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Comparison of carbon dioxide efflux in different land use typologies

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ABSTRACT

Management systems are crucial for soils functioning as a drain or source of greenhouse gas emissions. In this sense, among the alternatives for reducing the precursors of the greenhouse effect are integrated agricultural production systems, particularly Agroforestry Systems. These integrated systems maximize the use of biological cycles, soil, and animal waste, reducing agrochemicals and improving the condition of the rural populations involved. The present study aimed to evaluate the CO_2 efflux in different land use types. The study was conducted in four agroecosystems: Forest (FO), Agroforestry Systems (AFS), Mandala (MD), and Degraded area (DA). To quantify the CO_2 emanating from the soil, 10 mL of 0.5 N KOH aqueous solution is used and titrated using 0.1 N HCl, phenolphthalein, and 1% methyl orange as an indicator. The CO_2 concentration from 5:00 am to 5:00 pm was lower. The lowest CO_2 production occurred in FO (82.7 CO_2 mg m^{-2} h^{-1}), statistically differing from the other areas that obtained a CO_2 rate higher than 140 mg m^{-2} h^{-1}. As for kinetics, it was observed in all areas that the greatest release of CO_2 during the day occurred at 7:00 am, and this release decreased as the soil temperature increased. The greatest release of CO_2 and the highest temperatures occurred in DA, showing that these systems with anthropic modifications can be considered CO_2 emitters however, systems closer to the natural ecosystem, such as the AFS, will store carbon in the soil, functioning as a carbon store. Therefore, to reduce CO_2 emissions from agricultural activities, it is necessary to use systems that imitate natural ecosystems.

Keywords: Microorganisms, Climate change, Agroecosystems, Sustainable production.

Comparação do efluxo de dióxido de carbono em diferentes tipologias de uso da terra

RESUMO

Os sistemas de manejo são determinantes para que os solos funcionem como dreno ou fonte de fontes de emissão dos gases de efeito estufa. Neste sentido, entre as alternativas para redução dos precursores do efeito estufa se encontram os sistemas integrados de produção agrícola, em especial, os Sistemas Agroflorestais. Esses sistemas integrados maximizam o aproveitamento dos ciclos biológicos, solo e resíduos produzidos pelos animais, além de diminuir a utilização de agroquímicos e melhorar a condição das populações rurais envolvidas. O objetivo do estudo foi avaliar o efluxo de CO_2 em diferentes tipologias de uso da terra. O estudo foi conduzido em quatro agroecossistemas: Floresta (FL), Sistemas Agroflorestais (SAF), Mandala (MD) e Área degradada (AD). Para a quantificação do CO_2 emanado do solo utilizam-se 10 mL de solução aquosa de KOH 0,5 N, e depois dosado por titulação utilizando-se HCl 0,1 N, tendo como indicador a fenolftaleína e o alaranjado de metila a 1%. A concentração de CO_2 no período de 5h às 17h foi menor. A menor produção de CO_2 ocorreu na FL (82,7 CO_2 mg m^{-2} h^{-1}) diferindo estatisticamente das demais áreas que obtiveram uma taxa de CO_2 superior a 140 mg m^{-2} h^{-1}. Quanto a cinética, observou-se em todas as áreas que a maior liberação de CO_2 no período diurno ocorreram às 7 horas, e a essa liberação foi diminuindo à medida que a temperatura edáfica foi aumentando. A maior liberação de CO_2 e as maiores temperaturas ocorreram na AD, evidenciando que sistemas que sofreram modificações antrópica emitem mais CO_2, no entanto, sistemas mais próximos do ecossistema natural como o SAF irão armazenar carbono no solo, funcionando como estoque de carbono. Dessa forma, para que haja menores emissões de CO_2 originadas das atividades agrícolas se faz necessário o uso de sistemas que imitem os ecossistemas naturais.

Palavras-chave: Microrganismos, Mudanças climáticas, Agroecossistemas, Produção sustentável.

