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Impacts of replacing the Amazon rainforest with pasture on soil properties

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ABSTRACT

The conversion of the Amazon rainforest into pasture significantly impacts soil quality, affecting biodiversity, biogeochemical cycles, and carbon stocks. Studies indicate a reduction in microbial activity and biomass associated with this transformation. This study investigated the impact of converting forest into pasture on soil attributes in the northern Amazon, specifically at the Canto Verde farm in Iracema, Roraima, Brazil. Three land use systems were analyzed: Native Forest (NF), *Brachiaria brizantha* (BB), and *Brachiaria humidicola* (BH). Soil samples were collected at two depths (0-0.10 m and 0.10-0.20 m) in four representative blocks of 1 ha in each system. Chemical, physical, and biochemical properties, and microbial and metabolic coefficients were analyzed. The results were subjected to analysis of variance and the Tukey test ($p<0.05$). The transition from NF to agricultural use with *Brachiaria* significantly altered soil attributes. There was an increase in pH in the BB and BH systems and a reduction in total organic carbon and microbial biomass. Basal respiration and dehydrogenase activity decreased, indicating stress in the transformed systems. The BH system showed higher metabolic quotient (qCO_2) and lower microbial quotient (qMIC) values, highlighting the adverse effects of converting forests into pastures on soil microbiological activity. The conversion of forests into pastures negatively affects the soil, requiring sustainable agricultural practices.

Keywords: *Brachiaria brizantha*; *Brachiaria humidicola*; Conversion; Native forest.

Impactos da substituição da floresta Amazônica por pastagem nas propriedades do solo

RESUMO

A conversão da floresta Amazônica em pastagem tem impactos significativos na qualidade do solo, afetando a biodiversidade, os ciclos biogeoquímicos e os estoques de carbono. Estudos indicam uma redução na atividade e biomassa microbiana associada a essa transformação. O objetivo deste estudo foi investigar o impacto na conversão da floresta em pastagem nos atributos do solo no norte da Amazônia, especificamente na Fazenda Canto Verde, em Iracema, Roraima, Brasil. Foram analisados três sistemas de uso do solo: Floresta Nativa (FN), *Brachiaria brizantha* (BB) e *Brachiaria humidicola* (BH). As amostras de solo foram coletadas em duas profundidades (0-0,10 m e 0,10-0,20 m) em quatro blocos representativos de 1 ha em cada sistema. Foram analisadas propriedades químicas, físicas, bioquímicas e os coeficientes microbiano e metabólico. Os resultados foram submetidos à análise de variância e ao teste de Tukey ($p<0,05$). A transição de NF para uso agrícola com *Brachiaria* alterou significativamente os atributos do solo. Observou-se aumento do pH nos sistemas BB e BH, redução no carbono orgânico total e biomassa microbiana. A respiração basal e a atividade da desidrogenase diminuíram, indicando estresse nos sistemas transformados. O sistema BH apresentou maiores valores de quociente metabólico (qCO_2) e baixos de quociente microbiano (qMIC), ressaltando os efeitos adversos da conversão de florestas em pastagens na atividade microbiológica do solo. A conversão de florestas em pastagens afeta negativamente o solo, exigindo práticas agrícolas sustentáveis.

Palavras-chave: *Brachiaria brizantha*; *Brachiaria humidicola*; Conversão; Floresta nativa.

1. Introduction

Deforestation leads to the loss of environmental services, such as maintaining biodiversity, water cycling, and carbon stocks, which prevent climate change from worsening (Boateng and Marek, 2021; Villarino et al., 2016). In the Amazon region, between 2008 and 2022, 25,000 km^2 of forest were devastated, much of it affected by the growth of agricultural activities (IMAZON, 2023).

