

CO₂ flux emissions from Atlantic Rainforest soil: determining the most suitable sampling time

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ABSTRACT

Few studies have established protocols for measuring CO₂ emissions in the soil. In order to determine the time of day which best represents the average daily CO₂ emissions, the present study evaluated the variations in CO₂ emissions throughout the day and the relationship between these emissions and the soil moisture and temperature, in an attempt to standardize data collection in tropical soils. The study was carried out in an Atlantic forest fragment of the coastal tablelands, Brazil. A close relationship between CO₂ emission and soil temperature was observed, with CO₂ emissions decreasing as daytime temperatures increased. The soil moisture had no direct relation with the CO₂ emission, but was only related to the soil temperature. Two groups of CO₂ emissions were observed, forming between the sampling time from 09:00 a.m. to 10:00 p.m., and from 11:00 p.m. to 08:00 a.m. Due to the small difference found between the mean group formed between 09:00 a.m. and 10:00 p.m., which was ~ 8% when compared to the general average, and also the fact that CO₂ is easier to collect during this time, it is suggested that this period is the most suitable time to collect CO₂ in the field.

Keywords: Soil temperature; Soil moisture; Sandy texture

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1 INTRODUCTION

In the past decades, changes in climate have been noticed, especially in variables such as precipitation rates, temperature, and air moisture (THOMPSON et al., 2006). These changes occur due to global warming, which is directly influenced by greenhouse gas emissions (GHGs). These gases are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O).

Due to the impact that GHGs cause, the sustainability of human life on the planet could be affected. This issue has been discussed, and there is a worldwide tendency to commit to neutralizing these gas emissions. Countries have been establishing plans to balance GHG emissions, and there are international initiatives to propose gas mitigation by the year 2050 (OERTEL et al., 2015).

GHGs are important gases, and among them, CO₂ stands out. According to the Intergovernmental Panel on Climate Change (IPCC), it is the most emitted gas by humans, mainly due to the use of fossil fuels. Although CO₂ plays a relevant role on Earth, keeping it at a pleasurable temperature, its excess emission leads to a number of negative effects on global sustainability.

The amount of CO₂ released in the atmosphere is considerable, therefore it is important to study various aspects thereof. Among these aspects, agriculture stands out due to its use of soil as the main substrate for plant development. In addition, soil is the second largest carbon reservoir and can serve as a CO₂ source or drain, thus justifying the increasing number of studies that mention the emissions from soils (FÓTI et al., 2016; OERTEL et al., 2015). Although studies have been conducted in tropical soils (LA SCALA et al., 2000; PANOSSO et al., 2009; THOMAZINI et al., 2015), a number of questions still need to be answered regarding the flow dynamics of CO₂.

CO₂ production in soil is related to its biological and biochemical activity, such as decomposition of biomass, including microbial activity, and root respiration. The CO₂ is transported to the atmosphere by means of diffusion, which consists of the gas moving from the highest concentration zone to the lowest and is responsible for the transport of the majority of the CO₂ due to the pressure gradient.

CO₂ emissions from agricultural areas suffer from great spatial and temporal variability (La Scala et al., 2000; Meurer et al., 2016; Panosso et al., 2009; Teixeira et al., 2011). In addition, these emissions occur differently in tropical and temperate regions (PORTILHO; MERCANTE, 2012; TEODORU et al., 2011), being influenced by several soil attributes (BRITO et al., 2010; NOVARA et al., 2012).

Although several studies around the world are currently being developed using equipment with the principle Infrared Gas Analyzer to measure CO₂ (D'ANDRÉA et al., 2009; CARMO et al., 2014; GARCIA-MONTIEL et al., 2004; IAMAGUTI et al., 2015; MOITINHO et al., 2013; ARAÚJO NETO et al., 2014; THOMAZINI et al., 2015, 2014), most of the studies performed do not clarify the most suitable time to collect CO₂ flow data, or if this time exists. This information can indicate if there is a relationship between the time of day and CO₂ emissions (ALMAGRO et al., 2009; THOMAZINI et al., 2015). For the other gases, this variation has already been verified, for example (ALVES et al., 2012) studied the best time to collect N₂O in Seropédica, the northern region of the state of Rio de Janeiro, Brazil, and Edinburgh, in the United Kingdom. They observed that for both places, between 9:00 a.m. to 10:00 a.m. and 9:00 p.m. to 10:00 p.m. was when the flow best represented the daily average. However, due to the ease of working during the day, 09:00 a.m. to 10:00 a.m. was the preferable time. On the other hand, Costa et al. (2008) determined, based on daily emission curves, and considering operational aspects such as the feasibility of chromatographic analysis of samples 24 hours after collection, that the period between 09:00 a.m. and 12:00 p.m. was the most recommended time for the evaluation of CH₄ emissions in irrigated rice crops in southern Brazil when seeking to obtain values equivalent to the average daily gas emission.

