EVOLUTION OF C-CO2 IN SOILS OF DIFFERENT ECOSYSTEMS IN THE ALTO ACRE REGION, ACRE, BRAZIL

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ABSTRACT

Different studies, developed over the years, have shown that the increase in human activities on the soil can influence the release of gases related to the increase in the greenhouse effect. In this sense, the use of methods that evaluate the evolution of C-CO2 has been considered as important indicators to detect changes in the environment, since they can be influenced by the crop and its cultivation system as a result of impacts on microbial activity. The objective of this work was to evaluate the release of C-CO2 from soils submitted to different ecosystems. Laboratory tests were carried out where soil samples, submitted to five different ecosystems, were collected in three different periods throughout the year in the municipalities of Brasiléia and Epitaciolândia, Alto Acre region, in the state of Acre, and were subsequently incubated. Subsequently, the evolution of C-CO2 was evaluated, and the readings were carried out periodically until the 500th day of incubation of

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the samples. The data were analyzed in order to evaluate the effect of different plant species on the evolution of C-CO2. Regarding the collection carried out in April, there was no difference in the evolution of C-CO2 between the areas. However, in the month of June, which comprises the period of the beginning of the transition between the rainy season and the dry season, and in the month of August, the dry season, it was observed that in the area of native forest occurred the highest values of C-CO2 flux, differing statistically from other areas within these months of collection. Between the collection times, only in the area of agroforestry system no significant differences were recorded in the evolution of C-CO2. The highest accumulated values of C-CO2 were recorded in the following sequence: native forest > agroforestry system > area with cassava > cultivated pasture > area with banana. It is concluded that the areas that present a greater contribution of plant material to the soil can serve as a stimulus to the development of microorganisms that, consequently, increase the flow of CO2, especially until the beginning of the dry season and that the absence of moisture negatively influences the emission of C-CO2, causing significant differences in the amount of release of C-CO2 between the study areas at the same time of evaluation.

Keywords: Respirometry. Mineralizable carbon. Carbon dioxide.

INTRODUCTION

Studies regarding the implantation of different crops in the soil on its biota have proved to be a growing concern of society in search of improvements in the preservation and conservation of environments. It is known that soil is a dynamic natural body made up of mineral and organic materials and that it houses a series of organisms that determine the balance of many ecosystems.

This organic material, present in soils, is essential for improving their fertility and also for increasing plant productivity, in addition to serving as a substrate for microbial activity. Knowledge about the dynamics of decomposition of organic residues present in soils can contribute to the definition of more appropriate procedures for crop management and a better use of these materials with a view to increasing soil quality.

The biological processes that occur on the surface, or not, of soils also serve as indicators of their quality, being closely linked to each other, constituting a system that is considered complex and dynamic, where the density and diversity of the communities of microorganisms and how they are impacted by climate change, such as those that can be caused by the emission of carbon dioxide into the atmosphere, is often unknown. as well as on the implications related to the ecosystem itself.

It is known that during the decomposition of products such as organic materials, these microorganisms produce CO2, the release of which is an indicator of microbial activity, the supply (quantitative and qualitative) of organic substrates and other interactions between the microbiota and the soil matrix, as reported by Ciotta *et al*. (2004) and Araujo *et al*. (2016). In the soil, the main responsible for CO2 emissions are fungi and bacteria through the degradation of organic material (SILVA *et al*., 2007).

The measurement of the microbiological activity of these organisms, through respiration, biological nitrogen fixation, mineralization of organic compounds, enzymatic activity and microbial biomass is done by well-established techniques, and these characteristics are used, among other purposes, as sensitive indicators of pollution (BROOKES, 1995).

Thus, the metabolic activity of the microbial population in the soil can be analyzed through the amount of CO2 released by the respiration of microorganisms (ZIBILSKE, 1994), aerobic and anaerobes (GAMA-RODRIGUES *et al*., 2005). Microbial respiration is quantified from the oxidation of soil organic matter by aerobic microorganisms, which can be estimated by CO2 emission (MOREIRA; SIQUEIRA, 2006).

Soil respiration is given by the sum total of metabolic functions that result in the production of CO2, and that are related to soil biota, as well as to moisture, temperature and aeration (JOICE, 2012). The activity of soil microorganisms is dependent on energy source and C, obtained mainly by the decomposition of soil organic matter - MOS (VEZZANI; MIELNICZUK, 2009).

The addition of C below the soil surface is as important to microorganisms as the addition over the surface, in which live and dead roots provide readily available substrates for microbial activity to transform nutrients and alter soil structure (HINSINGER *et al*., 2009).

