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Biomass and microbial activity in soils under different cropping systems in the São Francisco valley

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ABSTRACT

The inadequate management of the soil can intensify the degradation and change the soil structure, providing a significant increase in gas emission, affecting mainly the dynamics of CO_2 emission, besides favoring the increase of the mineralization rate of the soil organic matter and reduction of microorganisms that act as biological indicators. In this context, the objective of this work was to evaluate the changes on soil biomass and microbial activity, due to the implementation of viticulture, mangiculture and forage crops in areas of the Caatinga Biome. The experiment was carried out in Petrolina-PE. Soil samples were collected at 0-5 and 5-10 cm depth, in areas cultivated with grapevine (in different phenological stages), mango, elephant grass and caatinga. The following were analyzed; pH, P, K^+, Na^+, Ca^{++}, Mg^{++}, total organic carbon (TOC), bulk density, particle density, total porosity, microbial biomass carbon (MBC), basal respiration and metabolic quotient. The soil chemical and biological properties are affected by the removal of natural vegetation. The managed areas presented high CO_2 emissions per unit of soil microbial biomass (SMB), favoring high carbon losses. The phenological phase of the vine in which the leaf mass is reduced, influenced the SMB.

Keywords: Bioindicators, Soil management, Soil microbiology.

Biomassa e atividade microbiana em solos sob diferentes sistemas de cultivo no vale do São Francisco

RESUMO

O manejo inadequado do solo pode intensificar a degradação e alterar sua estrutura, proporcionando um aumento significativo na emissão de gases, afetando principalmente a dinâmica de emissão de CO_2. Além disso, favorece o aumento da taxa de mineralização da matéria orgânica do solo e a redução de microrganismos que atuam como indicadores biológicos. Nesse contexto, o objetivo deste trabalho foi avaliar as alterações na biomassa e na atividade microbiana do solo decorrentes da implantação da viticultura, mangicultura e culturas forrageiras em áreas do Bioma Caatinga. O experimento foi conduzido em Petrolina-PE. As amostras de solo foram coletadas nas profundidades de 0-5 e 5-10 cm, em áreas cultivadas com videira (em diferentes fases fenológicas), mangueira, capim-elefante e caatinga nativa. Foram analisados: pH, P, K^+, Na^+, Ca^{++}, Mg^{++}, carbono orgânico total (COT), densidade do solo, densidade de partículas, porosidade total, carbono da biomassa microbiana (CBM), respiração basal e quociente metabólico. As propriedades químicas e biológicas do solo são afetadas pela remoção da vegetação natural. As áreas manejadas apresentaram elevadas emissões de CO_2 por unidade de biomassa microbiana do solo (BMS), favorecendo grandes perdas de carbono. A fase fenológica da videira em que a massa foliar é reduzida influenciou a BMS.

Palavras-chave: Bioindicadores, Manejo de solo, Microbiologia do solo.

1. Introduction

In recent decades, areas of the Caatinga biome in the semi-arid region is being replaced by perennial fruit crops, mainly vines (*Vitis spp.*) and mango (*Mangifera indica determiner*), and annual crops for animal feed, such as elephant grass (*Pennisetum purpureum Schum*). In this sense, the São Francisco Valley, located in the semi-arid region of the Brazilian Northeast and situated in the states of Bahia and Pernambuco, is one of the main fruit producing poles in the country (Santos Júnior et al., 2024). The region is receiving strong public investments, generating intense social and economic impacts, making it become an area of national space of great dynamism (Machado; Santos, 2020).

The intensive preparation of the areas for the implantation of crops in the semi-arid region, by the soil disturbance before the implantation, provides intense soil disturbance, increasing the mineralization of organic matter, loss of nutrients, compaction, reduction of the microbial community and enzymatic activities, besides providing erosion and global warming by the emission of carbon dioxide (Almeida et al., 2016; Sá et al., 2018). These losses, consequently, favor changes that intervene in the energy and biogeochemical cycle of ecosystems and in the formation of soil aggregates, in which microorganisms play a key role, thus resulting in reduced productivity of exploited crops (Sá et al., 2018).

The concern with the evaluation of soil quality has gained prominence, especially with regard to the quantification of changes in its chemical, physical and biological attributes, resulting from the intensification of use and management systems (Guimarães et al., 2017).