In the manual for equipment that uses the principle Infrared Gas Analyzer, the ideal time to collect CO₂ is not evident, and although studies have been developed (ZANATTA et al., 2014) for countries with a tropical climate, there are no studies indicating the best time for this data collection.

Setting a time at which CO₂ flow should be collected can make it easier to plan the data collection in the field, as well as avoiding overestimating or underestimating

the results when compared with other studies under similar climate conditions. Many of the temporal and spatial variations found in studies evaluating CO₂ flow in the field may be related to the lack of standardizing this stage of data collection, where the collection performed at different times of the day can influence the results collected. Since there is a variation of temperature and humidity during the day, this can consequently influence CO₂ emissions.

Therefore, it is necessary to develop a protocol that aims to establish the standardization of this initial part of the data collection. The objective of this study was to determine which time best represents the CO₂ emissions during the day in a tropical Tabuleiro costeiro soil.

2 MATERIAL AND METHODS

2.1 Site description

The train was built in three fragments of Atlantic Forest in the state of Espírito Santo, Brazil, between the coordinates 39°51'21" W, 18°40'20" S, 25 m above sea level. The soil of the study area was classified as Ultisol (Santos et al., 2018), with the following physical properties: 65 % coarse sand; 19 % fine sand; 13 % clay; and 2 % silt. The chemical analysis showed that the soil presented: pH, 4.8; P, 1.4 mg dm⁻³; K⁺, 8 mg dm⁻³; Ca₂₊ 0.2 cmolc dm⁻³; Mg₂₊ 0.2 cmolc dm⁻³; Al₃₊ 0.5 cmolc dm⁻³; H+Al 4.5 cmolc dm⁻³; and organic carbon 0.9 dag kg⁻¹. According to the Köppen-Geiger climate classification, the predominant climate of the region is Aw (tropical climate with rains in the summer). It has an average annual precipitation of 1,195 mm (INMET, 2017).

2.3 Soil CO₂ exchange

Soil CO₂ readings (μmol CO₂ m⁻² s⁻¹) were performed on eight different days between the months of August and December 2016 over a 24-hour period, with a break of one hour, in an automatic closed system chamber (LI-COR Biosciences, Lincoln, NE, USA) using an LI-8100A infrared gas analyzer with an LI-8100-104C opaque chamber. This system works by sampling the carbon dioxide concentration

though the use of optical absorption spectroscopy. PVC collars (20 cm in diameter) were placed into the soil at five sampling points spaced approximately 6 m apart. In order to be installed, the litter was cut (only for the collar to be attached), with 2.5 cm of the superior part of the collar being placed above the soil surface. The collars were installed thirty days before the readings. Each reading took 2 minutes, and the carbon dioxide concentration was measured every second inside the chamber.

2.4 Soil Temperature and soil moisture

The temperature (°C) and the soil moisture ($\text{m}^3 \text{m}^{-3}$) were sampled at the same time as the CO_2 flow readings from the soil, with a break of one hour over the 24-hour period. The equipment used was the Decagon Devices® 5TM. Sampling was performed 10 cm from the outside of the PVC collar, reaching a depth of 5 cm.

