Short communication

Short-term temporal changes in the spatial variability model of CO₂ emissions from a Brazilian bare soil

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Abstract

In this work, the spatial variability model of CO₂ emissions and soil properties of a Brazilian bare soil were investigated. Carbon dioxide emissions were measured on three different days at contrasted soil temperature and soil moisture conditions, and soil properties were investigated at the same points where emissions were measured. One spatial variability model of soil CO₂ emissions was found for each measurement day, and these models are similar to the ones of soil properties studied in an area of 100 × 100 m. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Soil CO₂ emission; Soil properties; Spatial variability

The study of soil CO₂ emissions is a relevant task due to the fact that it is related to many environmental issues. In this work, we have studied the spatial variability model of soil CO₂ emissions on bare soil, where microorganisms are the sole source of carbon dioxide. Studying an area of 100 × 100 m on three different days, we found average values of CO₂ emissions ranging from 1.26 to 2.48 μmol CO₂ m⁻² s⁻¹ (0.06–0.11 mg CO₂ m⁻² s⁻¹). By comparing these results with the literature, our emission values are within the same range as those reported in soils having vegetation cover (0.03–0.25 mg CO₂ m⁻² s⁻¹) (Fang et al., 1998; Rout and Gupta, 1989; Carlyle and Than, 1988). Also, we have found one spatial variability model of soil CO₂ emissions for each measurement day, and these models are similar to the ones of soil properties already studied. Other works in literature have also reported the complex nature of the spatial variability of soil CO₂ emissions (Fang et al., 1998; Dasselaar et al., 1998; Rochette et al., 1991). However, only a few have demonstrated short temporal changes and even fewer have compared the spatial variability patterns of CO₂ emissions with its possible controlling factors, the soil properties.

The study was conducted on an acid bare oxisol (pH around 4.8) at FCAV-UNESP (21°15’22” South; 48°18’58” West) located at an altitude of 650 m, São Paulo State — Brazil. The climate of the area is classified as Cwa, according to Köppen, subtropical with average annual temperature of 21°C. The mean annual precipitation is around 1380 mm, with a rain distribution concentrated in the period from October to March, and a relatively dry period from April to September.

A grid containing 65 points was established on the experimental site (100 × 100 m) where the points were spaced at distances of 20 and 10 m. Measurements of CO₂ emissions were conducted at each point on three different days: 19, 25 and 27 November 1998. Soil temperatures at 20 cm depth were measured at each grid point using LI-6400 soil temperature probe (LI-COR, NE, USA) during the same period that CO₂ emission measurements were taken. Soil samples were obtained from 0 to 20 cm depths at each grid point on 27 November. On these 65 samples, cation exchange capacity (CEC), total carbon, pH, the percentage of base

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saturation in colloids (V%), sum of bases \((\text{Ca}^{2+} + \text{Mg}^{2+} + \text{K}^+)\) (Raij et al., 1987), texture (Gee and Bauder, 1986), gravimetric water content (Gardner, 1986) and free iron oxide: \(\text{Fe}_8\) (Citrate ditionite bicarbonate extraction) (Mehra and Jackson, 1960) were determined.

The CO2 emissions were measured using a CO2 flux chamber built by LI-COR (LI-6400-09, LI-COR, NE, USA) (Healy et al., 1996). The chamber is a closed system that has an internal volume of 991 cm3, with an area exposed to the soil of 71.6 cm2. This was placed on the top of PVC soil collars installed in the field days before the measurements at each grid point. The chamber is coupled with a LI-6400 photosynthesis system that analyzes the CO2 concentration by infra red gas absorption. Prior to each measurement, the CO2 concentration inside the chamber was lowered to 370 \(\mu\text{mol mol}^{-1}\), by driving the air sampled through soda lime for a few seconds. After that, the increase in CO2 concentration was measured every 2.5 s, and the soil CO2 emissions were computed during approximately 90 s; CO2 concentration increased up to 390 \(\mu\text{mol mol}^{-1}\). On the end of the logging period, a linear regression between the soil CO2 emissions and CO2 concentration inside the chamber was computed, and the emission on that point is calculated when the chamber CO2 concentration is equal to that at the soil surface in the open (380 \(\mu\text{mol mol}^{-1}\)). On all the three days of measurement, a short sampling period of 1.5 min at each grid point was used, in order to complete the sampling from the whole 65 points as quickly as possible, to avoid soil temperature variation in the grid during this period. In all days of measurements, the deviation of temperature was smaller than 1°C, when temperature at different points in the grid were compared. Soil temperatures were 26.2, 32.4 and 27.4 for 19, 25 and 27 November, respectively.

Our results are presented in terms of descriptive statistics (mean, standard deviation) and semivariogram models, applied to the spatial variability determination (Webster and Oliver, 1990) of CO2 emissions and soil properties. The semivariogram has the form of:

\[
\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (z(x_i) - z(x_i + h))^2
\]

where \(\gamma(h)\) is called semivariance at separation distance \(h\); \(z(x_i)\) is the value of variable \(z\) at point \(x_i\); \(z(x_i + h)\) is the value of variable \(z\) at point \(x_i + h\). Plotting \(\gamma(h)\) against \(h\) gives the semivariogram, which either exhibits purely random behavior or some systematic behavior described by theoretical models (linear, spherical, gaussian and power law models). Model coefficients are determined by observing the best fit to all the semivariance data. For properties that are dependent on separation distance, it is expected that the values of \(z(x_i) - z(x_i + h)\) increase with distance \(h\) up to a determined distance, where after, the values are stabilized. The semivariance stabilization value, called sill, is represented by the symbol \(C_0 + C_1\) and is approximated similar to the variance of the analyzed data. The distance where stabilization of semivariogram occurs is called range distance, symbol \(a\). The nugget effect, represented by symbol \(C_0\), is the semivariance value found at the intercept with \(Y\) axis. Theoretically, this value should be zero for a lag distance of zero, however, sampling error measurements and short-scale variability can cause deviation from zero. Therefore, the nugget effect represents the amount of variance not explained or modeled as spatial correlation. The parameters \(C_0\), \(C_0 + C_1\) and \(a\) are currently used in semivariogram fitting equations and are presented here, in order to compare the spatial variability models of CO2 emissions and soil properties studied.