C is the main constituent of soil organic matter (SOM), which interferes and interacts with practically all physical, chemical and biological processes and attributes that occur in the soil, influencing, for example, water retention, nutrient availability and cycling, the activity of micro and macroorganisms, the formation of aggregates, the complexation of heavy metals, among others.

More specifically, among the global compartments of C, soil is the largest reservoir of the terrestrial ecosystem. According to Houghton (2001), the stock of organic C in soils varies between 1.5 and 2.0 Pg, being about twice as large as the stock of C in the atmosphere and about three times greater than the C contained in the planet's plant biomass (LAL, 2004).

Carbon is one of the main components of soil organic matter (GUEDES, 2009), and its stocks vary according to the rates of addition by plant and/or animal residues, and of loss, among them, those resulting from erosion and oxidation by soil microorganisms. In soils without anthropogenic action, the content and stock of these elements are basically determined by temperature, humidity and soil type (BAYER *et al*., 2009).

The carbon cycle is its closed circulation in the compartments of the biosphere, atmosphere, hydrosphere, and lithosphere. In the atmosphere there is mainly carbon dioxide (CO2), which, even in a small proportion in relation to planetary carbon (0.001%), is essential for life on Earth and for the balance of the climate. The slow carbon cycle is the circulation of carbon fixed in sedimentary rocks and fossil fuels, which return to the atmosphere on a millennial scale, through volcanism, erosion (fluvial) and extraction. The exchanges of the biosphere and the ocean with the atmosphere form what is called the rapid carbon cycle (ALICE, 2005).

Mineralizable carbon is quantified from the evolution of CO2 (MENDONÇA; MATOS, 2005; LOSS *et al*., 2013). The rate of decomposition of organic material and the consequent release of C-CO2 are determined mainly by the intrinsic characteristics of the organic matter itself, such as: C/N ratio; carbohydrate contents, lignin; degree of aggregation; soil characteristics (pH, nutrient contents and moisture) and environmental characteristics (temperature and precipitation) (DAVIDSON; BELK; BOONE, 1998; BROOKES, 1995).

CO2 has been the object of many recent studies, given that the increase in its concentration in the atmosphere causes the aggravation of the so-called greenhouse effect, which causes climate change through global warming, threatening the natural balance of the planet. This increase in the concentration of greenhouse gases (GHG) in the atmosphere over the years, which causes changes in vegetation, disturbances in aquatic levels and agriculture, affects food and nutritional security throughout the planet (HUNGATE *et al*., 2000; ALPINO *et al.* 2022), being called today as climate change.

Santos *et al*. (2024) report that the greenhouse effect is a natural phenomenon, composed of small amounts of GHGs, which maintains the Earth's average temperature due to the absorption of infrared radiation, however, the increase in the concentration of these gases can block the exit of thermal infrared rays and greatly increase the average temperature of the planet, causing negative consequences, such as decreased water; increase in the desertification process; extinction of plants and animals and decrease in agricultural and livestock productivity.

The report of the *Intergovernmental Panel on Climate Change* (IPCC, 2021), states that the planet will warm in the coming years, reaching an increase of 1.5 °C by the year 2030, and presents that in the year 2019 atmospheric concentrations of CO2 were higher than at any time in at least 2 million years and the concentrations of methane and nitrous oxide, Both significant greenhouse gases, they were higher than at any time in at least 800,000 years.

The results presented by the IPCC demonstrate that reducing deforestation in the Amazon would also be a way to balance the climate, which demonstrates the importance of studies that evaluate the impacts of the implementation of different agricultural systems on the dynamics of C-CO2 evolution. According to SEEG (2018), most of the greenhouse gases emitted come from indirect emissions, resulting from the conversion of forests into pasture and agriculture areas, and another portion comes directly from the agricultural sector, such as enteric fermentation and soil management.

Among the C reservoirs in terrestrial ecosystems, soil is the most expressive. According to the work of Jobbágy and Jackson (2000), the world stock of organic carbon in the soil is 1,502 Pg for the depth of 0 to 100 cm. In Brazil, Vasques *et al*., (2021), estimate, in the first meter of soil, an amount of 67 Pg of organic carbon. The Brazilian Amazon forest, according to studies by Cerri *et al*. (2006), has a potential to sequester C in the order of 421 to 470 Tg $^{year-1}$; of this total, about 30 % (126 to 141 Tg $^{year-1}$ of C) would be accumulated by the soil, and the remaining 70 % (295 to 329 Tg $^{year-1}$ of C), due to aerial biomass.

