 ± 0.02
27	1.41 ± 0.05	1.42 ± 0.02
28	1.04 ± 0.03	1.04 ± 0.02

from soil. Other studies on changes in bare soil CO_2 emission, including air or soil temperature plus soil moisture, accounted for 76% of the temporal variability in a silt loam soil (Buyanovsky et al., 1986).

We have also modelled F_{CO_2} as a function of the environmental variables, including T_{soil} into the model. The results of a backward stepwise regression showed that 99.9% of F_{CO_2} variability was explained by the model. Despite the fact that the range of applicability of the model is based on a short-time period, when soils are used in agriculture, these are kept bare for a short period in fallow, and during which this environment is purely a CO_2 emitter to the atmosphere. Therefore, the present results indicate that temporal changes in the carbon transfer of bare soils during fallow could be inferred by meteorological data.

4. Conclusion

The changes of a bare soil CO_2 emission was modelled in terms of daily variations of air temperature, relative humidity, solar radiation, atmospheric pressure and water evaporation. This study suggests that temporal variability of a bare soil CO_2 emission is dependent on several meteorological variables. Because the interactions of these variables were not able to specify the individual role of each variable on such emissions.

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