TEMPORAL DYNAMICS OF CO_2 EFFLUX AND LITTER DEPOSITION IN A DRY TROPICAL FOREST IN THE BRAZILIAN SEMIARID REGION

DINÂMICA TEMPORAL DO EFLUXO DE CO_2 E DA DEPOSIÇÃO DE SERAPILHEIRA EM UMA FLORESTA TROPICAL SECA NO SEMIÁRIDO BRASILEIRO

DINÁMICA TEMPORAL DE LA SALIDA DE CO_2 Y LA DEPOSICIÓN DE HOJARASCA EN UN BOSQUE TROPICAL SECO EN LA REGIÓN SEMIÁRIDA DE BRAZIL

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Abstract

The study of the dynamics of the Caatinga ecosystem, which includes the process of nutrient cycling through the contribution and litter decomposition, and the microbial activity measured through CO_2 efflux, can contribute to a better understanding of the ecological processes in this ecosystem. Thus, the present study sought to quantify the contribution of the litter forming material and its chemical composition, and CO2 efflux from soil respiration in an area of shrubby-tree caatinga. A transect with 3 arborescent stratum sampling points and 3 shrubby strata, totaling 6 sampling points (2 environments x 3 points per environment x 3 replications per point) was drawn. The litter production was collected monthly (October 2017 to October 2018), using 6 collectors. The monthly CO_2 emission was evaluated by the static closed chamber method. The influence of rainfall, soil moisture and temperature on the studied variables was evaluated. The annual litter production was estimated at 590 kg ha^{-1} for arboreal species and 767 kg ha-1 for shrubby species, and this layer is responsible for 23% more in the supply of plant material in the area. The highest CO2 emissions were found in the environment of shrubby vegetation with one annual total of 21.2 µmol $m^{-2}s^{-1}$ in relation to the area of arboreal vegetation that obtained 17.6 µmol $m^{-2}s^{-1}$. Spatial and temporal variability were observed in all analyzed variables and the strong influence of climatic factors such as precipitation, humidity and soil temperature.

KEYWORDS: Forests. Soil respiration. Semiarid. Climate changes.

Resumo

O estudo da dinâmica do ecossistema da Caatinga, que inclui o processo de ciclagem de nutrientes por meio da contribuição e decomposição da serapilheira, e a atividade microbiana medida pelo efluxo de CO2, pode contribuir para um melhor entendimento dos processos ecológicos desse ecossistema. Assim, o presente estudo buscou quantificar a contribuição do material formador de serapilheira e sua composição química, e o efluxo de CO2 proveniente da respiração do solo em uma área de caatinga arbustiva. Foi traçado um transecto com 3 pontos amostrais de estrato arborescente e 3 estratos arbustivos, totalizando 6 pontos amostrais (2 ambientes x 3 pontos por ambiente x 3 repetições por ponto). A produção de serapilheira foi coletada mensalmente (outubro de 2017 a outubro de 2018), utilizando 6 coletores. A emissão mensal de CO_2 foi avaliada pelo método estático de câmara fechada. Foi avaliada a influência da precipitação, umidade do solo e temperatura nas variáveis estudadas. A produção anual de serapilheira foi estimada em 590 kg ha-1 para espécies arbóreas e 767 kg ha^{-1} para espécies arbustivas, sendo esta camada responsável por 23% a mais no fornecimento de material vegetal na área. As maiores emissões de CO2 foram encontradas no ambiente de vegetação arbustiva com um total anual de 21,2 µmol $m^{-2}s^{-1}$ em relação à área de vegetação arbórea que obteve 17,6 µmol $m^{-2}s^{-1}$. Observou-se variabilidade espacial e temporal em todas as variáveis analisadas e forte influência de fatores climáticos como precipitação, umidade e temperatura do solo.

PALAVRAS-CHAVE: Florestas. Respiração do solo. Semiárido. Mudanças climáticas.

Resumen

El estudio de la dinámica del ecosistema Caatinga, que incluye el proceso de ciclo de nutrientes a través del aporte y descomposición de la hojarasca, y la actividad microbiana medida a través del eflujo de CO_2, puede contribuir a una mejor comprensión de los procesos ecológicos en este ecosistema. Por lo tanto, el presente estudio buscó cuantificar la contribución del material formador de hojarasca y su composición química, y la salida de CO_2 de la respiración del suelo en un área de caatinga arbustiva. Se trazó un transecto con 3 puntos de muestreo de estrato arborescente y 3 de estrato arbustivo, totalizando 6 puntos de muestreo (2 ambientes x 3 puntos por ambiente x 3 repeticiones por punto). La producción de hojarasca se recolectó mensualmente (octubre 2017 a octubre 2018), utilizando 6 recolectores. La emisión mensual de CO_2 se evaluó por el método estático de cámara cerrada. Se evaluó la influencia de las precipitaciones, la humedad del suelo y la temperatura sobre las variables estudiadas. La producción anual de hojarasca se estimó en 590 kg ha-1 para especies arbóreas y 767 kg ha^{-1} para especies arbustivas, siendo este estrato responsable de un 23% más en el abastecimiento de material vegetal en la zona. Las mayores emisiones de CO2 se encontraron en el ambiente de vegetación arbustiva con un total anual de 21,2 µmol $m^{-2}s^{-1}$ con relación al área de vegetación arbórea que obtuvo 17,6 µmol $m^{-2}s^{-1}$. Se observó variabilidad espacial y temporal en todas las variables analizadas y la fuerte influencia de factores climáticos como precipitación, humedad y temperatura del suelo.