According to Townsend *et al.*, (2006), the world's main cause of CO2 release into the atmosphere is the burning of fossil fuels. However, the decomposition of soil organic matter directly affects the cycle and the release of CO2, which can be increased according to the type of crop and soil management, by influencing the deposition and mineralization of soil organic matter (LA SCALA *et al.*, 2008; SCHWARTZ *et al.*, 2010 MALUF *et al.*, 2015).

Thus, studies that aim to understand the relationship between the plant community, the microbial community and the carbon emission associated with carbon dioxide are of fundamental importance to better understand the process of climate change. Thus, the objective of this work was to evaluate the evolution of C-CO2 from soils subjected to different crops, seeking to highlight the potential consequences in the environment.

METHODOLOGY

The experiment was carried out in the Alto Acre region, in the state of Acre, with soil sampling in the municipalities of Brasiléia (11° 00' 36" S - 68° 44' 52" W) and Epitaciolândia (11° 01' 44" S 68° 44' 27" W). According to Köppen's classification, the climate in the state of Acre is of the equatorial type, hot and humid. It has average annual temperatures ranging between 24.5 ºC and 32 ºC, remaining uniform throughout the state and predominating throughout the Amazon region. There are two distinct seasons: a dry season (May to October) and a rainy season (November to April). Rainfall rates vary from 1,600 mm to 2,750 mm per year (ACRE, 2010).

The treatments consisted of five areas, four in the municipality of Brasiléia (cassava planting, banana planting, agroforestry system and native forest) and one area in the municipality of Epitaciolândia (cultivated pasture), where soil samples, at a depth of 0 to 20 cm, were collected for physical characterization, and the granulometry and textural classification of the soil were determined. as shown in Table 1.

Table 1. Physical attributes of the surface horizon (0-20 cm) of the soils of the study areas

Experimental Area	Grain size				Textural Classification
	Coarse sand	Fine sand	Silt	Clay	
	----------------- Kg $^{Kg-1}$ -----------------				
Cassava	0,086	0,504	0,289	0,121	Franco-arenosa
Banana	0,006	0,588	0,281	0,125	Franco-arenosa
Pasture	0,435	0,031	0,152	0,082	Franco-arenosa
Agroforestry	0,081	0,518	0,254	0,148	Franco-arenosa
Eye	0,049	0,394	0,349	0,208	Franca

Regarding the chemical characteristics, these soils were analyzed for their hydrogen potential, phosphorus, potassium, calcium, magnesium contents, and organic matter content, as shown in Table 2, and all chemical and physical analyses were carried out at the Soil, Plant Tissue and Fertilizer Analysis Laboratory of the Federal University of Viçosa.

Table 2. Chemical attributes of the surface horizon (0-20 cm) of the soils of the study areas

Experimental Area	pH (H2O)	Ca2+	Mg2+	P	K	Organic matter
		------ cmolc dm^{-3} ------		------ mg dm^{-3} ------		day $^{kg-1}$
Cassava	6,08	2,69	0,71	3,6	27	1,98
Banana	6,10	7,34	2,48	17,8	63	0,26
Pasture	5,87	0,96	0,26	1,2	51	0,79
Agroforestry	5,47	2,13	1,44	5,8	81	2,96
Eye	5,59	4,94	3,32	4,4	81	3,00

For the study of the evolution of C-CO2, three soil samples were collected in each treatment at the depth of 0-20 cm. These samples were sent to the Multidisciplinary Laboratory of the Rio Branco Baixada do Sol campus of the Federal Institute of Education, Science and Technology of Acre, where they were air-dried for 72 hours. Then, 50 g of Air-Dried Fine Earth (TFSA) were incubated in plastic containers (hermetic closure) of 500 cm3, with humidity adjusted to 70% of the field capacity.

In each container containing soil, a vial containing 30 mL of 0.5 mol L-1 NaOH solution was inserted to capture CO2 and another containing 30 mL of H2O, in order to preserve the moisture of the samples. The containers were hermetically sealed and incubated at 25 ºC. After the first 48 hours of incubation, the containers were opened for approximately 15 minutes for air exchange and the flask containing the NaOH was removed. After the time, another flask containing 30 mL of a new 0.5 mol L-1 NaOH solution was placed for new incubation.

While waiting for the time for air exchange, 10 mL of the NaOH solution (previously incubated with the soil) was pipetteted to 125 mL erlenmeyer solution, and 10 mL of 0.05 mol L-1 BaCl2 solution and three drops of 1% phenolphthalein were added. Then, the samples were immediately titrated with 0.25 mol L-1 HCl solution until the titrated solution changed from violet to colorless. The incubation periods of the samples were repeated as described in Mendonça and Matos (2005). For the CO2 evolution assessments, soil samples were collected at three times, in April, June, and August 2021.