The replacement of natural forests with pasture, a common practice in the Brazilian Amazon, seriously compromises the region's carbon stocks, posing a threat to environmental sustainability (Schneider et al., 2021; Rego et al., 2023). The forage plants used in this substitution are mainly from the *Brachiaria* genus (Syn. *Urochloa*), as they are better adapted to the soil and climate conditions, the most common species being *B. humidicola* and *B. brizantha*. *B. humidicola*, known as quicuio da amazônia, is undemanding in soil fertility, tolerant to aluminum, and does not require high levels of phosphorus for its development (Nunez et al., 2018). The *B. brizantha* species has satisfactory adaptation and growth in acidic, low-fertility soils characteristic of the Amazon region (Cabral et al., 2016; Marchi et al., 2017). In general, *B. brizantha* outperforms *B. humidicola* in biomass production, crude protein content, acceptability, and growth rate (Tanaka et al., 2019; Tegegn et al., 2019).

It is generally considered to determine the biochemical properties to diagnose the level of soil degradation, fundamentally those associated with the number and activity of microorganisms, as well as those involving the elements of the biogeochemical cycle (Zhou et al., 2019) and general properties of the carbon of the microbial biomass (Mbuthia et al., 2015). Among soil quality attributes, organic matter content is the main indicator of the sustainability of a cropping system (Agbeshie et al., 2022). However, assessing the effects of incorporating crop residues on the cycling and accumulation of carbon (C), nitrogen (N), and other nutrients is important for adopting techniques that improve the soil's physical, chemical, and biological characteristics and reduce environmental impacts (Rego et al., 2023).

The conversion of native forests into pasture has significant implications for soil quality, especially concerning microbial activity. Several authors have evaluated the effect on microbial community activity, biomass, and diversity in Brazilian soils subjected to different management. Bunemann et al. (2018) point out that changes in soil properties due to agricultural management, including the removal of forests and the implementation of crops, generally manifest themselves slowly, except when the soil faces drastic changes. Kaschuk et al. (2011) demonstrated an approximate 30% decrease in microbial biomass carbon in soils subjected to replacing native vegetation with agricultural practices, highlighting the negative impact of these changes on microbial activity. Hassler et al. (2015) showed that soils under *Hevea brasiliensis* and *Elaeis guineensis* plantations have lower fertility and organic matter content than primary forests, attributing this difference to reduced litter deposition.

Forest preservation is essential, so it is necessary to consider the impacts of agricultural growth on these ecosystems. In this sense, it is important to conduct studies that analyze the changes caused to the soil and establish sustainable management strategies for the new system, seeking to break the damaging cycle of cutting down, burning, and abandoning forests. The aim was, therefore, to evaluate the changes in soil attributes caused by the conversion of the Ombrophilous Dense Forest into agricultural use systems with *Brachiaria brizantha* and *Brachiaria humidicola* in the Iracema region, Roraima.

2. Material and Methods

The areas selected for this study are located at Canto Verde farm, in Iracema, state of Roraima, Amazonia, Brazil (2°10′55″ N, 61°2′27″ W) (Figure 1). According to the Köppen classification, the region's climate is Aw-type, tropical rainy with a defined dry period (spring). The average annual temperature is 27 °C, and the average annual rainfall is 2,000 mm, with April to July being the wettest (Barbosa et al., 1997). In a recent study, Araújo et al. (2024) reclassified the region as Am-type (tropical rainy with a short dry season).

The soil in the study areas is classified as Argissolo Vermelho-Amarelo distrófico (EMBRAPA, 2018). The reference forest formation is called a Dense Ombrophilous Forest (IBGE, 2012), characterized by high rainfall, stratified structure, and rich biodiversity. In this region, the size of the forest tends to be higher. The species found are Angelim Pedra (*Hymenolobium petraeum* Ducke), Copaíba (*Copaifera landesdorffi*), Roxinho (*Peltogyne* spp.), Atamenju (*Duguetia marcgraviana* Mart.), Caferana (*Picrolemma pseudocoffea*), Cupiúba (*Goupia glabra* Aubl.), Balsamo (*Myroxylon peruiferum*), Itauba (*Mezilaurus itauba*), Canelas (Lauraceas), and Lecitidaceas, the latter two being more tolerant of the wetter environment. The canopy is always closed.