One of the parameters to evaluate soil changes is the use of microbiological indicators, which due to its sensitivity detect possible environmental changes in a short period of time, having the ability to present quick responses to changes in soil quality (Lopes et al., 2018). Among the main indicators for the characterization and evaluation of soil microbiological functioning, microbial biomass, microbial biomass carbon content, basal respiration, metabolic quotient and enzyme activities stand out (Bünemann et al., 2018).

Biomass is the living component of soil organic matter, comprises around 1 to 5% of total organic carbon (TOC), thus being a central compartment of the carbon cycle, besides acting in the decomposition and accumulation of organic matter, mineralization, formation and maintenance of soil structure, storing and cycling of nutrients in the system (Almeida et al., 2016; Gallo et al., 2019).

Basal respiration evaluates the process of biological oxidation of organic matter by microorganisms, determining the consumption of O_2 and production of CO_2 (Dadalto et al., 2015). According to Gallo et al. (2019), the increase in basal respiration can be stimulated by high productivity and the stress caused by environmental damage, such as soil preparation operations.

The ratio between basal respiration and carbon of the microbial biomass is the metabolic quotient (qCO$_2$), which in turn expresses the amount of CO_2 released by the microbial biomass as a function of time, presenting the specific respiration of the microbial biomass (Silva et al., 2007). The microbial quotient (qMIC) reflects the inputs of carbon and the conversion of organic substrates to the carbon of the microbial biomass (Lopes et al., 2012), determined by the ratio between the MBC and TOC (Sparling, 1992).

The size of the microbial community and its activity determine the intensity that the chemical processes occur in the soil (Lima et al., 2021; Sampaio et al., 2008). In this way, the present work aimed to evaluate the changes in soil microbial biomass and activity due to the implementation of viticulture, mangiculture and forage crops in areas of the Caatinga Biome.

2. Material and Methods

The experiment was performed in the Federal Institute of Education, Science and Technology of Sertão Pernambucano (IF SERTÃO-PE), Campus Petrolina rural area, in the year 2019, located in the city of Petrolina-PE, sub medium São Francisco (9º 9' latitude South, 40º longitude West and 365.5 m altitude). The region's climate according to Köppen's classification is of type BSw'h Semi-arid hot.

The soil samples were collected during the end of the rainy season, in seven areas named in the following order: T1 (hyperxerophytic Caatinga), T2 (vine cv. Italy at rest), T3 (vine cv. Benitaka in budding), T4 (vine cv. Benitaka beginning of pruning), T5 (vine cv. Benitaka at rest), T6 (vine cv. Superior Seedless at rest for another 2 years), T7 (mango cv. Tomy Atkins) and T8 (elephant grass). In each area five sub-samples were collected from the rhizosphere of the plants at the depths of 0-5 and 5-10 cm for the acquisition of 6 composite samples, totaling 96 samples.

The mineral supplementation of the areas was based on the recommendations the Manual of Fertilization and Liming for the Pernambuco State for grapevine, mango and elephant grass, using the micro-sprinkler, drip and conventional sprinkler irrigation systems, respectively. The vineyards received an average of 60 t/ha/year of manure.

After collection, the samples were divided into two fractions, one for chemical and physical analysis and the other for microbiological analysis. Regarding the chemical and physical analyses were analyzed pH, P, K^+, Na^+, Ca^{++}, Mg^{++}, total organic carbon (TOC), bulk density by the measuring cylinder method, particle density (p_s) and total porosity (TP), according to the procedures recommended by Teixeira et al. (2017).

The soil fraction destined to the evaluation of microbiological characteristics was kept under refrigeration (7 to 10 °C) during transportation and storage. Subsequently, the microbial biomass carbon (MBC) was estimated by the fumigation-extraction method (Vance et al. 1987), in which fumigated and non-fumigated samples were submitted to K_2SO_4 extraction (0.5 mol/L) and MBC quantification obtained by titration with ammoniacal ferrous sulfate (0.033 mol/L).

Soil basal respiration (SBR) was determined by incubating the soil in a screw-top jar with 25 mL of NaOH (0.05 mol L) for one day so that the initial effect of soil disturbance on respiration is minimized. After five days, the jars were reopened and CO_2 was quantified by titration with HCl (0.01 mol L) (Silva et al., 2007).

As the values of basal respiration and MBC the qCO_2, was determined by the ratio between the carbon of released CO_2 and the carbon of the soil microbial biomass (Silva et al., 2007). The microbial quotient (*q*MIC) was calculated by the ratio between MBC and TOC (Sparling, 1992).