1. Introduction

Management systems determine whether soils act as a drain or a source of GHGs (IPCC, 2001). Traditional production systems, with soil turning and applying agricultural inputs and pesticides, contribute to the high rates of CO_2 release (Bartz et al., 2013). Costa et al. (2014) point out that systems capable of increasing the addition of organic matter to the soil and carbon sequestration should be prioritized, which will act as a CO_2 drain. The systems with the best sustainability indexes feature conservationist methods, with Agroforestry Systems (AFS) standing out, as they condition living and well-aggregated soils, maintain biodiversity, plant cover, and greater organic matter decomposition dynamics, consequently acting positively on the soil microbiota (Simon et al., 2019; Lazeris et al., 2021).

Some studies have shown that well-managed agroecosystems are alternatives with a high carbon sequestration capacity, and with the right practices, they can keep it in the soil until it reaches its final equilibrium (West and Post, 2002; Armstrong et al., 2003; Luo and Zhou, 2006). In the quest to understand the processes that influence the global carbon balance and, consequently, global warming, several studies and surveys have been conducted in recent decades seeking to characterize CO_2 efflux through the soil in the most diverse biomes on the globe (Castellano et al., 2017).

CO_2 emission is linked to microbial activity, decomposition of soil OM, and root respiration and is an indicator for evaluating sustainable systems (Costa et al., 2017). The release of CO_2 depends on biotic and abiotic factors, so any factor that alters the microclimatic conditions of the soil and its interface with the atmosphere can affect the edaphic respiration rate (Valentini et al., 2015). Lima and Araújo (2018), emphasize that edaphic quality can be understood from changes in its physical, chemical, and biological characteristics, and if the organic matter content is high, the greater the presence of microorganisms in the soil.

Agricultural production systems are among the anthropogenic activities that emit CO_2 into the Earth atmosphere. This emission can be intensified according to the management and system used for agricultural production (Montenegro, 2020). It is important to improve knowledge of different multifunctional sustainable production systems that contribute to reducing CO_2 emissions, one of the greenhouse gases, and increase the carbon stored in the soil (López-Teloxa and Monterroso-Rivas, 2020).

Recent research (Mátyás et al., 2020; Gomes et al., 2021; Leal et al., 2020; Silva et al., 2020) has shown that different cropping systems have affected soil respiration and biological activity. Although soil processes play a key role in carbon fluxes, there are still few studies in the Agreste Mesoregion of Paraíba, in particular the Brejo Microregion, on the dynamics of respiration and leaf decomposition and knowing that this information is of great relevance, it is pertinent to make these evaluations (López-Teloxa and Monterroso-Rivas, 2020; Silva, 2022). This study aimed to evaluate CO_2 efflux in different land use typologies.

2. Material and Methods

The study was conducted in the municipality of Bananeiras, located in the Agreste mesoregion of Paraíba, characterized as a transitional ecotone between Caatinga and Atlantic Forest, at 6°46' S and 35°38' W, and 552 m of altitude. It has temperatures of 18 to 27 °C and average rainfall of 1200 to 1500 mm, with rainfall from fall to winter (concentrated in May to August) (Francisco et al., 2018). The evaluation of CO_2 release and soil temperature was conducted at the Center of Social Human and Agrarian Sciences (CCHSA) of the Federal University of Paraíba (UFPB), Campus III, Bananeiras - PB, in four different environments (Figure 1):

Forest (FO): presenting a transitional environment between the Caatinga and Atlantic Rainforest biomes; this ecosystem is characterized by large and medium sized trees such as Angico (*Anadenanthera macrocarpa* (Benth.) Brenan.), sete cascas (*Samanea tubulosa* (Benth). Barneby & JWGrimes), Canudo de pito (*Senna bicapsularis* L. Roxb), Embaúba (*Ceropia pachystachya* sp.), Canafistula (*Peltophorum dubium* Spreng. Taub.) among others. The soil has a layer of plant litter that comes mainly from the phytomass of the species found on the site, with native organic matter, which favors the soil conditions.

