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Nitrogen dynamics in small watersheds in the Atlantic Forest and Cerrado in Northeastern Brazil

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Abstract

The aim of this study was to determine concentrations of nitrogen (N) in two biomes, Atlantic Forest (AF) and Cerrado (CR), at the interface between terrestrial and aquatic ecosystems. This involved evaluating N in vegetation (litterfall), soil and water in small watersheds in environmental protection areas in northeastern Brazil. Soil chemical and physical analyzes were performed and mineralization and nitrification rates were determined. The forms of organic, inorganic and particulate nitrogen in water were determined by spectrophotometry. Two collections were carried out, one in the dry season (October and November 2019) and another in the rainy season (February and March 2020), in two environmental preservation areas, Estação Veracel Private Natural Heritage Reserve - (Atlantic Forest) and Chapada Diamantina National Park (Cerrado), with five small watersheds sampled in each biome. The N concentration in litterfall was similar in both biomes, with averages of 0.69%. In relation to soil and water, N concentrations were higher in AF compared to CR, with concentrations of 0.95 ± 0.40 and 0.59 ± 0.14 μg.Ng-1 of nitrate in the soils of AF and CR, respectively, and 3.53 ± 2.51 μM of nitrate in water in AF and 0.76 ± 0.78 μM in CR.

Keywords: Stream; Conservation units; Litterfall; nutrients, net mineralization.

Dinâmica de nitrogênio em microbacias na Mata Atlântica e Cerrado no Nordeste brasileiro

Resumo

O objetivo deste estudo foi determinar as concentrações de nitrogênio (N) em dois biomas, Mata Atlântica (AF) e Cerrado (CR), na interface entre os ecossistemas terrestre-aquático, avaliando o N na vegetação (serapilheira), no solo e na água em microbacias em áreas de proteção ambiental no nordeste brasileiro. Foram realizadas análises químicas e físicas do solo e determinadas as taxas de mineralização e nitrificação. Na água, foram determinadas as formas de nitrogênio orgânico, inorgânico e particulado por espectrofotometria. Foram realizadas duas coletas, uma no período seco (outubro e novembro de 2019) e outra no chuvoso (fevereiro e março de 2020) em duas áreas de preservação ambiental, na Reserva Particular de Patrimônio Natural - Estação Veracel (Mata Atlântica) e Parque Nacional Chapada Diamantina (Cerrado), sendo amostrados cinco microbacias em cada bioma. A concentração de N na serapilheira foi semelhante entre os biomas, apresentando médias de 0,69%. Em relação ao solo e a água, as concentrações de N foram maiores na AF comparados a CR, com concentrações de 0,95 ± 0,40 e 0,59 ± 0,14 μg.Ng^{-1} de nitrato no solo de AF e CR, respectivamente e 3,53 ± 2,51 μM de nitrato na água em AF e 0,76 ± 0,78 μM em CR.

Palavras-chave: Riacho; unidades de conservação; serapilheira, nutrientes, mineralização.

Introduction

Brazil is recognized for its megadiversity, a condition that is favored by the fact that most of the country is located within the southern tropical zone, between the Equator and the Tropic of Capricorn. Solar energy is abundant throughout the year, with annual precipitation of around 1300 mm across most of the country (Martinelli et al., 2020). These factors, combined with geology and relief, result in this diversity of biomes with distinct vegetation. The vegetation can be dense, with large trees, as observed in the Atlantic Forest biome, or composed of small- to medium-sized shrubs and trees, as in the "*Campos Rupestres*" (Silveira et al., 2016).

The "*Campos Rupestres*" vegetation consists of a mosaic of different physiognomies, the result of topographic conditions, soil depth and composition, and different microclimates. However, it is still a little valued and studied environment, especially in relation to its ecological aspects (Oliveira et al., 2015). On the other hand, the Atlantic Forest has been constantly researched, mainly in fragments of preserved areas. The natural environments in this biome have largely been replaced over time by agriculture and/or urbanization (De Santana, Delgado & Schiaveti, 2020).

The conservation of all phytophysiognomic gradients within an ecosystem is essential to ensuring the maintenance of functional diversity, as well as the ecological processes that regulate the nutrient dynamics between physiognomies (Mitre et al., 2018). The processes in forest ecosystems also reflect directly on the chemical composition of stream water, since nutrients not incorporated into the vegetation and the soil are exported to the streams (Gonçalves, França & Callisto, 2006).