The data were submitted to variance analysis and the means were compared by the Scott Knott test at 5% probability using the SISVAR program.

3. Results and Discussion

Soils from treatments 1 and 3 (Caatinga and vine cv. Italy in budding), respectively, showed higher density at depths 0-5 and 5-10 cm than the other treatments (Table 1). Although the highest density occurred, these values are within the values commonly found in the region, which generally range between 0.9 and 1.5 g cm^3. Lower density values favor water retention, root growth, gas exchange, thus stimulating their development and activity of microbial biomass (Barbosa et al., 2017).

Regarding total porosity, in both soil layers there was no significant difference between treatments (Table 1), with average values of 52.03 and 52.72% for depths 0-5 and 5-10 cm, respectively, being these values close to the value of 50% described as ideal (Kiehl, 1979). Since the total porosity expresses the circulation of air in the soil, reflecting directly on the activity of aerobic microorganisms (Borges et al., 1999).

Among the soil fertility indicators analyzed (Table 2), the treatments with agricultural activity (T2, T3, T4, T5, T6, T7 and T8) showed higher contents of P, K^+ and Ca^{++} than T1, at both depths studied. Regarding Mg^{++}, only the treatments (T3, T5, T6) differed among themselves, obtaining higher concentrations.

At the depth of 0-5 cm, the pH values did not differ for treatments T1, T2, T3, T4 and T5, and are within the range considered optimal for the development of microorganisms in tropical soils that varies from 5.3 to 6.1 (Moraes et al., 2018). On the other hand, T6, T7 and T8 showed the highest pH values at this depth. At the depth of 5-10 cm, only T2 obtained the lowest value, differing from the other treatments.

The pH variations are influenced by agricultural practices, such as nutrient input and irrigation, providing the increase of basic cations (Table 2), consequently, with the entry of water, there is release of strong bases, providing the increase in pH due to hydroxyl (OH^-) present in the soil solution. The pH of the rhizosphere can also be altered due to the uptake of NO_3^-, which promotes OH^- extrusion to maintain the electrical balance between the external and internal environment of the cell membrane (Liu et al., 2017).

The activity of soil enzymes occurs within a narrow range of pH, if it is inadequate the bacteria that depend on this activity will have its number reduced (Bueno et al., 2018). Requiring microorganisms' greater energy expenditure for cell maintenance in low pH conditions, consequently reducing the biomass population and carbon fixation in the soil (Zhang et al., 2021).

Bacteria and fungi have a high demand for nutrients, many of which are integral components of their own cellular composition. Bacterial biomass is rich in high-energy molecules such as phospholipids and amino acids. Fungi, in turn, are organisms whose main structural characteristics include cell walls composed of chitin, the presence of complex polysaccharides such as glucans, and energy storage in the form of glycogen (Jackson et al., 2007).

The soil microbial biomass (SMB), represents an expressive reservoir of nutrients, playing a key role in the retention and release of energy and nutrients to soils, the microbial, provides nutrients to vegetation, through mineralization of plant and animal waste, and organic matter to the soil (Bueno et al., 2018).

TOC concentrations varied in T1 (6.7 to 5.3 g kg^{-1}) and T7 (9.8 and 6.7 g kg^{-1}), at the depths 0-5 and 5-10 cm, respectively (Table 2). Evaluating the carbon stock at the depths 0-100, 0-50 and 0-60 cm, Santana et al. (2019), obtained values of 7.33, 7.84 and 3.08 g kg^{-1} in Ultisols, Entisols and Alfisols, respectively, under Dense Caatinga cover.

The increase in TOC in areas under agricultural activity may be related to the addition of organic matter in the form of manure, which is part of the management grid of these crops. On the other hand, the Caatinga (T1) provides low input of organic material to the soil, mainly leaves and thin branches, restricted to the beginning of the dry season. Even though they present diversified characteristics, areas of native caatinga may result in a greater amount of stable carbon present in the soil (Martins et al., 2010).

Table 1. Physical attributes of soil in areas with different cropping systems at two depths.