Three land use systems were considered for the study: native forest at the interface with cultivated areas 200 ha (NF), pasture with *Brachiaria brizantha* 10 ha (BB), and pasture with *Brachiaria humidicola* 10 ha (BH) in a randomized block design with 4 blocks. The pasture areas were established ten years ago by removing the native (primary) forest using fire, a common practice in the region. Since 2002, according to the owner's history, the areas have been maintained without fire, soil disturbance, acidity correction, and fertilization. Cattle management consisted of a 30-day grazing period followed by a 60-day fallow period, with an average of one animal unit per hectare. In addition to the pasture, the animals received mineral salt supplementation.

Each system was analyzed during the dry season, and four representative areas (blocks) of 1.0 ha were delimited in each system. Within each area, 12 mini trenches were established with a depth of 0.20 m, which were divided into two layers: 0.0-0.10 m and 0.10-0.20 m. The mini trenches were distributed using a diagonal path, ensuring a representative sample of the total area.

Each sampling point generated a 1 dm³ soil sample. The samples were air dried, crumbled, and sieved, with 500 g in a 4 mm mesh (used for biochemical analysis and determining enzyme activity) and 500 g in a 2 mm mesh (used for total carbon and nitrogen, pH, and granulometry).

The chemical analysis and granulometry of the soil in each area were determined according to Embrapa (1997). To determine the total carbon and nitrogen content, the soil samples were ground in a mortar and passed through a sieve with a mesh size of 0.210 mm. The total organic carbon (TOC) content was determined using the wet oxidation method with external heating described by Yeomans and Bremner (1988), and total nitrogen (TN) was determined using the Kjeldahl method (Tedesco et al., 1995).

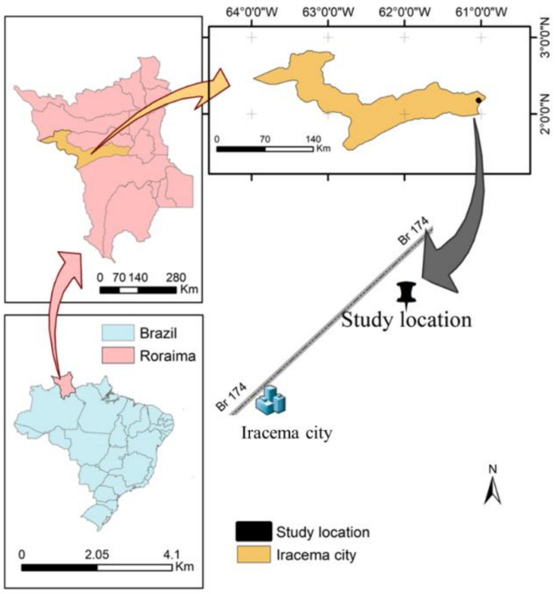

Figure 1. The study area is Canto Verde farm in Iracema, Roraima, Brazil.

For the biochemical analysis and determination of enzyme activity, the dried soils passed through a 4 mm mesh sieve were moistened to 60% of field capacity, kept for eight days, incubated at room temperature and in the dark, then stored at 4 °C in a refrigerator. Before analysis, the sample moisture content was measured gravimetrically in an aliquot of soil dried in an oven at 105 °C for 24 hours. The properties studied were carbon associated with microbial biomass, soil respiration, total inorganic nitrogen and mineralized ammonium, dehydrogenase enzyme activity, and metabolic quotient (qCO_2); they were determined according to methods described by Leirós et al. (2000) and the microbial quotient (qMIC), by the ratio between microbial biomass and soil TOC. The C content of the fumigated sample was subtracted from the value of the non-fumigated sample, and the difference was divided by the correction factor (Kc) of 0.45 to calculate microbial biomass.