Agroforestry System (SAF): approximately 16 years old, composed of the intercropping between *Gliricídia sepium* (Jacq.) Walp.) and coffee (*Coffea* sp.). The soil is of the podzolic type - characterized by its deep profile, clayey texture, and medium to high natural fertility (Araújo et al., 2022).

Mandala Vegetable Garden (MD): with approximately 17 years in the making, the system is introduced with organic fertilizer and inputs from ruminant waste (cattle and goat manure). The system is irrigated daily with hoses and sprinklers without many technical criteria. The main crops found in this system were coriander (*Coriandrum sativum*), lettuce (*Lactuca sativa*), cabbage (*Brassica oleracea*), papaya (*Carica papaya*), beans (*Phaseolus vulgaris*), and some varieties of unidentified medicinal plants. The soil is podzolic with a clay textural class and medium to high natural fertility.

Figure 1. Land use systems in areas of Brejo de Altitude in Bananeiras, Paraíba, Brazil: A) Forest, B) Agroforestry System, C) Mandala, and D) Degraded area.

Degraded area (DA): environment with no vegetation cover, compacted and poor in nutrients. An area in which the soil was plowed to possibly plant some crops, leaving the soil completely exposed to the sun, with some cucurbits being irrigated manually at the edges of the area. The soil is a typical Latossolo Amarelo distrófico with a sandy clay loam textural class.

Containers containing potassium hydroxide (KOH) were used to quantify the CO_2 released during the edaphic respiration process. These containers were changed every two hours over 12 hours, starting at 5 a.m. and ending at 5 p.m., totaling six treatments throughout the day and four replicates in each system. In these containers, 10 mL of 0.5 N aqueous KOH solution was used to capture CO_2 from the soil and then dosed by titration using 0.1 N HCl, with phenolphthalein and 1% methyl orange as indicators. A control bottle (control) was also used, which remained closed and was subjected to the same titration process.

The locations for the flow analysis were chosen at random, and four buckets with a diameter of 29.8 cm and a height of 36.5 cm were used, covering an area of 697.46 cm^2 and with the edge buried in the ground to prevent gas exchange (Valentini et al., 2015). After being removed from the field, the containers were immediately closed and taken to the CCHSA/UFPB Post-Harvest Laboratory for chemical analysis. The absorbed CO_2 was determined according to the methodology proposed by Gomes et al. (2022). The absorbed CO_2 was determined using the equation: ACO_2 = (A-B) x 2 x 2.2, in mg, $A'ACO_2 = ACO_2$ x (4/3 x 10,000/h + S), in mg m^{-2} h^{-1}

Where:

$A'CO_2$ - CO_2 absorption; A - difference between the 1st and 2nd stages of the sample titration (ml); B - difference between the 1st and 2nd stages of the control sample titration (ml); h - length of time the sample has been in the soil (hours); S - area covered by the bucket (cm^2).

At the same time as studying the kinetics of edaphic respiration, the soil temperature at a depth of 0-10 cm was checked using an Instrutherm® TE-400 skewer thermometer. The soil water content was also measured by selecting four collection points in each system at a depth of 0-10 cm, then weighed to determine the wet mass and taken to a 105 °C oven for 24 h, and the dry mass was determined using the following equation:

$$SM\% = \left(\frac{Ww - Dw}{Dw}\right).100$$

SM% is the soil moisture percentage, Ww is the wet weight (g), and Dw is the dry weight (g). Fisher test (F) was applied to assess the ratio between two variances. The normality of the data was checked by applying the Shapiro-Wilk (W) test to the residuals, making it possible to accept the null hypothesis since the data is normal ($p<0.05$). For the kinetics of edaphic respiration, the data of CO_2 (mg m^{-2} h^{-1}) and edaphic temperature (°C) were subjected to regression analysis according to the time given in hours, making up six treatments (evaluation periods) with four repetitions for each system.