Finally, the results were submitted to analysis of variance with the application of the F test and the mean values were compared to each other by Tukey's test at the level of 5 %

of significance, with the aid of the statistical program Sisvar 5.8 - Program for Analysis and Teaching of Statistics developed at the Federal University of Lavras (FERREIRA, 2011), considering a completely randomized design in a factorial scheme, according to the number of sampling areas and times.

RESULTS AND DISCUSSION

The distribution of the evolution of C-CO2 did not present, in April, significant differences in any of the areas under study (Table 3) in relation to the type of crop and, consequently, soil management adopted. However, there is a trend towards greater accumulation of organic matter in soils with agroforestry and native forest, as shown in table 2.

Table 3. Evolution of C-CO2 in the study areas in the three months of soil sampling

Area Experimental	April	June	August	Cumulative total
	------------------ mg CO2 100 cm^{-3} ------------------			
Cassava	135,58From*	162.26Mb	136,80From	434,64
Banana	149,33Aa	157.82m	86.75Bb	393,90
Pasture	137.12Aa	155.17Ba	105.45Bb	397,74
Agroforestry	152.10Aa	171.75Ba	133.40Aa	457,25
Forest	159.04ab	199.58Aa	137.45ab	496,07

*Means followed by the same uppercase letter in the column or lowercase in the row do not differ significantly by Tukey's test at the 5% level of significance.

These results of the first sampling period may be associated with the management conditions and presence and the areas of monoculture existing in these areas, in addition to the existence of moisture because it is still within the longest rainy season in the state and because these areas also have the highest content of organic matter in the soil (Table 2). Loss *et al*., (2013), observed in their study high levels of C-CO2 in an agroforestry system after contact with moisture, and relate this to better quality of soil organic matter, as there is greater plant diversity, which can also be extended to the area of native forest, when compared to the other systems analyzed in this work.

In June, there was a statistical difference for the evolution of C-CO2 in the native forest area in relation to the other areas under study. It is important to remember that in this month, the dry season begins. However, in the case of native forest, this area most likely has a greater capacity to maintain moisture in the soil for a longer period because it is an environment with a greater presence of organic material on the soil, contributing to keep the soil moist.

According to Costa *et al*. (2006), undecomposed organic matter has a water retention capacity of around 80% and humified materials can have a water retention capacity of 300 to 400%. Thus, in the area of native forest, the greater amount of organic material had a greater capacity to retain moisture in the soil, which, according to Miranda *et al*. (2008), favors edaphic respiration, consequently, the increase in the flow of CO2 in this environment.

Regarding the sampling carried out in August, the cultivated pasture and banana areas presented the lowest values of C-CO2 emissions, differing statistically from the other areas under study. This decrease may be associated with a lower availability of moisture in these areas and an excessive increase in temperature because it is the period when the climate is usually drier and sunnier.