PALABRAS CLAVE: Bosques. Respiración del suelo. Semiárido. Cambios climáticos.

1. Introdução

The contribution and transformation of the litter is essential for maintaining soil properties for native forests (PINTO et al., 2008; SCHUMACHER et al., 2013). The deposition of litter is continuous throughout the year, with its production and cycling of nutrients influenced by geographic, climatic, edaphic, physiological, anthropic factors and also due to the forest typology (COSTA et al., 2019; COSTA et al., 2020). These factors and processes of litter cycling are even more important when they are related to soils of low natural fertility (GAMA-BALIEIRO et al., 2004; BARLOW et al., 2007).

In forest ecosystems, mineral and organic reserves accumulate in plant and animal biomass, litter and soil (PEREIRA et al., 2008), and anthropic interventions compromise the effluent of nutrients entering and leaving the system (SUDDARTH et al., 2019). Andrade et al. (2008) reported that litter deposition is one of the most important aspects of nutrient cycling, as the nutrition of vegetables in ecosystems, usually with low nutrient content in the soil, depends on the cycling of nutrients contained in plant biomass. The litter production and the return of nutrients in forest ecosystems constitute the most important path of the biogeochemical cycle, that is, the nutrient cycle in the soil-plant-soil system (SCHUMACHER et al., 2004). This cycle together with the biochemical (circulation of nutrients inside the plant), allows trees to synthesize organic matter through photosynthesis, mainly recycling soil nutrients, where plant biomass can be the main reservoir.

The CO_2 efflux from the soil resulting from edaphic respiration is considered one of the main components of the global carbon cycle. The understanding of these processes is linked to the role of the biosphere in the control of evapotranspiration and CO_2 emission / fixation, thus it is strongly related to the issue of regional and global climate variability (SARMIENTO & GRUBER, 2002). It is estimated that approximately 50% of the carbon emitted to the ecosystem comes from soil respiration (WAGAI et al., 1998; ROBERTS, 2000). According to Luo and Zhou (2006), changes in soil respiration influence the equilibrium in the atmospheric CO_2 concentration of the ecosystem.

The mechanisms of soil respiration are associated with temperature and humidity conditions, and depend on the temporal and spatial variability of these variables, which have a strong influence on the microbial decomposition process. Rustad et al., (2000) in their studies observed that the relationships between litter decomposition and soil respiration to these environmental parameters vary in different ecosystems. In Brazil, studies of this nature, analyzing the CO_2 efflux in pastures, are still more restricted to the Cerrado and Amazon (VON RANDOW et al., 2004; RUHOFF et al., 2009; SILVA JÚNIOR et al., 2013). The present study sought to quantify the contribution of litter-forming material, and the CO_2 effluxes resulting from soil respiration in an area of shrubby-tree caatinga in the dry and rainy periods.

2. Materiais e Métodos

2.1. Experiment Location and Research Conduct

The research was developed in an area of native forest of the Caatinga biome, belonging to the Professor Ignácio Salcedo Experimental Station, of the National Institute of the Semi-arid, (INSA). It is located in the municipality of Campina Grande, located in the Geographical Mesoregion of Agreste da Borborema, in the state of Paraíba, between the coordinates 7º15,341' and 7º17,168 of south latitude and 35º59,473' and 35º57,627' of west longitude average altitude of approximately 480 meters above sea level. The experimental station has an area of 675 ha, of which approximately 300 ha are of Caatinga preserved in various stages of regeneration, where several studies are carried out to characterize the biome (Figure 1).

Figure 1. Location of sampling points in a preserved Caatinga area, the transect is positioned in two environments in transition from vegetation, Arboreal (C1, C2 and C3) and Shrubby. (C4, C5 and C6).

2.2.Climate of region

The Aw'i type climate, according to the climatic classification of Alvares et al., (2013) and is considered dry sub-humid. The rainy season is between the months of February to July and it rains annually, about 800 mm (1974-2004). The average annual maximum temperature is 26° C and the minimum 24° C, which varies little throughout the year. Figure 2 shows the rainfall data for the period from October 2017 to October 2018, precipitation (quantity and intensity) was monitored by a weather station (model HOBO® U30 / NRC from Onset, Massachusetts, USA) installed in transect area.