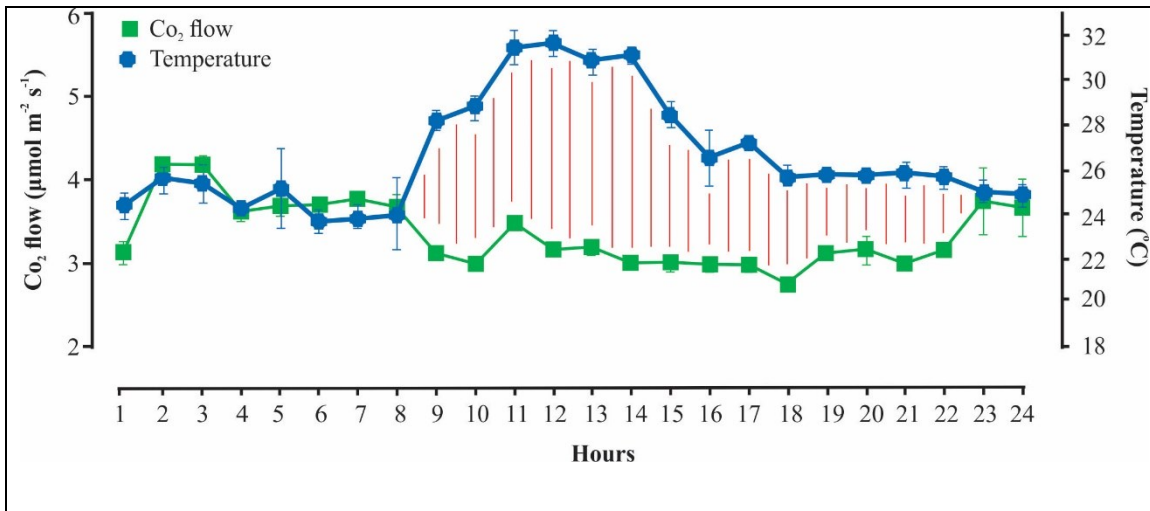
2.5 Statistical analyses

Descriptive statistics of CO_2 flow, temperature, and soil moisture were performed. In order to determine the most suitable time that best represents the daily CO_2 emission rate, a regression analysis of the CO_2 flow, temperature, and soil moisture data was performed using the linear model ($Y_i = b_0 + b_1X_i$). The CO_2 flow data was applied using the Scott Knott test to define a suitable time that best represents CO_2 readings.

3 RESULTS AND DISCUSSIONS

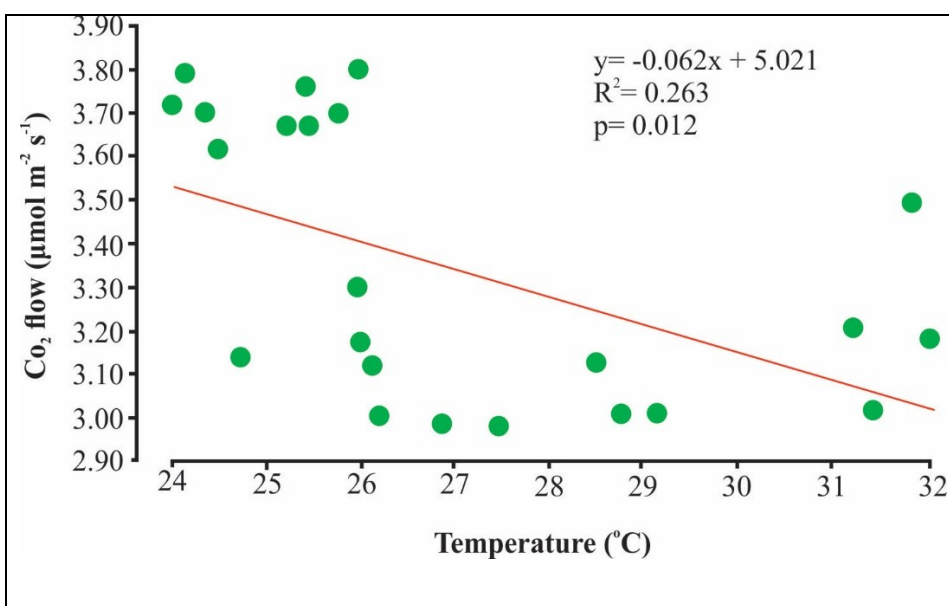
The CO_2 emission and soil temperature dynamics data are shown in Figure 1. It can be observed that there was a tendency for the CO_2 emissions of the soil to decrease as the soil temperature increased, so these variables are negatively related ($r = -0.513$) (Table 1 and Figure 1). The time between 08:00 a.m. and 11:00 p.m. was when the lowest variation occurred, whereas a large variation occurred between 9:00 a.m. and 10:00 p.m. (Figure 1).