Organic matter and nutrients can be transported to streams through the litter of riparian vegetation. Dissolved nutrients reach streams through groundwater, while particulate organic matter is transported through land flow, mainly by surface runoff during the rainy season. This matter may be retained and biochemically processed via consumption by microorganisms and invertebrates, or may be transported downstream (Wohl, 2017).

The aim of this study was to determine nitrogen concentrations at the interface between terrestrial-aquatic ecosystems in two biomes, Atlantic Forest and Cerrado, and to determine how seasonal variations (dry and rainy seasons) influence N dynamics.

Materials and Methods

Study areas

Samples were collected from two biomes, Atlantic Forest and Cerrado, located in protected areas in Bahia, Brazil. Samples were collected from ten small watersheds, five in each biome. The Atlantic Forest samples were collected in the Estação Veracel Private Natural Heritage Reserve – (RPPN-EV), and the Cerrado samples in the Chapada Diamantina National Park (PNCD) (Figure 1).

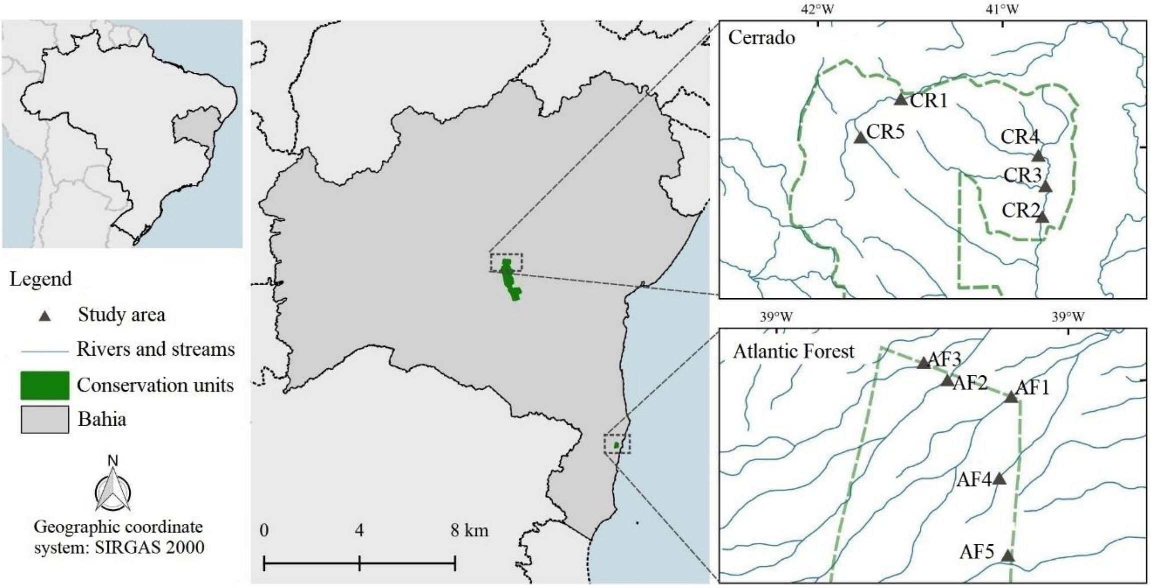

Figure 1. Map of the collection sites in the Atlantic Forest and Cerrado in Bahia, Brazil.

The Atlantic Forest consists of different forest formations, including Dense, Mixed, Open, Seasonal, Semi-Decidual, and Deciduous Rain Forests, and associated ecosystems (mangroves, sandbanks, montane grassland, inland bogs, and forest enclaves). The predominant vegetation in the RPPN-EV is Dense Ombrophilous Forest, characterized by arboreal vegetation of early pioneer and secondary species, usually with small diameters and closed canopy (Schorn & Galvão, 2006). The region's climate is characterized as rainy, hot, and humid due to its geomorphology and proximity to the ocean and is defined as an Af climate by the Köppen classification (RPPN - EV, 2016).

The PNCD displays characteristics of both the Caatinga and Cerrado biomes. However, the researched region is characterized as Cerrado, with *Campo Rupestre* representing the predominant phytophysiognomy. The climate is mesothermal, characterized according to the Köppen classification system as Cwb type - tropical semi-humid, with two seasons: dry, from May to October, and rainy, from November to April. Total annual rainfall is above 1000 mm, and the annual temperature ranges from 22 ºC to 25 ºC, with a minimum of around 15 ºC (Miranda, d'Afonsêca, Vitória & Funch, 2011).