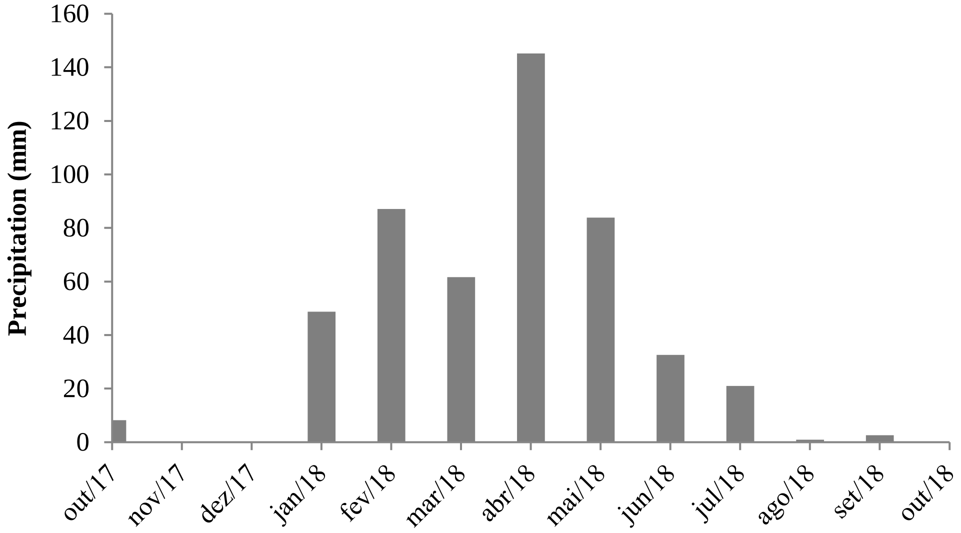


Figure 2. Monthly precipitation for 1 year in Caatinga area in natural regeneration stage.

2.3. Area soil

The soil in the experimental area was classified as Entisol. These soils are generally characterized as shallow, with some sites having a maximum depth of 10 cm, with moderate to imperfect drainage, with cases of excessive stony, flat to gently undulating relief.

2.4. Area history and vegetation type

According to information obtained from the National Institute of the Semi-Arid (INSA), the area was formerly privately owned and the history shows grazing and use of woody biomass by neighboring communities. As of 2005, the experiment area was acquired by INSA, which has been trying to preserve it and use it as a Caatinga reference for research. The predominant vegetation is formed by the sub-deciduous and deciduous forest known in the region as Caatinga de lipo, which changes dramatically throughout the dry and rainy seasons. Currently the area is in the process of regeneration, and as for vegetation, the predominant species are characterized as arboreal and shrubby.

Second, Albuquerque (2013), in a phytosociological survey carried out in the area of the INSA experimental station in Campina Grande, PB, 1,479 individuals were sampled, representing 26 genera, 26 species and 16 families. Of the 26 species found, 15 are arboreal in size and 11 are shrubbyby, characterizing the area as a shrubby-tree layer (Table 1). The families with the greatest wealth were Fabaceae with six species, Euphorbiaceae with five species, Anacardiaceae, Cactaceae and Capparaceae were represented by two species. The other families were represented by a single species totaling nine species.

Table 1. Vegetable species recorded in the Caatinga area under Neossol Litolic. E. E. Prof. Ignácio Salcedo, INSA, Campina Grande, PB. * Of the 26 species found, 15 have an arboreal habit and 11 are shrubbyby.

SPECIES FOUND* (POPULAR NAME)	HABIT
Baraúna (Schinopsis brasiliensis Engl), Umbu (Spondias tuberosa), pereiro (Aspidosperma pyrifolium), imburana (Commiphora leptophloeos), mandacaru (Cereus jamacaru), icó (Neocalyptrocalyx longifolium (Mart.), catingueira (Poincianella pyramidalis [Tul.] L.P.), jucá (Caesalpinia ferrea Mart.), jurema preta (Mimosa tenuiflora), jurema branca (Mimosa verrucosa), unha de gato (Uncaria tomentosa), imbiratanha (pseudobombax marginatum), joão mole (Pisonia tomentosa) e juazeiro (Ziziphus joazeiro).	Arboreal
Cipó de nego (Thumbergia Alata), facheiro (Pilosocereus pachycladus), feijão bravo (Capparis hastata), aveloz (Euphorbia tirucalli), burra leiteira (Chamaesyce hyssopifolia), pinhão (Jatropha mutabilis), maniçoba (Manihot caerulescens), mameleiro (Croton blanchetianus Baill), mororó (Bauhinia forficata), veludo (achigali subvelutina (Benth.) e chumbinho (Lantana câmara).	Shrubbyby

The transect installed in the area was positioned in two environments in transition from vegetation, of arboreal and shrubbyby strata, and was formed by 6 consecutive segments of 30 m each (Figure 3), totaling an area of 180 m (2 environments x 3 points per room x 3 repetitions per point). During the wet and dry season the measurements can be considered statistically independent at a distance of 23 and 12 meters, respectively. Therefore for this study, the minimum distance between points of 30 meters was used.