Treatments*	Depth 0-5 cm							
	T1	T2	T3	T4	T5	T6	T7	T8
p_s (g cm³)	1.4a	1.3b	1.3b	1.3b	1.1b	1.1b	1.2b	1.2b
TP (%)	45.8a	55.8a	49.9a	55.8a	55.9a	56.1a	44.8a	52.2a
	Depth 5-10 cm							
p_s (g cm^3)	1.4a	1.2b	1.3a	1.2b	1.1b	1.1b	1.2b	1.2b
TP (%)	46.8a	54.7a	49.2a	42.8a	55.5a	58.9a	59.7a	54.2a

*Means of six repetitions followed by the same letter within each depth did not differ by the Scott-Knott test at 0.05 probability. T1 (Caatinga hyper xerophytic), T2 (vine cv. Italy at rest), T3 (vine cv. Benitaka in budding), T4 (vine cv. Benitaka beginning of pruning), T5 (vine cv. Benitaka resting), T6 (vine cv. Superior Seedless resting for over 2 years), T7 (mango cv. Tomy Atkins) and T8 (elephant grass).

Table 2. Soil chemical attributes in areas with different cropping systems at two depths.

Treatments	Depth 0-5 cm					
	P	K^+	Ca^{++}	Mg^{++}	pH	TOC
	mg dm³	--------------cmol$_c$ kg^{-1}-----------			H_2O	g kg^{-1}
T1	24.8d	0.2c	2.5b	0.1b	6.0b	6.7c
T2	176.8a	0.5a	5.1a	1.0b	5.9b	19.7a
T3	154.4a	0.4a	3.4b	1.4a	5.9b	19.8a
T4	159.6a	0.4a	3.2b	1.0b	6.2b	19.1a
T5	143a	0.4a	3.1b	1.2a	6.1b	17.7a
T6	151.9a	0.4a	4.9a	1.7a	6.8a	21.2a
T7	107.2b	0.3b	2.7b	1.4b	6.9a	9.8b
T8	75.8c	0.2c	1.6b	0.8b	6.7a	4.1b
	Depth 5-10 cm					
Treatments	P	K^+	Ca^{++}	Mg^{++}	pH	TOC
	mg dm³	--------------cmol$_c$ kg^{-1}-----------			H_2O	g kg^{-1}
T1	24.8d	0.2d	3.2b	1.1b	6.1c	5.3d
T2	188.0a	0.5a	3.9a	0.9b	5.6d	16.9a
T3	154.4a	0.4b	2.8b	1.2b	5.9c	15.9a
T4	161.5a	0.4b	4.0a	1.3b	6.3b	15.0b
T5	127.2b	0.3c	3.6a	1.5a	6.4b	12.8b
T6	133.5b	0.3c	4.1a	1.5a	6.9a	18.8a
T7	91.5c	0.2d	3.9a	1.7a	6.7a	6.7c
T8	71.4c	0.2d	1.7b	0.9b	6.6b	2.9d

*Averages of six repetitions followed by the same letter, within each depth do not differ by the Scott-knott test at 0.05 probability. T1 (Caatinga hyper xerophytic), T2 (vine cv. Italy at rest), T3 (vine cv. Benitaka in budding), T4 (vine cv. Benitaka beginning of pruning), T5 (vine cv. Benitaka resting), T6 (vine cv. Superior Seedless resting for over 2 years), T7 (mango cv. Tomy Atkins) and T8 (elephant grass).

At depth 0-5 cm, there was significant difference between the values of microbial biomass carbon (MBC) only for T6 with mean value of 1023.83 µg g^{-1} (Figure 1A). At depth 5-10 cm, there were differences between T5, T6 and T7, with results of 327.3; 794.2 and 312.5 µg g^{-1} respectively. T1 and T2, obtained lower values at both depths, ranging from 170.7 (0-5 cm) and 130.8 µg g^{-1} (5-10 cm) (Figure 1A).

At both depths (0-5 and 5-10 cm), a significant difference was observed in microbial biomass carbon (MBC) values. Treatment T6 showed the highest mean values, with 723.8 and 594.2 µg g^{-1}, respectively, differing statistically from the other treatments (Figure 1A).

The increase in MBC can be explained in large part, by the greater availability of TOC (Table 2), due to the deposition of organic residues, which stimulate the maintenance of soil microbiota, resulting in lower losses of nutrients in the soil-plant system (Zhou et al., 2017).

According to Primieri et al. (2017), in natural ecosystems, there is a tendency to obtain higher values of MBC in relation to environments managed by anthropic action, showing that the maintenance of the use of conservation systems provides an increase in microbial activity in the topsoil layers with direct reflection in the increase of carbon in this fraction. However, the low values found in the Caatinga may be related to the type and quantity of plant residue deposited in the soil, when very homogeneous, the lower plant diversity, resulting in lower biomass, may result in reduced values for MBC.