Differences between systems and soil depths were tested by analysis of variance (ANOVA) at a 5% significance level. In the event of a significant difference between the treatments, the statistical analyses mean, standard deviation, and Tukey test were conducted using the SISVAR statistical package, version 5.3 (Ferreira, 2011).

3. Results and Discussion

A detailed study of the soil chemical properties showed an increase in pH in the BB and BH systems compared to the NF system, possibly due to the burning of the area to establish pastures (Table 1). The small increase in the pH of the pastures was due to the ash deposited in the soil after burning. Freitas et al. (2013)

found similar results when comparing native forests with agroforestry systems that were also burned to open up agricultural systems.

A study by Agbeshie et al. (2022) points out that burning, depending on its intensity, can alter the chemical characteristics of the soil. In low to moderate severity burns, there is a transient increase in pH and available nutrients due to the deposition of ash and transformation of organic matter, while severe burns result in significant loss of MOS and nutrients through volatilization and erosion. Changes in pH over time depend on soil properties, vegetation cover, quality of organic matter (litter), and environmental conditions (Arévalo Gardini et al., 2015). Correcting the soil with lime is one of the management practices aimed at increasing or maintaining organic matter and reducing the potential for nutrient leaching in soils (Lopes and Guilherme, 2016) by increasing the effective CEC.

However, the use of limestone and fertilizers in the northern region of Brazil is still incipient due to several factors, such as the high price of inputs, the logistical difficulty of transport and storage, the tradition of a non-technified subsistence crop in the region, the lack of supply and supply of these inputs, among others (Cravo et al., 2020; Frare et al., 2023). The transition from native forest to pasture reduced total organic carbon (TOC) by up to 1.18% in the 0-0.20 m soil layer (Table 1).

Table 1. Mean values (±s.d.) of some soil properties in each area (NF, BB, and BH) and depths studied.

Attribute	Layer (m)	Area					
		NF[1/]		BB[2/]		BH[3/]	
pH KCl	**0.00 – 0.10**	3.26 ± 0.04	aC	4.02 ± 0.05	aB	4.34 ± 0.14	aA
	0.10 – 0.20	3.80 ± 0.15	bC	4.08 ± 0.03	aB	4.21 ± 0.09	aA
TOC (%)[4/]	**0.00 – 0.10**	2.31 ± 0.19	aA	1.13 ± 0.19	aB	1.48 ± 0.33	aB
	0,10 – 0.20	1.36 ± 0.26	bA	0.86 ± 0.12	aB	0.88 ± 0.06	bB
TN (%)[5/]	**0.00 – 0.10**	0.143 ± 0.034	aA	0.145 ± 0.038	aA	0.168 ± 0.042	aA
	0.10 – 0.20	0.142 ± 0.035	aA	0.194 ± 0.036	aA	0.151 ± 0.032	aA
C:N	**0.00 – 0.10**	17.00 ± 3.00	aA	8.00 ± 2.00	aB	10.00 ± 6.00	aB
	0.10 – 0.20	10.00 ± 4.00	bA	5.00 ± 1.00	aA	6.00 ± 1.00	aA
Sand (g kg^{-1})	**0.00 – 0.10**	807.00 ± 12.00	aA	790.00 ± 26.00	aA	803.00 ± 32.00	aA
	0.10 – 0.20	833.00 ± 6.00	bA	783.00 ± 13.00	aB	768.00 ± 40.00	aB
Clay (g kg^{-1})	**0.00 – 0.10**	103.00 ± 6.00	aB	168.00 ± 15.00	aA	160.00 ± 35.00	aA
	0.10 – 0.20	130.00 ± 10.00	bB	190.00 ± 16.00	aA	175.00 ± 24.00	aA

[1]/NF: Native forest; [2]/BB: *Brachiaria brizantha*; [3]/BH: *Brachiaria humidicula*; [4]/TOC: Total organic carbon; [5]/TN: Total nitrogen. Equal uppercase letters indicate that the values for the same layer in the different areas are not significantly different, while equal lowercase letters indicate that in each study area, the values in the two layers are not significantly different ($p \leq 0.05$).