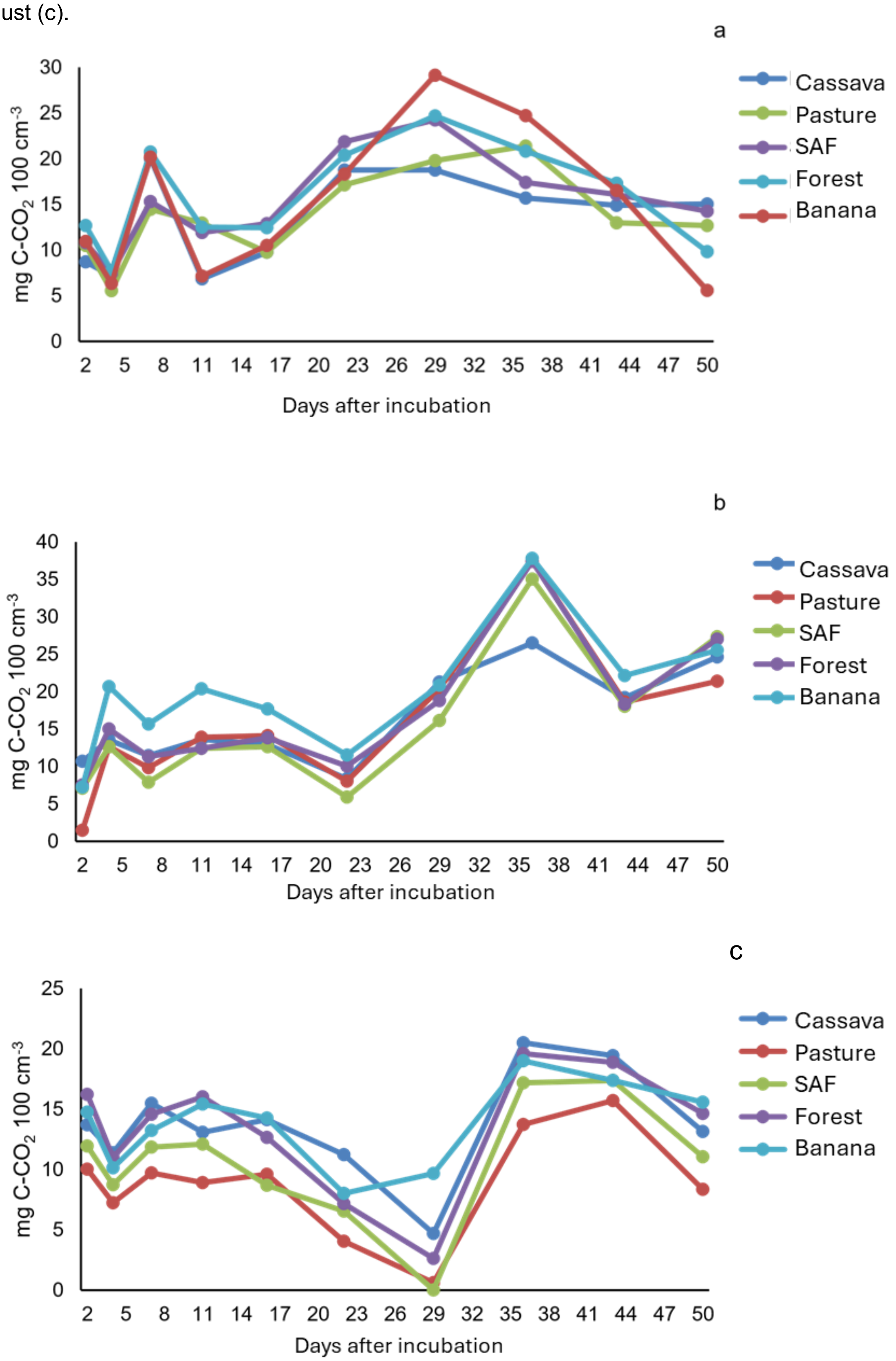
According to Araújo *et al*. (2016), the microbial activity, responsible for the production of CO2, is controlled by the temperature and water content in the soil, if it does not present a favorable temperature within the physiological limits of the organisms involved, the activity of C-CO2 emission may be interrupted.

Regarding the evolution of C-CO2 between the different soil sampling times, it is possible to see that there was a trend of increase in the values of C-CO2 evolution from April to June, coinciding with the end of the rainy season and, subsequently, a reduction in this evolution from June to August, when the effects of the dry season are accentuated (Table 3).

According to some authors (COSTA *et al*., 2008; PANOSSO *et al*., 2009; SILVA-OLAYA *et al*., 2013), soil temperature and moisture are the variables that best explain the changes in CO2 emissions over time, as can be observed throughout the incubation period during the months under study (Figure 1). Oliveros (2008) states that soil moisture exerts a great influence on CO2 emissions, as it can both favor and inhibit the production of CO2, with theoretically an optimal humidity that maximizes biological respiration.

Carvalho *et al*. (2008) and French *et al*. (2009), explain that soil microorganisms, when feeding on the available SOM, release C-CO2, culminating in peaks that can be observed over time (Figure 1). However, as they die due to lack of substrate, the evolution of C-CO2 slows down. However, these organisms that have died will be used as a source of energy by the others, which will multiply as the process of evolution of C-CO2 continues.

Figure 1. Evolution of C-CO2 in samples (0-20cm) incubated up to 50 days in the months of April (a), June (b) and August (c).



Junior Reis and Mendes (2007) emphasize that a high respiration rate can also be interpreted as a desirable characteristic when considering that the decomposition of residues will make nutrients available to plants. In addition, it is known that the activity of microorganisms also depends on the availability of nutrients so that there is quantity and quality of organic material to serve as a source of energy for this population (GNANKAMBARY *et al*., 2008).

CONCLUSIONS

The areas that have a greater contribution of plant material to the soil can serve as a stimulus to the development of microorganisms that, consequently, increase the flow of CO_2, especially until the beginning of the dry season;

In soils with low humidity, there is a reduction in C-CO_2 emissions, causing significant differences in the amount of C-CO_2 release between the study areas at the same time of evaluation.

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