Collection and analysis procedures

Samples were collected in two periods, during the rainy and dry seasons. In the Cerrado (CR), the collections were carried out in October/2019 (dry) and February/2020 (rainy) and in the Atlantic Forest (AF) in November/2019 (dry) and March/2020 (rainy). Average accumulated precipitation in the CR was 54.36 mm in the dry season (August-October) and 110.53 mm in the rainy season (December-February). In the AF, the accumulated average in the dry season (September-November) was 70.54 mm, and in the rainy season (January-March) was 96.48 mm.

Accumulated litterfall

The accumulated litterfall was collected with a quadrant of PVC pipe, with an area equivalent to 0.25 m^2, with all litter within the area collected and packed in paper bags (Barbosa, Barreto-Garcia, Gama-Rodrigues & Paula, 2017). Five samples were collected from each watershed. Firstly, a starting point was determined (0 m), and then samples were collected every 10 m (parallel to the stream) over 40 m.

After each collection, the sampled litter was dried in an oven at 60 ºC for 72 hours, separated into four fractions (leaves, branches, reproductive structures, and miscellaneous), and weighed. Concentrations of Total Nitrogen (TN) were then determined from the leaves alone, this being the predominant fraction, and analyzed according to Flind & Lillebø (2005) using the adapted N-Kjeldahl method (Barbosa et al., 2017; Silva, 2005).

Soil samples

Soil samples were collected from the topsoil (10 cm) to determine the net mineralization, nitrification, and physico-chemical parameters. Five subsamples were collected at each sampling site and mixed to form a composite sample, which was analyzed for organic matter (OM), pH, P, K^+, Ca^{2+}, Mg^{2+}, Al^{3+}, potential acidity (H +Al), the sum of bases (SB), and cation exchange capacity (CEC). The samples were dried in an oven at 60 ºC for 72 hours, and the OM was determined by titration after extraction by dichromate solution. The P analyses were performed by Mehlich extraction and determined by colorimetry and flame photometer. Ca^{2+}, Mg^{2+} and Al^{3+} were extracted by KCl $1 mol.L^{-1}$, with Ca^{2+} and Mg^{2+} determined in an atomic absorption spectrophotometer and Al^{3+} by titration. The grain size was determined by the Buyoucos method (density meter).

The incubation method adapted from Piccolo, Neill, and Cerri (1994) was used to determine the net mineralization and nitrification. The $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$ in the soil extract were analyzed by spectrophotometry (Grasshoff, Erhardt & Kremling, 1983). Soil moisture was determined by gravimetry, whereby a sub-sample of approximately 10 g was separated and dried at 60 ºC until reaching constant weight. The calculations used to determine net mineralization and nitrification are based on the following equations:

$$\text{Mineralization} = (N\text{-}NH_4^+ tn + N\text{-}NO_3^- tn) - (N\text{-}NH_4^+ t0 + N\text{-}NO_3^- t0) / tn$$

$$\text{Nitrification} = (N\text{-}NO_3^- tn - N\text{-}NO_3^- t0) / tn$$

tn: Incubation time (5, 7, 14, 21 days) and t0 initial time (collection day).

Stream water samples

Stream water samples were collected manually in dark polyethylene bottles and filtered in glass microfiber filters with a porosity of 0,7 µm, calcined at 450 ºC for 4 hours. Samples were frozen in polyethylene bottles for further analysis of Dissolved Organic Nitrogen (DON) and Dissolved Inorganic Nitrogen (DIN). After filtration, the filters were dried in an oven at 60 ºC for 72 hours until reaching a constant weight, and subsequently analyzed for particulate organic nitrogen (PON).

Spectrophotometry (UV 1800 Shimadzu) was used to determine DIN, nitrate, nitrite, and N-ammoniacal ions (NO_3^-, NO_2^- and NH_4^+), according to Grasshoff et al. (1983). After digestion of the samples with potassium persulfate, the organic forms of total dissolved nitrogen (TDN) and PON were analyzed by spectrophotometry (Grasshoff et al., 1983). The dissolved organic form was determined by the difference between the inorganic forms of N and TDN (DON = TDN-DIN).