The descriptive statistic and spatial variability parameters are presented in Table 1. Here, we call the CO2 emissions on 19, 25 and 27 November as F19, F25, and F27, respectively. By comparing their mean values, we observe that emissions increased on 27, after a rainy period occurred on the night before (14.6 mm). As the soil CO2 emissions are strongly dependent on soil moisture (Howard and Howard 1993), such a result seems to be in accordance with the literature. It is important to notice that mean soil CO2 emissions from this study were lower than mean daily emissions from cropped surfaces (Singh and Gupta, 1977). Also, the coefficients of variation (CV) of soil CO2 emissions, ranging from 32% to 21% on the three days of measurements, are typically smaller than those reported in soil having vegetation: around 55% (Fang et al., 1998). The soil properties studied have similar range distances from 20 to 35 m. For F19 and F25 we have found different range distances, 58.4 and 29.6 m, respectively. Emissions on 27 November show no spatial variability structure. We believe that modifications in the spatial variability model of CO2 emissions could be related to the weather events. Therefore, changes occurred from F25 to F27 is presumably related to the rainy event occurred on 26 November.

Significant linear correlations \((P < 0.05)\) were obtained when we plotted F19 vs. total carbon \((r = 0.47)\), F25 vs. CEC \((r = 0.33)\) and F27 vs. Fe\(_d\) \((r = -0.42)\). It is important to notice that soil properties correlated with F19, F25 and F27 have similar semivariogram models (Fig. 1 and Table 1). Therefore, the results presented in Fig. 1 indicate that the spatial variability model of CO2 emissions are similar to their possible controlling factors, the soil properties. In this work, we have not found significant linear correlation...
of CO₂ emissions with gravimetric water content, texture, pH and V%. The semivariograms presented in Fig. 1 show changes in the emission pattern on the three days studied. We believe that the differences in the spatial pattern of CO₂ emissions are an additional indication of the strong influence of soil temperature and soil moisture on such emissions. Short-term temporal changes in

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>CV (%)</th>
<th>$C_0$</th>
<th>$C_1$</th>
<th>$C_0 + C_1$ (%)</th>
<th>$a$ (m)</th>
<th>Model</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>F19 (μmol m⁻² s⁻¹)</td>
<td>1.46</td>
<td>0.63</td>
<td>31.7</td>
<td>0.09</td>
<td>0.08</td>
<td>53.76</td>
<td>58.4</td>
<td>Sph</td>
<td>0.91</td>
</tr>
<tr>
<td>F25 (μmol m⁻² s⁻¹)</td>
<td>1.72</td>
<td>0.56</td>
<td>24.1</td>
<td>0.05</td>
<td>0.10</td>
<td>32.89</td>
<td>29.6</td>
<td>Sph</td>
<td>0.68</td>
</tr>
<tr>
<td>F27 (μmol m⁻² s⁻¹)</td>
<td>2.80</td>
<td>0.83</td>
<td>21.1</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>CEC (mmol kg⁻¹)</td>
<td>69.47</td>
<td>4.28</td>
<td>5.5</td>
<td>3.90</td>
<td>28.50</td>
<td>12.04</td>
<td>20.4</td>
<td>Sph</td>
<td>0.57</td>
</tr>
<tr>
<td>Total carbon (% weight)</td>
<td>1.23</td>
<td>1.52</td>
<td>11.4</td>
<td>0.21</td>
<td>1.83</td>
<td>10.30</td>
<td>20.2</td>
<td>Sph</td>
<td>0.79</td>
</tr>
<tr>
<td>Fe₄ (g kg⁻¹)</td>
<td>84.1</td>
<td>1.43</td>
<td>16.1</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

* SD: standard deviation, CV: coefficient of variation, $C_0$: nugget effect, $C_1$: structural variance, $C_0 + C_1$: sill, $a$: range distance, Sph: spherical.

Fig. 1. Semivariograms of CO₂ emissions on the three days studied F19, F25, F27 emissions on 19, 25 and 27 November 1998, respectively. Also, the semivariograms of the soil properties correlated with CO₂ emissions are presented: Total Carbon, CEC and Fe₄.
the spatial dependence of gas emission in soils have also been reported by Dasselaar et al. (1998) on succeeding days of measurements.

Our study has shown that the CO₂ emissions from a Brazilian bare soil exhibit different spatial variability for each day of measurement and such models are similar to the ones of soil properties studied. Also, the results indicate that changes in the spatial variability of CO₂ emission are possibly related to the weather event occurring between the days of measurement. Therefore, even eliminating complicating effects of vegetation cover, our results are not so obvious, indicating changes in the spatial variability model from one day to another. As CO₂ emissions from a bare soil are directly related to microbial activity, changes in the spatial variability model are probably due to a complex relationship of several physical, chemical and biological aspects in soils.

Acknowledgements

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References


