Experimental Determination of Carbon Dioxide Flux in Soil and Correlation with Dependent Parameters

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Abstract. Carbon dioxide is one of the greenhouse gases responsible for the effects of climate change. The soil respiration process is an important component of the carbon circuit in nature, through which carbon dioxide returns to the atmosphere. The concentration of CO₂ in the atmosphere is directly influenced by any change of carbon flow produced in soil, as the latter is the largest carbon sink in terrestrial ecosystems. The objective of this paper is to present the experimental results obtained using CO₂ flow determination with portable GHG analyzer with closed static chamber, and the relation and influence of the main pedoclimatic parameters, namely temperature and humidity. Future research directions will consider the development of a plan to monitor CO₂ flow from the soil, for different types of land use, in different climatic conditions. During one month of data collection, has been found that soil CO₂ efflux was influenced by soil moisture and soil temperature. Also, the processed data showed how soil respiration rates were dependent on soil moisture.

1. Introduction

In the current context of the increasing carbon content in the atmosphere under the form of carbon dioxide, as well as other greenhouse gases that are related to the soil (the most important being methane and nitrous oxide), soil management and vegetation contributes to increase or decrease of the intake of greenhouse gases from the atmosphere [1]. The CO₂ content of the air in soil is higher compared to the atmospheric air, which means that ecosystems and the soil are an important carbon sink [2], but can also become a potential source for carbon emissions into the atmosphere. Regarding terrestrial ecosystems, soil is the most important carbon reservoir by storing approximately 1600 Pg of carbon to a depth of 1 m [3] and at the same time a complex heterogeneous environment (aqueous, gaseous and solid components) including constituents, organic matter and being a support for living organisms [4,5].

The process of releasing carbon from soil is called soil respiration - carbon dioxide flow in soil [6] [7] being also defined as carbon dioxide produced by living organisms from soil, namely microorganisms, soil fauna and parts of plants found in the soil such as roots and rhizomes [3]. Soil respiration is therefore the sum of autotrophic and heterotrophic respiration of the soil [8]. The CO₂ flow from soil roots and rhizomes represents autotrophic respiration and the CO₂ flow from bacteria, fungi and fauna to decompose organic matter is soil heterotrophic respiration [9]. According to a research
conducted by Raich and Potter (1995), during a year, the carbon flow due to soil respiration is estimated at 77 Pg C, being 10 times higher than the CO$_2$ flow produced by burning fossil fuels [10].

However, determining and quantifying CO$_2$ flow in soil is a rather difficult process to achieve, as the production of CO$_2$ in soil is affected by the various biochemical and physical processes in soil generated by the influence of biotic and abiotic factors. Autotrophic respiration of the soil depends on plant metabolism, the quantity of fine roots and the quality of soil carbon reserves, while heterotrophic respiration of the soil depends on the type and size of the microbial population [8]. Depending on the type of research and on the analyzed ecosystem, several methods to determine CO$_2$ in soil are distinguished, namely the ‘Eddy Covariance’ method, the concentration gradient method or by using the respiration chamber system [11].

Eddy Covariance method is one of the most accurate and direct approaches to measure gas fluxes and monitoring of gas emissions from areas with sizes ranging from a few hundred to millions of square meters. The method relies on direct and fast in-situ measurements of actual gas transport by a 3-D wind speed in real time, resulting in calculations of turbulent fluxes within the atmospheric boundary layer [12]. The concentration gradient method takes into account the differences in CO$_2$ in soil and atmosphere as well as between the soil horizons at a given time [7].

Soil respiration chamber systems classify the methods of determining the CO$_2$ flow into static and dynamic according to the air circulation inside the chamber. Thus, if the air circulates inside the chamber, the method is dynamic and static when there is no air circulation. Both static and dynamic methods are the most widely used and most direct means of determining the carbon flux in the soil. Among the advantages of these systems are greater flexibility in selecting locations and isolating certain components of an ecosystem [13]. Regarding the limitations of the method, they are related to manual settings and use of the device or the lack of continuous observations [14], if the device is not automatic for continuous measurements.

In this paper is presented an experiment with a static chamber system with the aim to establish a measurement plan for different land uses by observing the relations between CO$_2$ flow and other dependent variables as air and soil temperature or soil moisture.

2. Experimental
One of the usual methods of measuring the flow of CO$_2$ at ground surface is by using portable analyzers with dynamic or static chamber systems of known surface and the CO$_2$ concentration is determined over a short period of time [15]. In this experiment the static chamber system was used systematically to record CO$_2$ flows together with other related variables as soil and air temperature and soil moisture. A diverse spatial variability of land use was selected in a compact urban area. The results were statistically analyzed for each location and also for all measurements together.