Statistical analysis

The results were submitted to the Shapiro-Wilk normality test when it was observed that the variables did not present normal distribution. The non-parametric Mann-Whitney test was used to verify possible significant differences ($p < 0.05$) between N concentrations from litter, soil, and stream water, comparing the concentrations between the phytophysiognomies and between the collection periods, with the aid of the software Statistica 10 (trial version).

Results and Discussion

The total amount of accumulated litterfall was similar between the biomes but differed between the collection periods, with higher values in the rainy season in both areas. Leaves represented the main fraction in both areas, representing more than 50% of the total litter. There were more branches in the rainy season in both areas, with the reproductive structures (flowers and fruits) representing a lower percentage among the fractions. (Table 1).

The biogeochemical processes that occur in the soil reflect the availability of nutrients within an ecosystem, with the production and decomposition of litter being an important way of exporting nutrients from terrestrial to aquatic ecosystems (García-Palacios, McKie, Handa, Frainer, & Hättenschwiler, 2015). In general, leaves are the predominant fractions in the litterfall and provide an important role in the availability of nutrients in the soil (Alves et al., 2018; Oliveira et al., 2015) as well as in streams, constituting more than 50% of the allochthonous particulate organic material (Gonçalves et al., 2006).

The nitrogen in the leaves was similar between the biomes and between the collection periods. In AF, percentages varied from 0.68% to 0.77% in the dry and rainy seasons, respectively, and in CR, 0.69% in both periods (Figure 2).

Table 1. Total litterfall (g.m^{-2}) and litterfall fractions (%) in Atlantic Forest (AF) and Cerrado (CR) in the dry and rainy seasons (mean ± standard deviation).

Litterfall	Dry	Rainy
	AF	
Total	386.2 ± 212.3	511.0 ± 87.8
Leaves	53.5 ± 8.4	56.5 ± 7.9
Branches	21.0 ± 2.8	25.9 ± 6.7
Miscellaneous	23.2 ± 4.2	16.8 ± 4.5
RS*	2.4 ± 4.0	0.9 ± 0.9
Litterfall	CR	
Total	397.0 ± 178.8	516.8 ± 254.3
Leaves	65.2 ± 14.5	51.5 ± 12.3
Branches	18.0 ± 5.4	27.6 ± 5.8
Miscellaneous	14.0 ± 8.4	18.5 ± 7.5
RS*	2.8 ± 3.1	2.4 ± 1.9

*Reproductive structure

The hypothesis that the quantity and quality of accumulated litterfall would be higher in AF watersheds was not confirmed, since no significant differences were observed in the litter production and N concentrations in the leaves between the biomes. The *"Campo Rupestre*" region can be considered to be an ecotone between Caatinga and Cerrado. Moreover, it can present a great richness of plant species, influencing the quantity and quality of litter of this phytophysiognomy (Rezende et al., 2017).

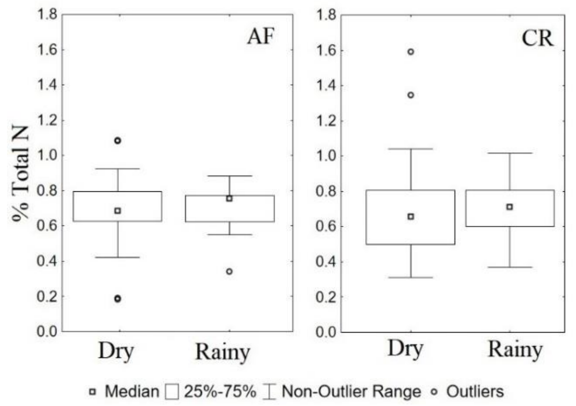

Figure 2. Total nitrogen (%) in litterfall leaves in Atlantic Forest (AF) and Cerrado (CR) streams in the dry and rainy seasons.

As well as the amount of accumulated litterfall in the watersheds, the total N in leaves was also similar, rejecting the hypothesis that low N concentrations in the Cerrado would be associated with low N concentrations in soil. Cerrado vegetation, growing in dystrophic soils, can reabsorb and conserve nutrients. The efficiency of resorption increases as soil fertility decreases, representing a conservation strategy to reduce their dependence on the availability of nutrients in the soil (Resende, Markewitz, Klink, Bustamante & Davidson, 2011; Alves et al., 2018).