3. Results and Discussion

Analysis of the production of CO_2 emanating from the soil showed that there was a significant effect ($p<0.05$) among land use systems (Table 1). Checking the average CO_2 levels obtained in each area, it was observed that the lowest CO_2 production occurred in the FO (82.7 CO_2 mg m^{-2} h^{-1}), differing statistically from the other areas with a CO_2 rate higher than 140 mg m^{-2} h^{-1}. This can be explained by the fact that the FO has more soil cover because it is a system in which the tree and shrub extract is denser, with mild temperatures that allow carbon to enter the soil system (C sequestration), allowing it to remain in the soil.

According to Torres et al. (2015), the distribution of CO_2 in soil management systems throughout the day reflects their physical capacity, which is why conservation systems show less CO_2 dispersion throughout the day, thanks to the characteristics that conservation management has, which also provide greater protection against extreme environmental conditions such as erosive rains, water crisis, and high rates of solar radiation. However, cultivated systems with less tree cover contribute to the carbon stored in the soil in organic and microbial form and in the form of plant biomass, being returned to the atmosphere (Araújo et al., 2016).

At the time of the experiment, the soil water content was 8.35, 1.95, 3.65, and 4.75% for the Forest (FO), Agroforestry Systems (AFS), Mandala (MD), and Degraded Area (DA), respectively. It should be noted that the average soil temperature was 24.0, 25.9, 28.8, and 30.6 °C for the FO, AFS, MD, and DA, respectively (Figure 2). Soil moisture is essential for microbial metabolism and can directly and indirectly influence soil CO_2 emissions (Farhate et al., 2018; Denardin et al., 2020; Veeck et al., 2018).

Table 1. CO_2 release (mg m^{-2} h^{-1}) by land use system.

Systems	CO_2 release (mg m^{-2} h^{-1})
Forest	82.7 b
Agroforestry system	144.1 a
Mandala vegetable garden	146.4 a
Degraded area	141.9 a

Means followed by the same letter do not differ by Tukey test at $p \leq 0.05$ probability

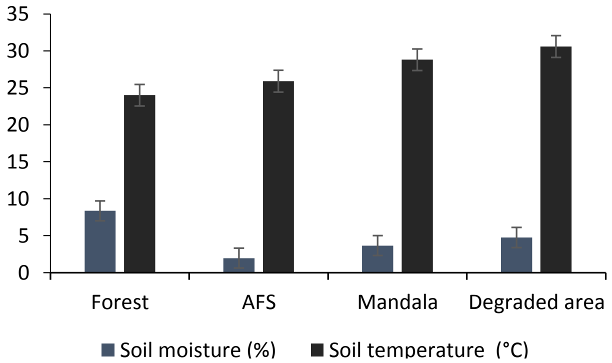

Figure 2. Soil moisture and temperature under different land use systems in a highland humid forest enclave in Bananeiras, PB. Vertical bars indicate Standard Error

Monitoring the evolution of CO_2 in the soil over a 12-hour period showed important variations and differences among the systems (Figure 2). It was observed in all the areas studied that the greatest release of CO_2 occurred in the containers removed at 7 a.m., and the release decreased throughout the day as the soil temperature increased. This may be related to the microbiota in the samples being adapted to lower temperatures (Silva et al., 2020).

The greatest CO_2 release and the highest temperatures occurred in the DA (Figure 3A), with a value of 55.1 mg m^{-2} h^{-1} of CO_2 and 26 °C (7 hours). This area would be functioning more as a source than a drain of atmospheric CO_2 due to the absence of vegetation cover, in addition, this bare soil caused by traditional agriculture, the burning of crop remains is intensively used, intensifying the loss of organic matter by the soil, which makes agricultural sustainability unfeasible (Silva et al., 2020; Moura et al., 2015). According to Castellano et al. (2017), the main soil characteristics that influence emissions include air temperature and moisture, which can be associated with the type of cover in each area. In addition, cultivated areas can cause more intense soil respiration due to the use of chemical fertilizers compared to the application of biofertilizers in sustainable systems (Mátyás et al., 2020).