This decrease is partly attributable to the reduction in litter deposition, essential for maintaining C stocks in the soil. Comparatively, pastures introduce organic material differently, both through the deposition of excreta and rhizo-decomposition and the release of root exudates, influencing nutrient cycling and the contribution of C. However, the effectiveness of this contribution ranges between pasture systems and is impacted by the management and characteristics of the vegetation.

Regarding total nitrogen (TN), no significant variations were observed at depth and between the different systems due to environmental change (Table 1). These results align with Huygens et al. (2008), who, when studying virgin temperate forests in southern Chile, did not identify significant variations in TN, emphasizing the efficiency of these ecosystems in maintaining high rates of bioavailable nitrogen through effective retention mechanisms.

The C:N ratio showed greater amplitude in the NF and was more restricted in the pasture areas at a depth of 0-0.10 m, corroborating the findings of Geisseler and Scow (2014) and Agbeshie et al. (2022) that changes in land use lead to carbon loss (Table 1). In addition, there was a tendency for TN to increase in the systems with grasses (BB and BH), even though there was no significant difference between the systems, which helped to decrease the C:N ratio concerning NF. This difference may be related to the quality of the organic material present in the different use systems.

The greater amplitude of the C ratio in the NF may indicate the presence of more recalcitrant materials, such as lignin and aromatic compounds, which are difficult for microorganisms to degrade. On the other hand, the lower C ratio in grass systems may reflect the greater availability of labile materials, such as carbohydrates and proteins, which favor decomposition and nutrient cycling. Zeferino et al. (2023) reported that converting the Amazon rainforest to pasture resulted in significant changes in the stocks and distribution of C and N in the granulometric fractions of TOC after conversion from forest to pasture. According to Winck et al. (2014), the greater potential of these systems to provide phytomass with a high C:N ratio results in a high addition of C and N, which was not observed in this study. Rashti et al. (2024) found that sugarcane cultivation significantly decreased stocks of organic carbon (45 48%), total nitrogen (51 54%), and phosphorus (26 37%) compared to native forest and pasture, emphasizing how intensive agricultural practices can drastically alter biogeochemical processes and the bioavailability of nutrients in the soil. Kaschuk et al. (2011) found a 31% reduction in microbial biomass with the introduction of agriculture, varying between biomes. Meanwhile, Abdalla et al. (2018) observed that the impact of grazing on soil carbon is climate-dependent, with some climates showing increases in carbon storage under certain grazing intensities. These results highlight the importance of adapting management practices to local conditions to protect soil quality and carbon stocks.

As expected for the Argissolos class, the clay content increased with depth (Table 1). However, converting soil under NF to agricultural systems reduced the textural gradient by increasing the clay content in the two layers studied. The NF showed a greater textural gradient, with a higher sand content, in line with the values obtained by Martins et al. (2006), studying forest and native grassland in the Humaitá AM region. The significant increase in clay content in the BB and BH systems indicates increased loads and greater nutrient dynamics. The increase observed in the clay fraction in agricultural systems can be explained by the formation of organomineral complexes, where organic matter associates with the silt and clay fractions, providing colloidal protection and affecting the dynamics of nutrients in the soil (Nanzer et al., 2019).

This association can influence organic matter stability and, consequently, TOC content, especially in pasture areas, where changes in soil texture can reflect variations in organic matter protection and nutrient availability. In addition, it is important to consider that inherent differences between forest and pasture areas and erosion processes can contribute significantly to the changes in soil texture observed (Agbeshie et al., 2022).

The conversion of native forest into pasture affects soil structure and TOC, mainly through soil disturbance, which reduces aggregate stability and exposes MOS to decomposition (Butzke et al., 2020). However, management practices and selecting suitable grass species can mitigate these effects, promoting aggregate formation and potentially increasing TOC (Souza et al., 2018). Native forests, with their dense root network, sustain high levels of TOC by physically protecting the MOS, while pastures, depending on management, can also contribute to aggregate formation and carbon sequestration, as evidenced by Kamau et al. (2017), Muchane et al. (2020), and Agbeshie et al. (2022).