The areas displayed distinct soil textures, with the Atlantic Forest areas classified as sandy clay loam with 23.1% of clay, 59.4% of sand, and 18.5% of silt, and the Cerrado areas as loamy sand with 9.5% of clay, 82.1% of sand and 8.45% of silt. The amount of OM in AF soil was significantly higher than in the CR, with 87.7 g.Kg^{-1} in AF and 35.0 g.Kg^{-1} in CR. Phosphorus concentrations were similar between areas, corresponding to approximately 5 mg.dm^{-3}. Soil acidity (pH; H+Al) and CTC values did not differ between areas. The percentage of base saturation (V%) was low in both areas, but was significantly higher in the AF (Table 02).

Table 2. Physical and chemical characteristics of soil from the Atlantic Forest (AF) and Cerrado (CR) (mean ± standard deviation).

Characteristics of soil	AF	CR
pH	4.25 ± 0.16	4.24 ± 0.20
OM (g.Kg^{-1})	87.74 ± 38.79	35.0 ± 16.90
P (mg.dm^{-3})	5.38 ± 1.87	5.70 ± 2.39
H+Al (cmolc.dm^{-3})	13.22 ± 2.83	9.98 ± 3.68
BS (cmolc.dm^{-3})	1.68 ± 0.43	0.50 ± 0.46
CEC (cmolc.dm^{-3})	14.90 ± 3.14	10.48 ± 3.86
V(%)	11.20 ± 2.16	4.40 ± 3.36

Legend: OM = organic matter; P = phosphorus; H + Al = potential acidity; SB = sum of bases; CEC = cation exchange capacity; V = base saturation.

The soils of both regions are considered dystrophic because they have a base saturation (V%) below 50% (reference value for tropical arable soils), but the CR soil displayed characteristics of poorer quality compared to the AF soil. The CR soil has a sandy texture, less OM, and lower CEC, BS and V% values, indicating lower soil fertility in this biome (Ronquim, 2010).

The highest concentrations of inorganic nitrogen (N-NH_4^+ and N-NO_3^-) and soil moisture were observed in the AF soil, differing significantly between areas. Soil moisture in the AF was ten times higher than in the CR in the dry season (32% in AF and 3.2% in CR). Among the collection periods, the highest N concentrations and moisture were observed in the rainy season in both areas, with N-NH_4^- averages of 6.87 µg.Ng^{-1} in AF and 5.17 µg.Ng^{-1} in CR, and N-NO_3^- concentrations were 0.95 and 0.59 in AF and CR soil, respectively (Table 3).

Table 03. Moisture (%) and nitrogen concentrations (N-NH_4^+; N-NO_3^- at µg. N g^{-1}) in Atlantic Forest (AF) and Cerrado (CR) soils during the dry and rainy seasons

Biome	Season	Moisture (%)	N- NH_4^+	N- NO_3^-
AF	Dry	32.2 ± 13.1	5.11± 2.77	0.44 ± 0.30
	Rainy	36.4 ± 16.4	6.87 ± 3.98	0.95 ± 0.40
CR	Dry	3.2 ± 2.7	1.27 ± 0.54	0.11 ± 0.05
	Rainy	8.4 ± 3.1	5.14 ± 2.45	0.59 ± 0.14

High decomposition coefficients result in a rapid release of nutrients from the litterfall into the soil. These coefficients are associated with soils with a higher moisture value, as found in the AF (Peña-Peña & Irmler, 2016). The processes of net mineralization and nitrification also depend on soil moisture. The low percentage (maximum of 8.4%) of moisture in the CR may have a negative impact on these processes. The low N concentrations, mainly of NO_3^- in soil and streams, corroborate other studies conducted in the Cerrado that define it as a closed N cycling system (Silva, 2005; Resende et al., 2011).

Of the N transformation processes in the soil, higher values were observed for mineralization than nitrification in both areas; with 0.49 µg.Ng^{-1} day^{-1} in the AF and 0.18 µg.Ng^{-1} day^{-1}in the CR. Nitrification values in the AF and CR were 0.18 and 0.01 µg.Ng^{-1} day^{-1}, respectively. Both processes were significantly faster in the AF (Figure 3).

Net mineralization and nitrification in the AF were higher in the rainy season with values of 1.43 and 0.48 µg.Ng^{-1} day^{-1}. In the CR, the influence of temporal variations in the mineralization process was also observed, with higher values in the rainy season (0.43 µg.Ng^{-1} day^{-1}). Nitrification did not differ between seasons, with 0.01 µg.Ng^{-1}day^{-1} in the dry season and 0.05 µg.Ng^{-1}day^{-1} in the rainy season (Figure 3).