Thus, we can associate the CO_2 efflux in DA with cultivation and soil management. The conversion of native areas into horticultural fields has changed the chemical and biological attributes of the soil and altered biogeochemical cycling processes (Lazeris et al., 2021). Besen et al. (2018) observed that adopting cover crops is a highly effective measure for reducing water loss and is considered a crucial factor in the agricultural scenario, where the aim is to reduce gas emissions.

In their studies, Oliveira et al. (2023) also identified that in areas with less vegetation cover and tree areas, there is a greater emission of CO_2 from the soil into the atmosphere, part of which cannot be captured by plant leaves and spreads into the atmosphere, contributing to the greenhouse effect.

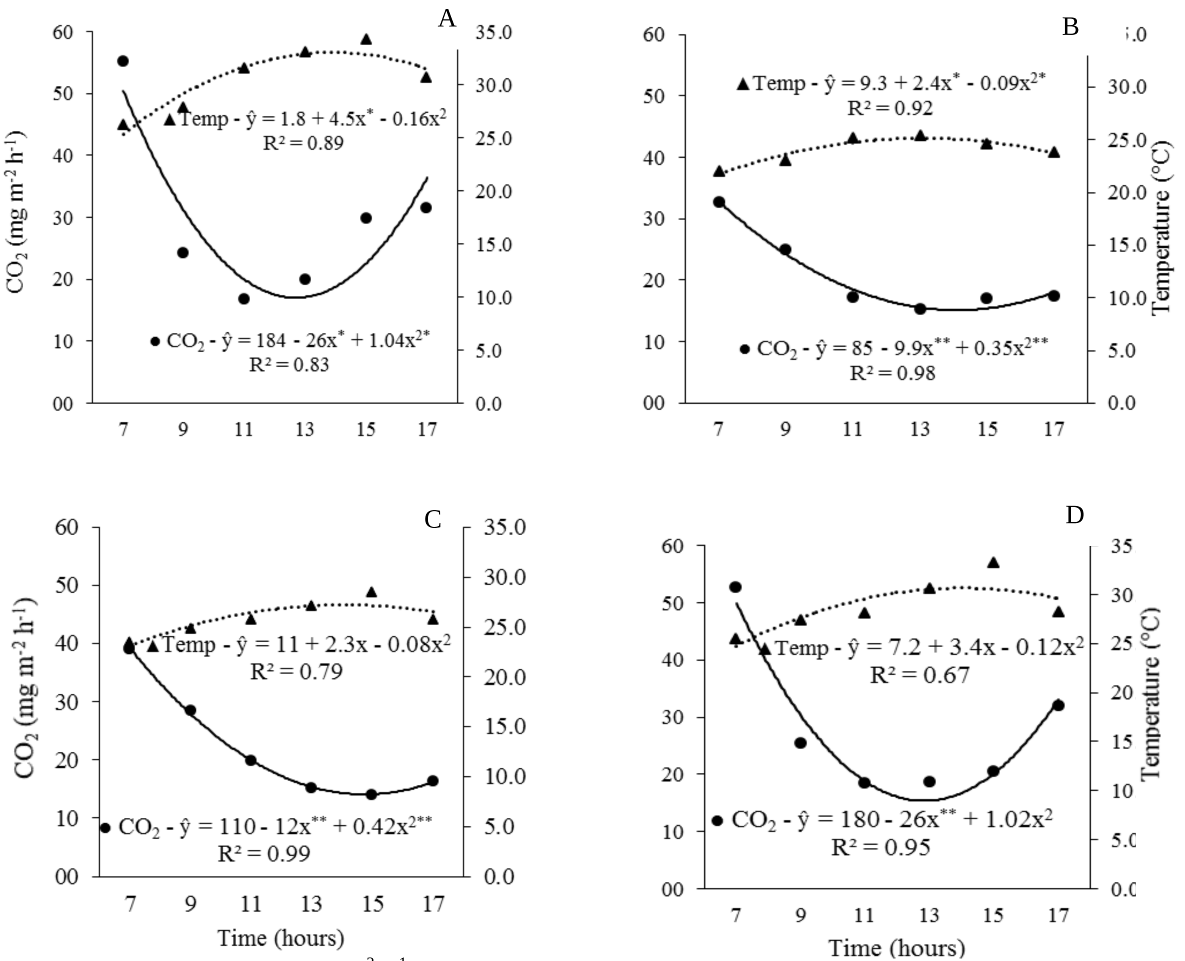

Figure 3. CO_2 release kinetics (mg m^{-2} h^{-1}) and daytime edaphic emperature (°C) in different land use systems according to the time (hours). Degraded area (A), Forest (B), Mandala vegetable garden (C), and Agroforestry system (D).

FO showed carbon dioxide emissions of around 32.7 CO_2 mg m^{-2} h^{-1} at a temperature of 22 °C (5-7 hours) (Figure 2B), i.e., lower CO_2 release values. Simon et al. (2019) described that microbial respiration decreases in more stable systems. Natural vegetation conditions make it possible to sequester carbon by allowing it to remain in the soil, unlike when it is released in the form of CO_2 into the atmosphere due to cultivation methods leading to greater oxidation of organic matter.

It was also observed that soil moisture in the FO was 8.35%, a higher value than in the other areas studied. As such, Gomes et al. (2021) found that as this is a system in which the tree and shrub extract is denser, it has a unique microclimate with mild temperatures, thus presenting a low-temperature range throughout the day.

Evaluating the values found in the MD area, it was found that there was a higher CO_2 increase of 52.6 mg m^{-2} h^{-1} at 7 am, with a decrease in the hottest hours of the day (Figure 2C). Higher temperatures and lower soil water content (3.65%) were observed compared to FO. Mátyás et al. (2020) consider that soil moisture content strongly affects CO_2 production. This is due to a partial vegetation cover, leaving the soil exposed to solar radiation and the area being constantly managed. Chaves et al. (2012) add that the highest soil density can be found in agricultural areas with partial soil cover due to the action of machinery and intensive use, which causes greater pressure on the soil; consequently, more compacted soil with low moisture.