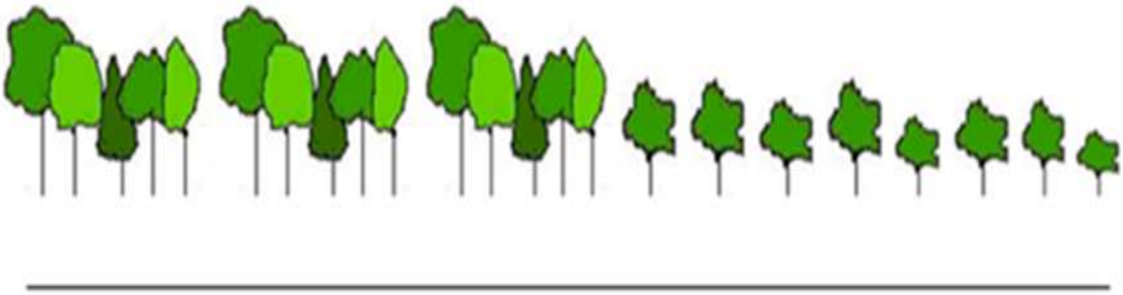


Figure 3. Sketch of the 180 m transect in a Entisol area under arboreal / shrubbyby vegetation.

2.5.Litter production

In order to study the contribution of the litter, wooden collectors with dimensions of 1.0 x 1.0 m were used, nylon mesh bottom with 2.0 mm x 2.0 mm mesh, arranged at 0.30 m from the ground, and distributed in six points along a transect in the study area under tree-shrubby vegetation, being fixed below the canopy, using six frames, one for each point. The material intercepted by the collectors was collected regularly every 30 days, and divided into two seasons, dry and rainy, (Figure 4).

The collected material was stored in paper bags and sent to the laboratory, where it was dried in an oven with forced circulation at 65ºC until constant weight, and later weighed to determine the mass deposited in the period.

A)

B)

Figure 4. General aspect of vegetation in the study area in the A- dry and B- rainy periods in the same location.

2.6.CO_2 Efflux

The measurements of CO_2 effluxes were carried out along the 180 m transect, in the arboreal and shrubby environments, using the closed static chamber method to capture the CO_2 evolved on the soil surface directly in the field by means of an alkaline solution (GRISI, 1978) through collections made monthly during the dry and rainy period. The method is based on the use of an alkaline solution disposed under closed chambers to capture C-CO_2 evolved from the soil, using static chambers and a container placed inside the chambers with sodium hydroxide solution 40 mL of NaOH at 2 Mol L^{-1} for 24 hours (IVO & SALCEDO, 2012).

The alkaline solution was left for 24 h at each sampling point, after this period had elapsed, the solution with the absorbed C was transferred to properly sealed containers and then taken to the laboratory for carbonate quantification by means of potentiometric titration with HCl 0,05 N (SAMPAIO and SALCEDO, 1982).

2.7. Soil Moisture

In determining the water content in the soil (%), soil samples were collected in the 0-10 cm deep layer, the samples were collected in aluminum cans of known weight. After being collected, the cans were taken to the Laboratory where the sample from the field (Pu) was weighed and then placed in an oven at 105° C for 24 hours. Subsequently after cooling, we weighed again (Ps) and noted the difference between the weight of the wet sample and the weight of the dry sample, the difference refers to the amount of water lost during oven drying. The water content in the soil was determined using the formula:

$$M\% = (Ww - Dw) / Dw \times 100$$

2.8.Soil Temperature

The soil temperature was measured on the surface, with the aid of a digital thermometer, these assessments were made monthly in both arboreal and shrubby environments, at each sampling point.

2.9.Statistical analysis

The data were subjected to analysis of variance, and the means compared by the Tukey test at 5% probability, using the statistical program R.

3. Resultados e Discussão

3.1.Soil moisture in the area

Figure 5 shows the monthly averages of rainfall and soil moisture that were calculated for the two environments, tree and shrubby. The total precipitation for the study period (October 2017 to October 2018) was 491.90 mm.