There was a decrease in microbial biomass in the BB and BH systems at a depth of 0-0.10 m and BH at 0.10-0.20 m. This decrease also occurred at depth for all systems (Table 2). These changes can be attributed to the removal of the native forest, which results in soil exposure and oxidation of organic matter, reducing the availability of substrates for microorganisms and, consequently, microbial activity.

Although the initial conversion may temporarily increase aeration and incorporate organic matter, the lack of subsequent management and the lower input of fresh organic material contribute to the reduction of microbial biomass in the long term. These observations corroborate Freitas et al. (2013), who reported similar results when comparing an agroforestry system, cultivating pasture and stubble fields with native forests.

Zeferino et al. (2023) demonstrated that the conversion of the Amazon rainforest into pasture affects microbial biomass and results in significant changes in soil carbon and nitrogen stocks. Basal soil respiration, measured by CO_2-C emissions, was significantly higher in the surface layer (0-0.10 m) in all the systems studied, with lower values for the BH system than the other managements (Table 2).

Table 2. Mean values (±s.d.) of some general biochemical properties of the studied areas (NF, BB, and BH) and depths.

Attribute	**Soil layer (m)**	**Area**					
		NF[1/]		**BB[2/]**		**BH[3/]**	
Microbial biomass (mg kg^{-1})	**0.00 – 0.10**	189.20 ± 29.00	aA	157.30 ± 27.00	aB	97.80 ± 16.00	aC
	0.10 – 0.20	108.20 ± 26.00	bA	129.80 ± 32.00	bA	74.80 ± 27.00	bB
Basal respiration (CO_2–C emitted) (mg kg^{-1} 10 days^{-1})	**0.00 – 0.10**	191.28 ± 20.00	aA	185.73 ± 23.00	aA	147.82 ± 20.00	aB
	0.10 – 0.20	109.20 ± 23.00	bB	146.49 ± 13.00	bA	112.65 ± 12.00	bB
Dehydrogenase (µmol INTF g^{-1} h^{-1})	**0.00 – 0.10**	0.150 ± 0.010	aA	0.060 ± 0.020	aB	0.066 ± 0.020	aB
	0.10 – 0.20	0.108 ± 0.010	bA	0.052 ± 0.010	bC	0.061 ± 0.010	bB
Total inorganic N (mg kg^{-1})	**0.00 – 0.10**	13.34 ± 2.81	aA	9.41 ± 1.67	aA	10.85 ± 2.35	aA
	0.10 – 0.20	12.78 ± 2.19	aA	11.09 ± 4.19	aA	7.02 ± 4.17	bB
NH_4^+-N (mg kg^{-1})	**0.00 – 0.10**	11.21 ± 2.64	aA	8.30 ± 3.00	aB	2.40 ± 1.01	aC
	0.10 – 0.20	7.57 ± 0.88	bB	11.90 ± 1.11	bA	5.74 ± 1.16	bB
NO_3-N (mg kg^{-1})	**0.00 – 0.10**	2.13 ± 5.05	aB	1.11 ± 2.35	aB	8.45 ± 2.43	aA
	0.10 – 0.20	4.77 ± 1.83	bA	0.78 ± 3.34	aB	1.28 ± 3.59	bB

1/NF: Native forest; 2/BB: *Brachiaria brizantha*; 3/BH: *Brachiaria humidicula*. Equal uppercase letters indicate that the values for the same layer in the different areas are not significantly different, while equal lowercase letters indicate that in each study area, the values in the two layers are not significantly different ($p \leq 0.05$).