Although the AFS area had a low water content (1.95%), it was the most similar to the FO with 39.0 CO_2 mg m^{-2} h^{-1} (Figure 3D) and a temperature of 23.53 °C (7 hours). There was an increase in CO_2 levels at 5 p.m. (16.3 CO_2 mg m^{-2} h^{-1}), also observed in MD. According to Pezarico et al. (2013), these characteristics in this environment, with abiotic conditions similar to the FO, such as a greater diversity of species, make this system the closest to the ideal characteristics, considering the FO as a benchmark for a condition of balance and stability.

Castellano et al. (2017) state that moisture can be one of the main controllers of emissions in different areas. This significant correlation between moisture and soil respiration can be explained by the fact that microbial activity is regulated by moisture due to the chemical reactions involved in the decomposition of organic matter. Primieri et al. (2017) not only correlated microbial activity with environmental variations but also stated that microbial activity can be an important characteristic when considering that the decomposition of organic waste will make nutrients available to plants.

4. Conclusions

Given the arguments presented, it can be seen that systems closer to the natural ecosystem, such as the AFS, will store more carbon in the soil, acting as a carbon stock. In contrast, systems that have undergone anthropogenic modifications, such as the degraded area, are CO_2 emitters. It was noted that the areas with the highest CO_2 releases were the degraded area and the mandala, also with the highest soil temperatures. To reduce CO_2 emissions from agricultural activities, systems that mimic natural ecosystems, such as AFSs, must be used.

Authors' Contribution

Maria Janaina Lira Vital, data collection and manuscript writing. Alex da Silva Barbosa, supervised the first author. Daniel da Silva Gomes, analyzed and tabulated the data and built the graphs. João Henrique Constantino Sales Silva, helped set up the experiment and manuscript writing and reviewed the data. Ariel Roxany da Silva Brasileiro, helped with field activities.

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