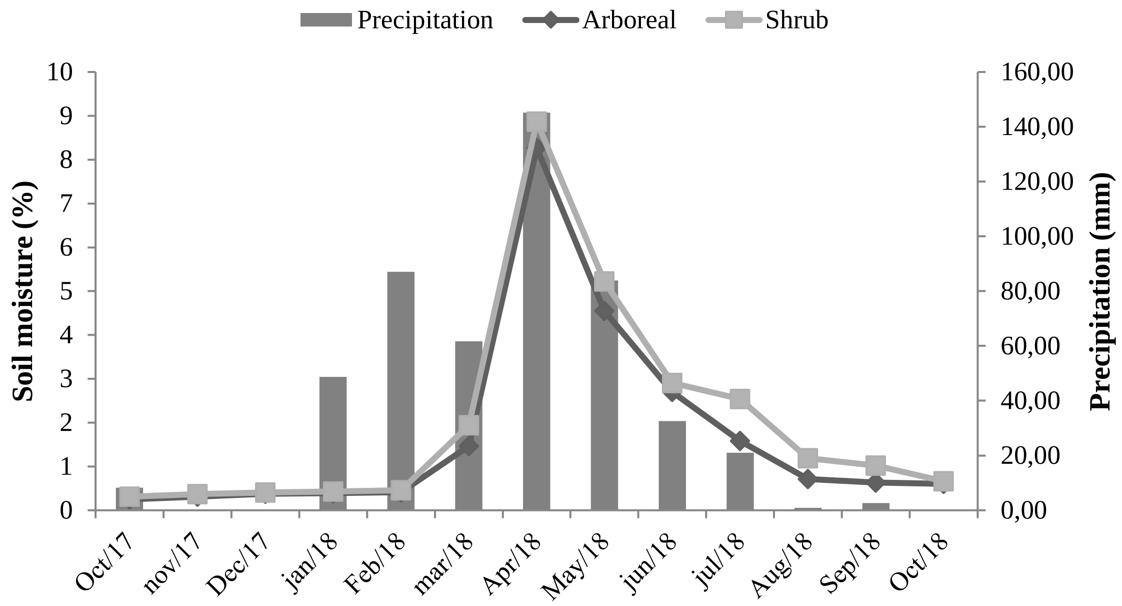


Figure 5. Precipitation (mm) and soil moisture (%) in the arboreal and shrubby Caatinga environments, during the experimental period, in an area of Entisol in the semi-arid region of Paraíba.

As for the water content in the soil, it was observed that the peak humidity values were just above 8% in both environments, and were recorded in April, in both environments. In the months of greatest rainfall, there was an increase in water content in the soil, with immediate decreases when there was a decrease in rainfall. It is observed that the pluviometric regime in the region showed high spatial and temporal variability, being of fundamental importance the monitoring of atmospheric conditions and soil water content in the evaluation of the decomposition process and activity of edaphic microorganisms.

3.2. Area soil temperature

Figure 6 shows the occurrence of temperatures above 30° C in the 0-10 cm topsoil in the months of October, November, and December 2017 and January, September and October 2018 in both environments, arboreal and shrubbyby, these months being considered as a dry season due to the low rainfall rate.

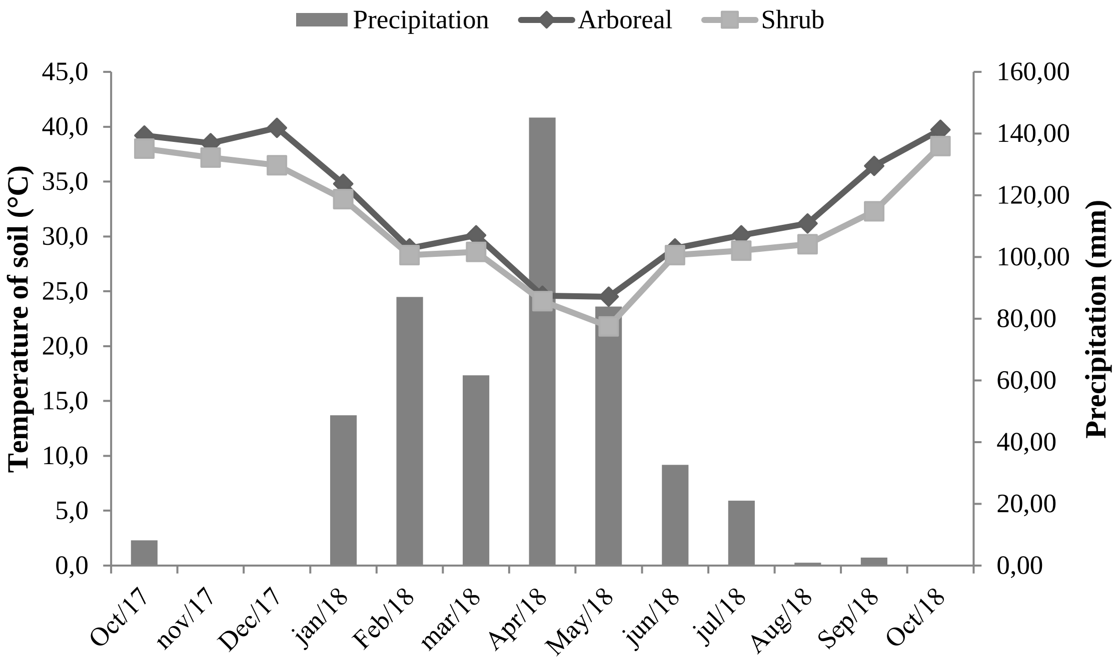


Figure 6. Precipitation (mm) and soil temperature (°C) in the arboreal and shrubbyby Caatinga environments, during the experimental period, in an area of Entisol in the semi-arid region of Paraíba.

In the months in which precipitation occurred, in both environments, there were decreases of almost 10° C, with the temperature below 30° C in the months from February to August 2018.