At greater depths (0.10-0.20 m), the NF and BH systems showed similar basal respiration rates, but both were lower than in the BB system, where there was a correlation between higher microbial biomass production and higher basal respiration. These results indicate that microbial activity in the NF system can be negatively impacted by the process of MOS mineralization conducted by microorganisms. This process generates organic acids and other compounds that contribute to soil acidification, reducing the availability of essential nutrients for microbiota and affecting their activity. This phenomenon suggests that the differences in basal respiration between the management systems can be attributed to variations in the contribution and quality of organic matter, plant cover, and the intrinsic characteristics of the soil rather than to specific mechanical soil management practices, which were not applied.

Tanaka et al. (2019) observed that the application of nitrogen to *Urochloa* spp. cover crops increased biomass production, suggesting a potential increase in microbial activity and basal soil respiration due to the greater decomposition of organic residues. Tegegn et al. (2019) found that high biomass production by *Brachiaria* implies a greater contribution of organic matter to the soil, potentially influencing basal respiration. Dehydrogenase activity (ADH) was higher for NF at 0-0.10 and 0.10-0.20 m. In addition, ADH decreased in depth in the three systems evaluated (Table 2). This reduction reflects the decrease in TOC between the systems and at depth (Table 1). ADH in the soil reflects the total oxidative capacity of the microbiota and works as a good indicator of microbial activity (Januskiewicz et al., 2019), being stimulated by the C content in the soil (Yada et al., 2015). ADH can be influenced by the

amount of decomposable carbon, establishing a close relationship with microbial biomass and showing sensitivity to environmental impacts (Januskiewicz et al., 2019). The reduction in ADH in the systems implemented follows the same pattern as TOC.

Mineralized N was minimally affected by the different systems and depths, except for the 0.10-0.20 m layer in the BH system, where there was a reduction (Table 2). In the NF system, NH4+-N mineralization decreased as depth increased. When the systems were compared at different depths, the decrease pattern was as follows: NF showed the highest mineralization, followed by BB and BH in the 0-0.10 m layer. However, BB had the highest mineralization in the 0.10-0.20 m layer, while NF and BH had similar mineralization. This variation can be attributed to the influence of soil pH, which directly affects microbial activity and, consequently, the processes of nitrification and nitrogen mineralization. The highest NO_3-N content was found in BH (8.45 mg kg^{-1}) in the 0-0.10 m layer and NF (4.77 mg kg^{-1}) in the 0.10-0.20 m layer (Table 2).

According to Geisseler and Scow (2014), in different management systems, the content and quality of organic matter, together with the environmental conditions of humidity and heat, are the factors that most influence nitrogen mineralization.

Figures 2A and 2B show the microbial (qMIC) and metabolic (qCO_2) quotients in the areas and layers studied. It can be seen that the qMIC was lower in NF and higher in BB, differing significantly between layers only in BB ($p \leq 0.05$).

A) B)