The soil microbial activity, represented by the soil basal respiration (SBR), in the period of 48h, in the depth of 0-5 cm, the T4, T5, T6 and T7, with medians 1,6; 1.4; 1.2 and 1.1 mgC - CO_2 kg^{-1} soil h^{-1}, respectively, did not differ among themselves, however differing from T1, T2, T3 and T8 (1; 0.6; 0.3 and 0.4 mgC - CO_2 kg^{-1} soil h^{-1}). At depth 5-10 cm, T4 (1.8 mgC - CO_2 kg^{-1} soil h^{-1}) T5(1.2 mgC - CO_2 kg^{-1} soil h^{-1}) and T6 (1.4 mgC - CO_2 kg^{-1} soil h^{-1}), obtained higher averages.

The high values of SBR and low MBC indices indicate that in this system there is a greater loss of carbon in the form of CO_2, thus incorporating less carbon to the soil microbial biomass. These changes are also influenced by abiotic factors, such as loss of vegetation cover, soil exposure, reduced water infiltration and increased temperature, so it is important to determine specific management for each type of soil and growing, ensuring biological activity in the soil (Primieri et al., 2017).

Evaluating two irrigated production systems Gomes et al. (2021) found microbial biomass carbon values of 28.80 and 18.45 μg g^{-1} soil in one organic and one conventional growing, differing in 34.02% and 42.26% compared to the preserved area, respectively.

Observing the soil microbial carbon at depth (0 to 10 cm), Lopes et al. (2012), obtained an average value of 180 mg kg^{-1} in an area of Caatinga, and this fact may be attributed to the higher concentration of OM in the upper layer of soil, a result close to that found in this study.

Comparing the cycles of Benitaka vine, it can be observed that MBC (Figure 1A), in the stages of sprouting (T3), pruning (T4) and resting (T5), exhibited similar behavior (0-5cm), with an increase of biomass in the depth 5-10 cm for T5, due to the mineralization and movement of organic residues from the previous stage (pruning).

When the same treatments were analyzed in terms of soil microbial activity (Figure 1B), it was observed that T5 differed significantly from T3, showing that the area had high microbial activity. The culture treatment (pruning) reduces the foliar mass, favoring the entry of solar radiation, consequently increasing soil temperature and reducing moisture, causing greater stress on microorganisms (Lima et al., 2021; Sampaio et al., 2008). For T5, the process of reducing the water layer in the resting phase also causes disturbances in the soil microbial community.

Evaluating the treatments T2, T3 and T8 with Benitaka vine (T4 and T5), it was observed that the microbial activity in the soil (Figure 1B), was lower, justified by the phenological conditions of the treatments, Italy vine at rest (T2) and Benitaka vine at sprouting (T3). In relation to elephant grass (T8), the edaphoclimatic conditions, such as greater densification of the crop, reflect in the conservation of moisture and reduction of solar incidence, ensuring less stress on the microbiota (Sampaio et al., 2008).

The results of metabolic quotient (qCO_2) for 48h period (Figure 1C), at 0-5 cm depth, T1 and T4, with medians 5.7 and 9.1 mgC – CO_{2}.g^{-1}C-SMB h^{-1}, respectively, did not differ among themselves, but differed from T2, T3, T5, T6, T7 and T8 (3.8; 1.8; 4.4; 1.6 4.5 and 2.7 mgC – CO_{2}.g^{-1}C-SMB h^{-1}). At the 5–10 cm depth, only treatments T1 (6.5 mgC – CO_{2}.g^{-1}C-SMB h^{-1}) and T2 (6.1 mgC – CO_{2}.g^{-1}C-SMB h^{-1}) showed significant differences compared to the other treatments.