3.3. Litter production

The annual litter production was estimated at 590 kg ha^{-1} for tree species and 767 kg ha^{-1} for shrubby species, this environment being responsible for the greater supply of plant material in the area, and also for the greater variation in the area. contribution between the collection months.

Seasonality in litter deposition is illustrated in figure 7, where the influence of precipitation on their behavior during the study period is verified. It was observed that in the months considered as a period of full drought, the two strata had the lowest deposition rates that were registered in the months of November and December with 12.6 and 12.0 kg ha^{-1} in the tree and vegetation environment. 23.7 and 21.7 kg ha^{-1} in the bush environment respectively. This behavior was expected, since the vast majority of species in the area are deciduous and, during this period, which corresponded to the end of the dry season and the beginning of the rainy season, the trees were completely defoliated, thus reducing the production of litter.

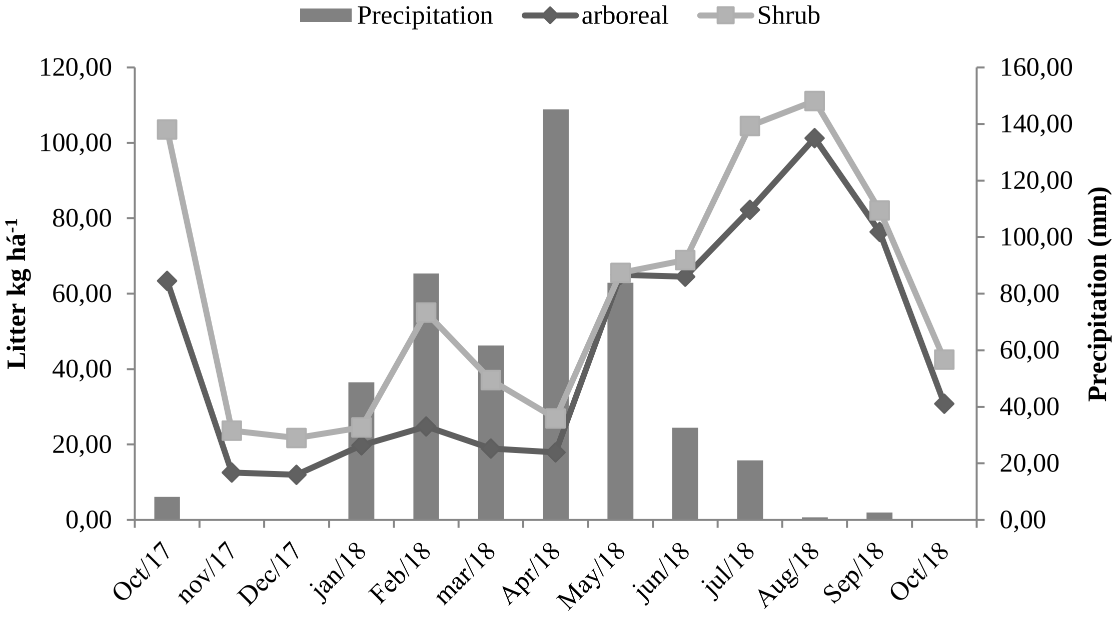
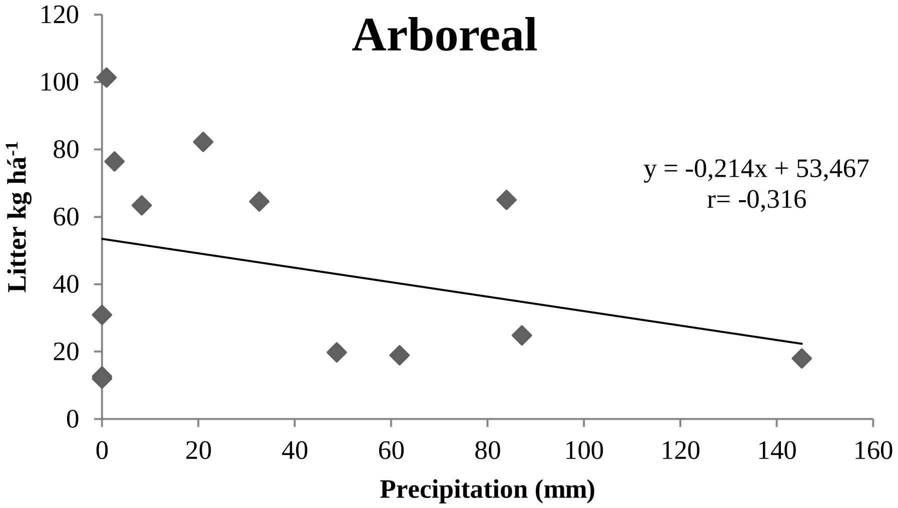
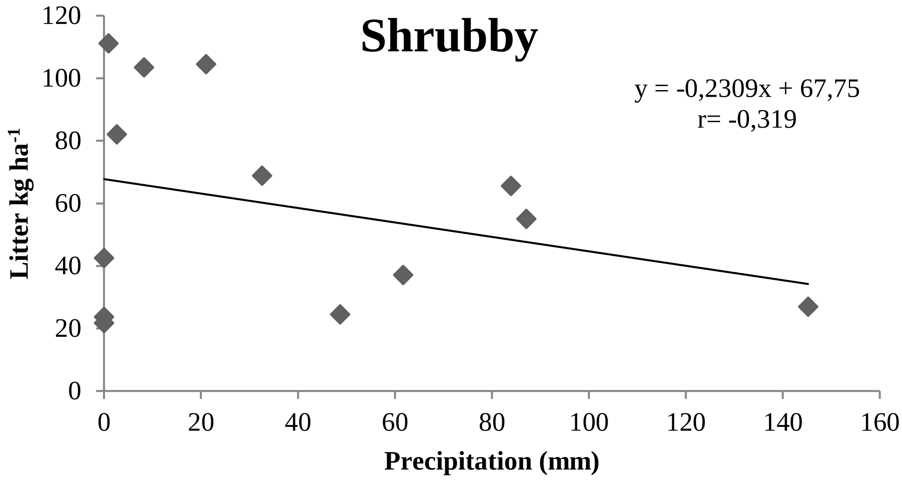