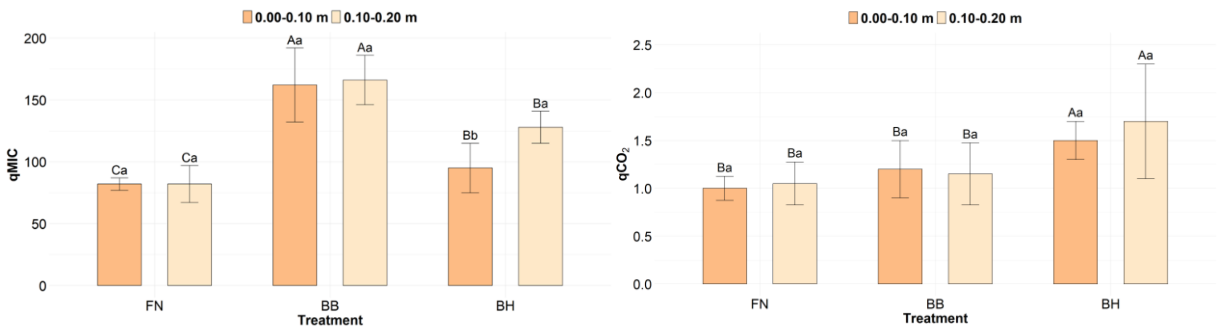

Figure 2. Microbial dynamics in the areas (NF, BB, and BH) for the two layers studied (0.0-0.10 and 0.10-0.20 m). A: microbial quotient (qMIC) in g 100 g^{-1}; B: metabolic quotient (qCO_2) in mg CO_2-C mg biomass TOC h^{-1}. Equal uppercase letters indicate that the values for the same layer in the different areas are not significantly different, while equal lowercase letters indicate that in each study area, the values in the two layers are not significantly different ($p \leq 0.05$).

The qMIC values observed in the three systems (Figure 2A) suggest that the amount of microbial biomass incorporated into the soil organic carbon was inadequate. Specifically, the average qMIC value in NF (82 g 100 g^{-1}) is significantly below that recommended for systems considered in equilibrium, as Rego et al. (2023) described. This discrepancy indicates a potential limitation in the system ability to sustain a healthy and active microbial community, reflecting challenges in soil management that impact its biological quality.

In the BB and BH systems, although also below this critical level, the qMIC was higher than that obtained in the NF, with the BB system standing out as having greater potential for making substrates available. Higher qMIC values indicate that more labile organic substrates are being kept in the soil, allowing for greater microbial biomass per unit of soil organic carbon (Santos et al., 2021). It is possible that the sampling time (dry season) disadvantaged these systems. Lourente et al. (2016) observed a qMIC higher than 200 in the rainy season, with fewer restrictions on plant development and exudation from the rhizosphere.

The BB system did not differ from NF in the maintenance of microbial biomass measured by qCO_2 (Figure 2B). This system incorporated significantly more carbon into the soil (qMIC). On the other hand, the greater inefficiency of the BH system, recorded by higher qCO_2 values, may be associated with the species adapting to conditions of low soil fertility. According to Stieven et al. (2014), establishment time is one factor that promotes inefficiency in incorporating C into the soil, showing that BB is faster in this process.

High metabolic quotient values indicate environmental stress or imbalance (Lourente et al, 2016). The replacement of NF is the primary condition of this imbalance, aggravated by others that result from the establishment of pastures, accelerating a large loss of CO_2 (Rego et al., 2023). In contrast, Rashti et al. (2024) observed that the lengthy conversion of the soil to sugarcane cultivation resulted in a significant reduction in microbial biomass and changes in nitrogen cycling processes, leading to increased qCO_2 and lower carbon use efficiency. Santos et al. (2021) found no significant differences between the qCO_2 of forest environments and those subjected to burning, although the authors note the high qMIC in the natural ecosystem.

4. Conclusions

The conversion of NF into agricultural systems modifies soil chemistry, raising the pH due to the burning and removal of vegetation, which also affects nutrient dynamics. This increase is accompanied by changes in microbial biomass and total organic carbon, with the BH system showing the most significant reductions.

The decrease in microbial biomass and the changes observed in basal respiration and dehydrogenase activity highlight a reduction in soil microbial activity, highlighting the negative impact of land use conversion on microbial biodiversity and ecological health.

Analysis of qMIC and qCO_2 reveals that conversion to pasture can reduce the soil's ability to support an active microbial community, with the BH system showing greater stress.

Authors' Contribution

Sandra Cátia Pereira Uchôa: Conceptualization, data collection, laboratory data analysis, data interpretation, and manuscript writing. Sasha de Souza Farage: Data interpretation and manuscript writing. José Maria Arcanjo Alves: Data collection, data interpretation, and manuscript revision. Carlos Henrique Lima de Matos: Statistical data analysis, preparation of graphs and tables, data interpretation, and manuscript revision. Ingridy do Nascimento Tavares: Preparation of graphs and tables, data interpretation, and manuscript revision. Valdinar Ferreira Melo: Data interpretation and manuscript revision.

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