Figure 1 - Mean and standard deviation of CO₂ flow emission and soil temperature at different times of the day. Vertical bars in red indicate the variation between CO₂ flow emissions and temperature



According to Figure 2, it is estimated that 26.3 % of the CO₂ emission variation can be explained by the soil temperature variation, and that the linear model best described this behavior. Every 1 °C increase caused a decrease of 0.26 μmol m⁻² s⁻¹ in the CO₂ stream.

Figure 2 - CO₂ flow due to soil temperature



The correlation between CO₂ emission data, soil temperature, and soil moisture can be classified as moderate, being -0.513 and 0.422, respectively. Although the Pearson coefficient was significant for the relationship between CO₂ flow and the soil water content, there was no significance correlation between the CO₂ emission rate and soil moisture ($b_0 = 3.22^*$, $b_1 = 2.29^{ns}$) (Table 1).

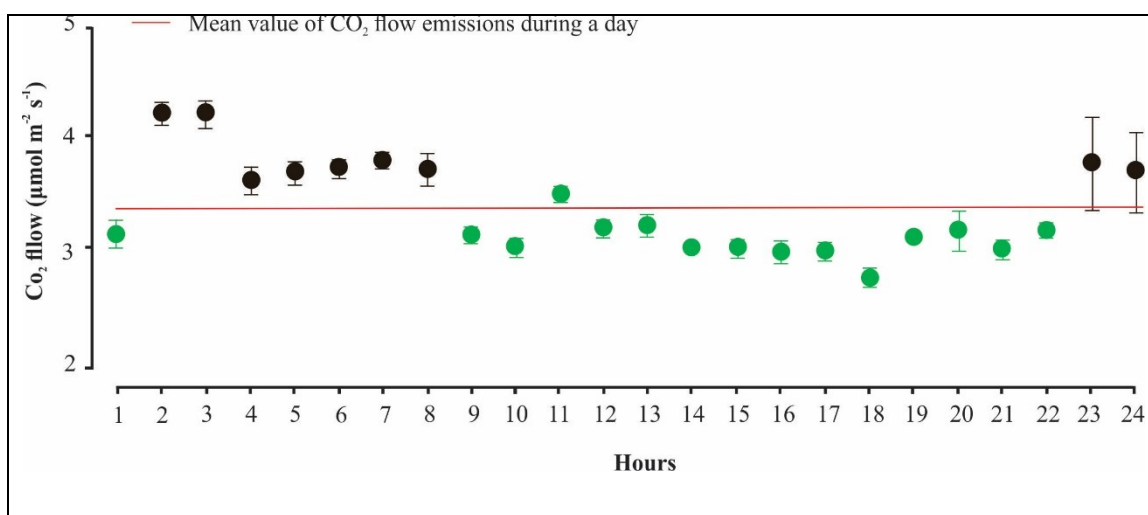
Table 1 - Pearson correlation from the CO₂ flow data, soil temperature and soil moisture

	CO ₂ flow	Soil Temperature
Soil temperature	- 0.513*	-
Soil moisture	0.04 ^{ns}	0.422*

* Significant correlation coefficient ($p < 0.05$)

Figure 3 indicates the CO₂ flow dynamic behavior during the reading period. According to Scott Knott's statistical test, the mean could be grouped into two groups ($p < 0.05$). Emissions observed from 09:00 a.m. to 10:00 p.m. (also includes 01:00 a.m.) do not differ significantly from each other, as well as the readings from 11:00 p.m. to 08:00 a.m. (excluding 01:00 a.m.). The CO₂ flow readings of the second group are significantly higher than those of the first group.

Figure 3 - Mean and standard deviation of the CO₂ emission soil dynamics during the 24-hour reading



The emission average of the group formed in the period between 09:00 a.m. and 10:00 p.m., including 1:00 a.m., underestimated the CO₂ flow by ~8% in relation to the general average, while the group formed between 02:00 a.m. and 08:00 a.m., including 11:00 p.m. and 12:00 a.m., overestimated emissions by ~13 %.

In Brazil, it is possible to identify a large number of soil classes (EMBRAPA, 2006) which were subjected to different pedogenetic processes and which today present variations in the clay fraction texture, mineralogy, structure, and fertility, all of which are known to influence the CO₂ emissions from the soil (LA SCALA et al., 2000; THOMAZINI et al., 2015). The data obtained in this study to standardize the time of day that best represents the CO₂ flow in tropical soils shows that other studies must be conducted in different soil classes and periods of the year. The obtained data provides a notion of how the CO₂ emissions in the soil can behave throughout the day due to the moisture and temperature variation, therefore standardizing the data collection. This is beneficial when comparing the data obtained in different studies.