Figure 7. Monthly variation in litter production kg ha^{-1} in the arboreal and shrubby environments and precipitation (mm) in the study area during October 2017 to October 2018.

The highest production peaks of the two strata occurred at the end of the rainy season, despite continuous fluctuations, having reached the highest deposition in August 2018 in the two environments with the highest deposition in the shrubbyby environment with 111 kg ha^{-1} and 101 kg ha^{-1} in the tree. In general, there was an increase in litter deposition as the rainy season ends and during the beginning of the dry season of the year, reducing its production during the months of full drought (Figure 8).



A)



B)

Figure 8. Correlation between the production of litter kg ha^{-1} in the arboreal (A) and shrubbyby (B) and precipitation (mm) environments in an area of Entisol, in the semi-arid region of Paraíba, in the period from October 2017 to October 2018.

3.4. CO_2 efflux

It was observed that the highest CO_2 emissions have always occurred in times when greater rainfall was recorded regardless of the environment, a fact evidenced by the CO_2 emissions in the samples from the months of April and May, where there was a high increase in CO_2 emissions due to effect of rains that occurred in the period, associated with milder temperatures and higher soil moisture, which shows that there is greater biological activity of the soil when water is available in the soil associated with temperatures that are around 30 °C. This result is associated with climatic factors, especially the rainfall regime, since the soil at that time stores a higher water content (Figure 9). This water storage causes the soil temperature to decrease, maintaining the humidity and this in turn associated with the temperature provides a better condition for the soil biota, reflecting in greater biological activity.

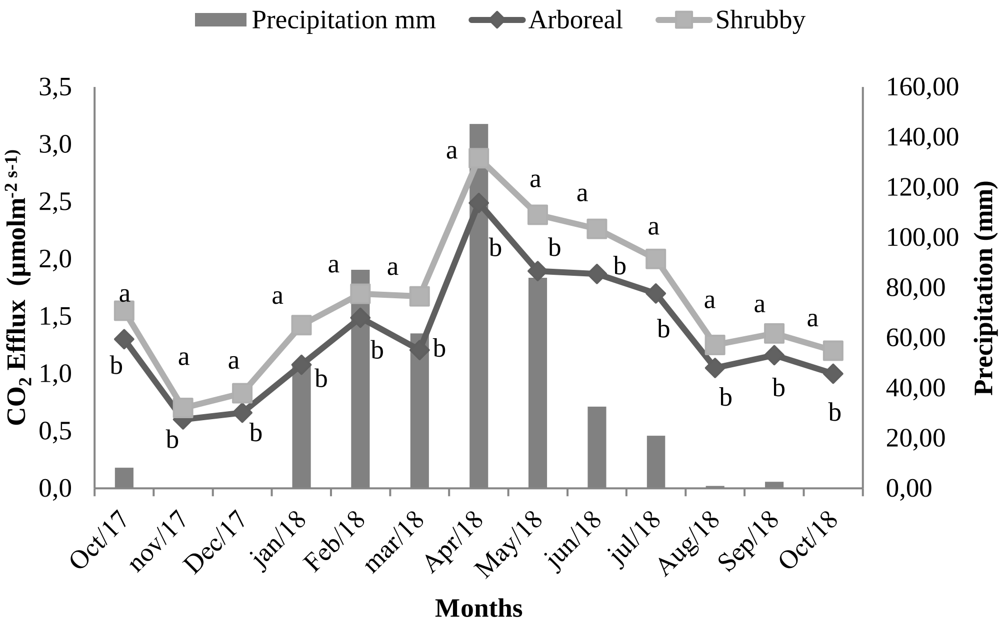


Figure 9. CO_2 efflux in arboreal (A) and shrubby (B) and precipitation (mm) environments in Entisol area, in the semi-arid region of Paraíba, from October 2017 to October 2018.