2.1. The study area
A compact urban area with diverse spatial variability is chosen for data collection was monitored for one month. Measurements have been made according to a schedule, in relation to changes in dependent pedoclimatic variables. The data collected were combined with soil moisture and temperature analysis, as well as climatic conditions (air temperature and precipitations) to capture the dynamic complexity of the carbon flow from soil. The distribution of plots was selected to comprise different land use conditions: low (plot 1, 4, 6 and 8) to high (plot 5) forested areas or without vegetation (plot 2, 3 and 7) to grassland (plot 9).
2.2. Methods
The equipment used in the study area to measure the carbon flux from the soil surface consists of the portable CO$_2$ gas analyzer EGM-5 provided by PP Systems with static closed chamber, together with a sensor for temperature and humidity measurement.

Soil respiration consists of the CO$_2$ production in soil and their release into the atmosphere (gas diffusion and mass flow). The concentration gradient between the soil and the atmosphere determines the diffusion of CO$_2$ into the atmosphere. Mass flow is defined as the pumping of air by fluctuations in atmospheric pressure on turbulent stairs [16,17].

The SRC-Soil Respiration Chamber process measures CO$_2$ flux of the soil surface. The volume of the chamber is 1171 ml, its covering surface is 78 cm$^2$ and the time period set for a measurement is 60
seconds [18]. The EGM-5 calculates both a linear and a quadratic match of the measured data. In the following are defined the equations and parameters involved in CO₂ flux measurement and other dependent variables (temperature and moisture).

\[
FCO_2 = (C_n - C_0) T_n \times V \times A,
\]

where

- \( FCO_2 \) = respiration/assimilation rate
- \( C_0 \) = CO₂ concentration at \( T=0 \)
- \( C_n \) = concentration at a given time \( T_n \)
- \( A \) = area of exposed soil
- \( V \) = total volume of the system

Delay (seconds) = The countdown in seconds from \( x \) to 0, where \( x \) is the value specified for the delay in the SRC; the amount of time the instrument waits at the beginning of each session before starting to calculate the respiration. In this case the delay is 12s [18].

Soil Respiration measurements was carried out using EGM-5 Software. EGM-5 Software assumes a quadratic relation \( y = a + bx + cx^2 \) between the chamber concentration \( (C = y) \) and the time \( (T = x) \) from the beginning of the measurement to take account of the nonlinearities caused by leakage. The quadratic equation is \( y = a + bT + cT^2 \) where \( C \) and \( T \) are a series of measurements of the CO₂ concentration of the chamber taken over time and \( a, b, c \) are calculated coefficients. The respiration rate is calculated based on CO₂ change rate at time zero or \( \frac{dC}{dT} \) at \( T = 0 \) [18].

Soil temperature and moisture affect CO₂ soil flow in different ways. Soil temperature is the most significant factor that controls CO₂ soil flow in all sites, based on the results from analyzes that identify temperature as the dominant independent variable [19-24].

In order to verify soil temperature values recorded with the EGM-5 device, additional measurements were made at the same time, with the Water/shockproof thermometers, Traceable® produced by Control Company, with an accuracy of +/- 0.5 degrees Celsius. Soil moisture was measured with the soil moisture sensor attached to the static closed chamber system designed for CO₂ flux measurement from soil. It is an in situ sensor that can measure both soil moisture and soil temperature. It measures the volume of moisture content of the soil based on the dielectric constant, which is proportional to the moisture content of the soil. The effect of soil moisture on CO₂ soil flux is less clear, and soil moisture may interact with soil temperature [25].

3. Results and Discussions

Within the perimeter for measuring the soil CO₂ flux, where 9 distinct areas were selected in terms of vegetation cover, it was found that the highest values of CO₂ flow in the soil were obtained in the area covered with abundant forest vegetation (figure 3).
Figure 3. Representation of recorded values for soil CO\textsubscript{2} flux (DC and SRL) and the soil moisture (M\textsubscript{soil}) during the measurements for one month period in the area covered with forest vegetation (Plot 5).

From the previous figure it is observed the variation of the CO\textsubscript{2} flux in the analyzed period as well as the soil moisture for the plot in which measurements were made on the type of soil cover with abundant forest vegetation. Within this plot were recorded the highest values of CO\textsubscript{2} flux, which also shows an increasing trend over the period time in which measurements were done. The lack of data for soil moisture and the lowest values for CO\textsubscript{2} flow were observed in a period with low temperatures and solid precipitations. These recorded measurements will be used to detect future errors and will help to improve the interpretation of future results. The following figure shows the result of checking the recorded soil temperature values.