The thermal behavior observed in the soil in the present study is similar to the results obtained by Costa et al. (2019). Due to the permanent vegetative cover that contributes to the conservation of soil moisture and decreases thermal oscillations, little temperature variation was expected throughout the day, which benefits the soil biota (BRIONES; INESON, 2010, NEGASSA, 2015). However, since the studied soil is predominantly sandy in the surface layer, this texture is characterized by abrupt temperature variations throughout the day when subjected to great atmospheric temperature variations (VAN LIER, 2010), which may explain the oscillation observed throughout the day.

Since the thermal energy is not conducted in the subsurface due to the high air resistance of the macropores, which are present in greater numbers in sandy texture soils, the temperature variations that occurred during the day lead to changes according to gas distributions within the atmosphere, as a result of gases of the gas fraction tending to occupy greater volumes when heated and lower volumes when cooled (VAN LIER, 2010). This fact explains the increase in CO₂ concentration in the

readings at lower temperatures and the decrease at higher temperatures, thus assuming the behavior observed in Figure 1.

The abrupt changes in soil temperature have a strong influence on biological activity in the soil. According to Gholz et al. (2000), when the temperature increases, microbial activity also increases; in the decomposition of leaves it increases up to 2.6 times, and in roots up to 2.0 times with an increase of 10°C, and this consequently raises the CO₂ emissions. However, in the present study, CO₂ flow emissions decreased by 0.26 μmol m⁻² s⁻¹ for every 10 °C of temperature rise. This could be due to the high temperatures which were recorded throughout the day (24-32 °C), which may have caused stress in the microbial biomass, especially during the day, therefore leading to the decrease in microbial activity.

Microbial biomass may play a key role in reducing emissions throughout the day, and one of the major contributors of elevating the soil CO₂ flow during the night may be related to emissions from the root system in the forest area. According to Chu et. Al (2019), the rate of respiratory activity of plants throughout the day, especially at night, is characterized by the release of CO₂ and water. During the study, the water saturation inside the chamber did not remain constant and showed considerable increases during the night. Since it did not rain during the sample collections, it is evident that the roots performing their respiratory processes were responsible for this occurrence. The studied area is characterized as an Atlantic forest fragment, and the collars that were installed had abundant litter and plants with no clearings. As a result, the soil is largely colonized by roots of all types and succession stages, which explains the greater CO₂ flows in the soil between 11:00 p.m. and 08:00 a.m.

Considering the smaller difference between the CO₂ flow mean measured between 09:00 a.m. and 10:00 p.m. compared to the daily average, as well as the lower dispersion of the readings measured by the standard deviation in relation to the general average, it is assumed that the most adequate time to measure the CO₂ flows in the soil is between 09:00 a.m. and 10:00 p.m. In addition, this time of the day is better for working in the field, since it is preferable to collect during the day in Brazil (ALVES et al., 2012).

Although this work indicates the existence of a lower time range, more studies in other soil classes should be done. These studies should focus, in particular, on the different positions of the landscape and altitudes throughout Brazil, since these characteristics can also greatly influence CO₂ emissions, depending on the adopted management practice.

5 CONCLUSIONS

The present study described the CO₂ emissions throughout the day and the relationship of these emissions with the temperature and soil moisture, in order to determine the time of day that approaches the daily emission average, with the aim of standardizing data collections in tropical soils. It was possible to observe a close relationship between CO₂ emissions and soil temperature, where an increase in temperature throughout the day decreased CO₂ emissions. The soil moisture had no direct relationship with the CO₂ emissions, being only related to the soil temperature. It was possible to observe the formation of two CO₂ emission groups, namely the group formed between 09:00 a.m. and 10:00 p.m., including 01:00 a.m., and the group formed between 11:00 p.m. and 08:00 a.m. Due to the smaller difference observed between the mean groups formed between 09:00 a.m. and 10:00 p.m. (including 01:00 a.m.), and as it is easier to collect CO₂ during this time, this period is suggested as the most suitable time to perform CO₂ collections in the field.

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