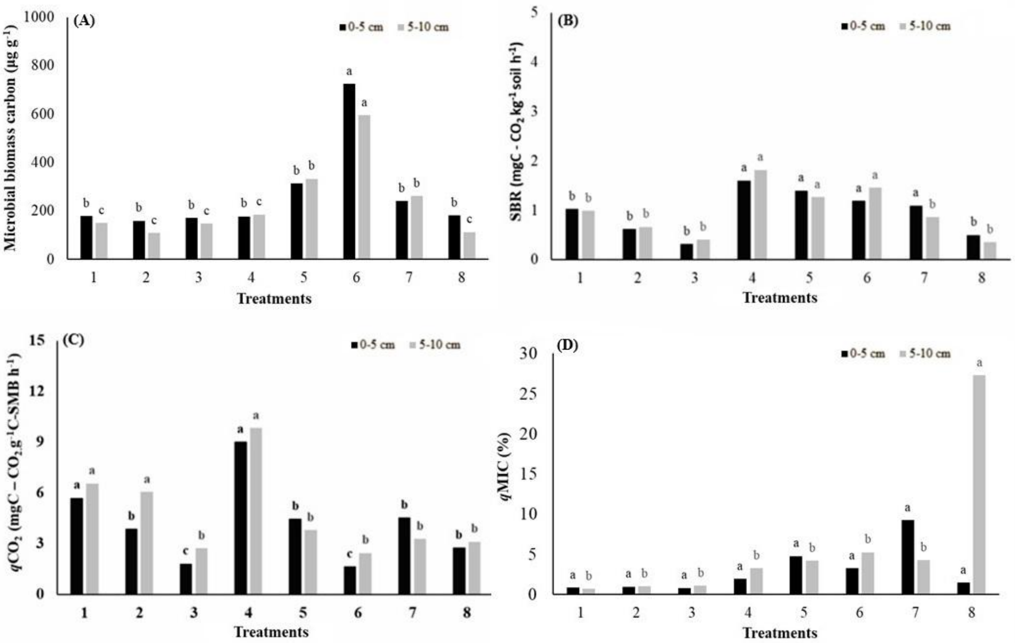

Figure 1. Microbial biomass carbon (A), soil basal respiration (B), metabolic quotient in 48h (C) microbial quotient (D) with different cropping systems at two depths. T1 (Caatinga hyper xerophytic), T2 (vine cv. Italy at rest), T3 (vine cv. Benitaka in budding), T4 (vine cv. Benitaka beginning of pruning), T5 (vine cv. Benitaka at rest), T6 (vine cv. Superior Seedless resting for more 2 years), T7 (mango cv. Tomy Atkins) and T8 (elephant grass).

High values of qCO_2 are indicative of microbial community in early stages of development, i.e., a higher proportion of active microorganisms in relation to inactive ones (Guimarães et al., 2017; Lima et al., 2021). However, according to Ferreira et al. (2017), higher values of qCO_2 may indicate stress on microorganisms, reflecting in a microbial community metabolically inefficient in the use of carbon as energy and presenting higher losses of CO_2 to the atmosphere.

The microbial quotient (*q*MIC) showed a significant difference only in treatment T8 (27.3%) at the 5-10 cm depth, standing out from the other treatments (Figure 1D). Higher qMIC values indicate greater nutrient cycling, reflecting lower carbon accumulation in the soil and higher conversion of total organic carbon (TOC) into microbial biomass carbon (MBC) (Lopes et al., 2012).

Evaluating the microbial biomass and organic matter in Caatinga soil Lopes et al. (2012), observed the significant increase of *q*MIC, under Caatinga, in the depth/time interaction, attributing these results to the input of OM in these soils, in which the level of the *q*MIC ratio indicates that the carbon is in equilibrium.

Low *q*MIC indicates that the microbiota is under stress, or the low nutritional quality of the organic residues makes the microbial biomass unable to fully utilize the TOC (Gama-Rodrigues et al., 2008). In this sense, according to Gallo et al. (2019), *q*Mic and qCO_2 are sensitive to anthropic changes and environmental effects on the soil microbial community, being indicators of ecosystem stress.

4. Conclusions

The removal of natural vegetation affects the chemical and biological properties of the soil, which was demonstrated in the MBC values.

Managed areas showed higher CO_2 emissions per unit of SMB, evidencing conditions of high carbon losses due to high nutrient and water inputs.

The phenological phase of the vine influences the BMS, mainly in the phases in which the leaf mass is reduced.

Authors' Contribution

Kathianne Rodrigues de Souza: Investigation, writing-original draft. Graciene de Souza Silva: Writing-original draft, writing-review and editing. Gilberto Saraiva Tavares Filho: Formal analysis, figure design, writing-review and editing. Cicero Antônio de Sousa Araújo: Conceptualization, writing-review and editing. Fabio Freire de Oliveira: Conceptualization, methodology, formal analysis, writing-review and editing. Sammy Sidney Rocha Matias: Investigation, writing-original draft.

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