Studies have shown that the rate of soil respiration is an indicator of soil microbial activity, and that this rate is strongly influenced by temperature as it increases (Bekku et al., 2003; Subke; Reichstein; Tenhunen, 2003), these works consider that the production of CO_2 inside the soil is basically a biochemical process and responds strongly to variations in temperature and humidity, the results of this work are presented in Figure 10. The mechanisms of soil respiration are associated with temperature conditions and humidity, and depend on the temporal and spatial variability of these variables, which have a strong influence on the microbial decomposition process.

As in this work, others have found a significant relationship between soil temperature and CO_2 efflux (Chambers et al., 2004; Kang et al., 2003). Soil moisture was also a factor responsible for controlling soil respiration, helping to regulate the activity of organisms. According to Chambers et al., (2004) variations in soil moisture, whether due to lack or excess of water in the soil, can influence CO_2 effluxes.

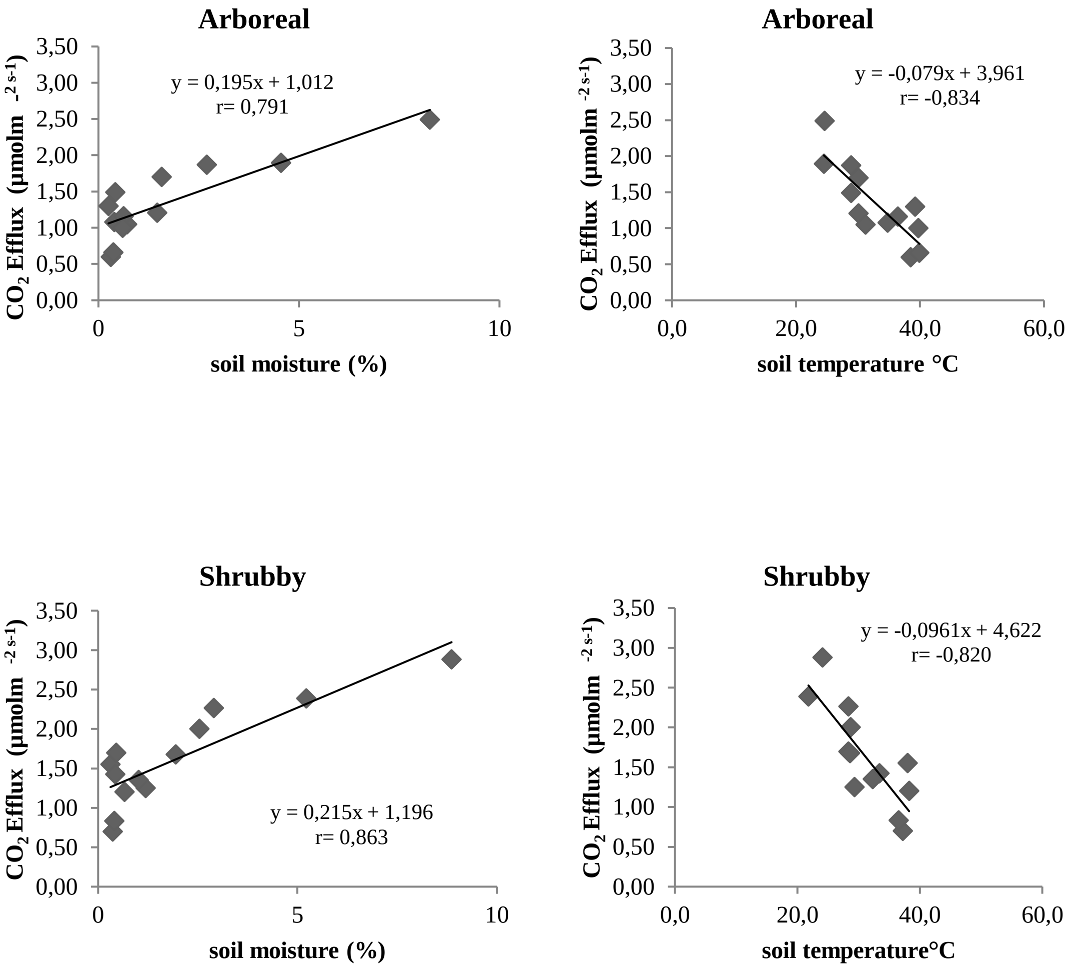


Figura 10. Effluence of CO_2 in the arboreal and shrubbyland environments and the influence of humidity and soil temperature for each environment in a Neossol Litolic area, in the semi-arid region of Paraíba, from October 2017 to October 2018.

4. Conclusão

The shrubby stratum was responsible for the largest contribution of litter in most of the year. However, the production of litter presented a seasonal character with a close relationship with the rainfall regime, being its peak of production right after the rainy season, regardless of the caatinga vegetation stratum.

The highest CO_2 emissions were found in the environment of shrubby vegetation, due to the greater contribution of litter, promoting an increase in microbial activity.

The efflux of CO_2 varied on a spatial and temporal scale and had a strong influence of climatic factors such as precipitation, humidity and soil temperature on microbial activity.

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