Mineralization can be influenced by the mesothermal climate in the CR, where there are colder winters (Miranda et al., 2011). In these areas, minimum temperatures can reach 15 ºC, while in the AF they do not fall below 19 ºC. The fluctuations in temperature throughout the day due to higher altitudes (Villela, de Mattos, Pinto, Vieira & Martinelli, 2012) lead to a lower temperature at night. This characteristic reduces microbial activity in the soil, which leads to slower mineralization. This is reflected by the lower rates in the CR (0.18 µg.Ng^{-1} day^{-1}) when compared to the AF (0.49 µg.Ng^{-1} day^{-1}), and leads to a higher accumulation of organic matter on the surface of the soil (Benites, Schaefer, Simas & Santos, 2007).

Cerrado vegetation displays certain strategies to help its development, especially in dystrophic and low humidity soils. It is common for the leaves to have a higher lignin content, making them more rigid and preventing water loss due to water stress. These strategies can influence the plants' palatability, restricting the colonization of decomposing organisms. Lignin is recalcitrant to enzymatic degradation and acts as a structural barrier that hinders the access of microorganisms. This slows down the decomposition process and consequently influences nutrient availability in the CR soil and streams (Peña-Peña & Irmler, 2016; Austin & Ballare, 2010).

Among the forms of N analyzed in the streams, DIN was the main form in the AF and DON in the CR. Concentrations of NH_4^+ were similar in both areas, with 5.55 µM in the AF and 4.26 µM in the CR. Concentrations of NO_3^- were significantly higher in the AF, with a value of 3.53 µM.

In the CR, the concentration of DON was significantly higher than in streams in the AF. PON was the form with the lowest concentration in both areas, 3.07 µM in the AF and 0.90 µM in the CR (Figure 4).

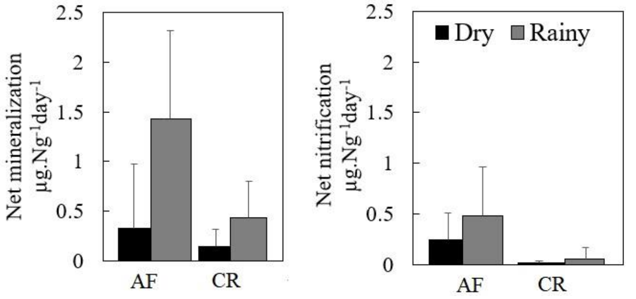

Figure 3. Net mineralization and nitrification in Atlantic Forest (AF) and Cerrado (CR) soils in the dry and rainy seasons.

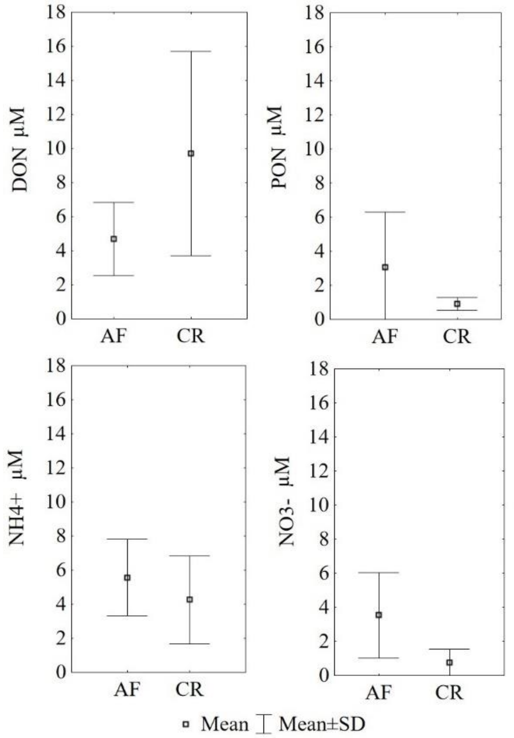

Figure 4. Forms of nitrogen in streams in the Atlantic Forest (AF) and the Cerrado (CR). Where, PON = Particulate organic nitrogen; DON = Dissolved organic nitrogen; NH_3^+/NH_4^+ = N-ammoniacal; NO_3^- = nitrate.