Figure 4. Comparison of soil temperature values recorded with the control thermometer and those recorded with the probe attached to the EGM-5 device.
The evolution of the temperatures recorded in the soil with the control thermometer compared to those recorded with the attached sensor to the EGM CO$_2$ determination device can be observed. Thus, at the moment of first measurement (plot 1) the differences were higher than 4 Celsius degrees. At the last measurement (plot 5), made at an interval of 15 minutes from the first one, the differences approached 2 Celsius degrees. Thus, it can be seen that in order to stabilize the soil temperature recorded with the EGM-5 sensor is required an interval of at least 15 minutes.

Figure 5 shows the recorded values of the CO$_2$ flow and the variables with which it can be related for all measurements made on the 9 plots. The CO$_2$ flux values, accumulated within 60 seconds for each recorded measurement. The values recorded for all plots are represented consecutively and chronologically on the same graph.

**Figure 5.** All soil CO$_2$ (DC) flux data from successive measurements.

From the analysis of the previous figure can be deduced the increasing trend of CO$_2$ flux in the measurements represented chronologically for all plots. It is also possible to distinguish the points where the recorded flow was maximum, which also maintained the increasing trend during the period of measurements. The following two graphs (figure 6 and figure 7) show the relationship between CO$_2$ flow and soil respiration. It is observed that, under normal conditions, the soil CO$_2$ flow increases proportional with the soil respiration rate.
Figure 6. Correlation between soil respiration rate (SRL) and soil CO$_2$ flow (DC).

Figure 7. Correlation between soil quadratic respiration rate (SRQ) and soil CO$_2$ flow (DC).

The following figure shows the CO$_2$ flow (DC) values and the air temperature recorded with the EGM-5 device.
Figure 8. Difference of soil CO$_2$ concentration (DC) and the dependence on air temperature (Tair) inside the closed dynamic chamber.

From figure 8, it can be observed that the tendency to increase the soil CO$_2$ flux in the presence of higher air temperatures. At peaks where the air temperature was higher (19-24°C) were recorded values of soil CO$_2$ flux between 27 and 41 ppm, compared to lower values of soil CO$_2$ flux recorded under the influence of temperatures in the range of 8-12°C.

The graph in figure 9 shows the relation between the values of soil CO$_2$ flow and the soil temperature recorded with the EGM-5 sensor. The sensitivity of soil CO$_2$ flux can be observed in the presence of higher soil temperatures, the maximum temperature range was 19-22°C, with an accuracy of (+/− 0.3°C) [15].

Figure 9. The difference of soil CO$_2$ concentration (DC) and the dependence on soil temperature (Tsoil).
From the charts presented in figure 8 and 9 results the tendency to increase soil CO$_2$ flow during the measured period, correlated with the air and soil temperature. By interpreting the chart presented in figure 10 can be concluded that soil CO$_2$ flux (DC) increase proportional with soil respiration rate (SRL).

**Figure 10.** Soil respiration according to the values of the CO$_2$ concentration inside the closed dynamic chamber and the volumetric soil humidity for all successive measurements.

The effect of soil moisture on CO$_2$ flux is somewhat less clear, but the interaction of soil moisture (Msoil) with soil respiration is visible at the maximum peaks recorded during successive measurements.

4. **Conclusions**

During the recorded successive measurements for CO$_2$ flow, a wide range of changes in physical conditions occurred, being represented on the same graphs (e.g. soil temperature as well as soil moisture). The results support previous research that has shown the major influence of soil temperature on soil CO$_2$ flux, furthermore the overall sensitivity of soil CO$_2$ flux changed with soil temperature. Soil moisture had a significant influence on soil CO$_2$ flux and also was recorded the magnitude change of the overall sensitivity of soil CO$_2$ flux to soil temperature change. The variation in soil CO$_2$ fluxes during the recorded measurements may indicate that the soil CO$_2$ flux is influenced by the climatic conditions. As shown in Fig.10, soil respiration rates (SRL) depend on soil moisture, and the difference in soil CO$_2$ concentration increase proportional with them. Higher soil respiration rates were often observed in warmer and wetter conditions, while lower soil respiration rates were observed in cold and dry conditions. These recorded measurements will be used to detect errors, for the preparation of future measurements on other plots and will help to improve the interpretation of future results.

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