Soils associated with rocky outcrops, as found in the CR, display an accumulation of organic matter derived from undisturbed plant residues. However, most organic substances in these soils are strongly humified, with a predominance of humic acid (Benites et al. 2007). This is reflected in the brown color of the streams and the predominance of DON and probably DOC (dissolved organic carbon). The export of DON demonstrates that the biological demand of the soil is insufficient to retain all available DON before it can be leached. Therefore, DON in streams may be positively correlated with dissolved organic carbon, suggesting that its export to streams is associated with the leaching of humic substances from soil (Hedin, Armesto & Johnson, 1995; Taylor et al., 2015).

Among the N forms in the AF streams, only the PON differed significantly between the collection periods, presenting higher concentrations in the rainy season. The DON concentrations did not differ between the periods, with 4.67 µM in the dry season and 3.73 µM in the rainy season. The inorganic forms did not differ statistically between the collection periods, but it can be observed that NH_4^+ concentrations were higher in the rainy season and NO_3^- concentrations were highest in the dry season. In the CR streams, PON did not differ between collections and presented one of the lowest concentrations among the N forms. DON was the main form in CR streams, presenting significantly higher concentrations in the rainy season (Table 04).

In the CR, the DIN did not differ statistically between collections, but NH_4^+ concentrations were higher in the rainy season and NO_3^- in the dry season (Table 04), as observed in the AF streams. Regarding DIN in the streams, similar NH_4^+ concentrations were observed in both biomes. However, their concentrations were higher in the rainy season in both areas. In tropical soils, increased precipitation during the rainy season, after a significant dry period, can result in a large stock of nutrients being released quickly, with increased soil moisture and nitrogen mineralization. Part of this N can be carried to streams, influencing the increase in NH_4^+ concentration in this period (Parron, Bustamante & Markewitz, 2011; Peña-Peña & Irmler, 2016).

Table 04. Organic and inorganic (at µM) in Atlantic Forest (AF) and Cerrado (CR) streams in the dry and rainy seasons. PON = Particulate organic nitrogen; DON = Dissolved organic nitrogen; NH_4^+ = N -ammoniacal and NO_3^- = nitrate (mean ± standard deviation).

	AF		CR	
	Dry	Rainy	Dry	Rainy
PON	1.07 ± 0.81	5.07 ± 3.61	0.72 ± 0.42	1.08 ± 0.21
DON	4.67 ± 2.83	3.73 ± 2.38	5.44 ± 3.43	13.96 ± 4.91
NH_4^+	4.46 ± 2.12	6.65 ± 1.97	2.39 ± 2.37	6.12 ± 0.84
NO_3^-	4.77 ± 2.75	2.30 ± 1.68	1.29 ± 0.67	0.23 ± 0.47

The principal component analysis (PCA) shows that the areas (AF and CR) were grouped on opposite sides, and all variables, except DON and %N, are positively related to AF. The first two axes explain 93% of the total variation of the data. The NO_3^- is positively correlated to the AF in the dry season, while the other forms of nitrogen in the water and soil and N transformation rates, are positively related to the rainy season. Net mineralization was directly related to N concentrations in soil and NH_4^+ concentration in water. DON was inversely related to the AF and directly related to the CR (Figure 5).

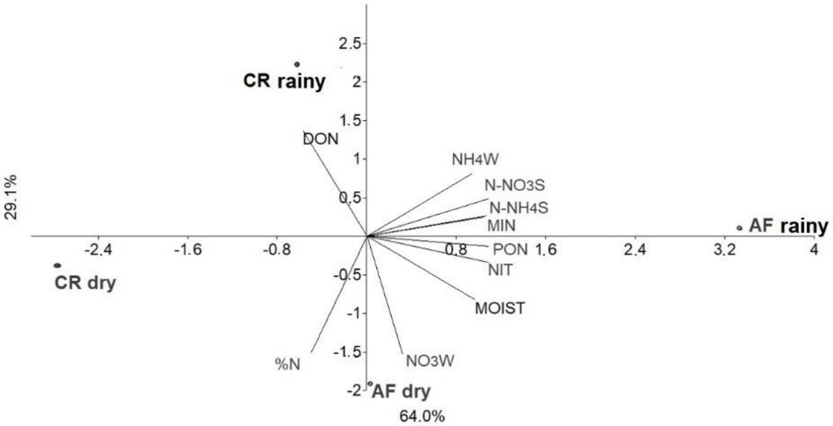

Figure 5: Principal component analysis (PCA) for the Atlantic Forest and Cerrado in the dry and rainy seasons. Legend: Dissolved organic nitrogen (DON), Particulate organic nitrogen (PON), N-ammoniacal in stream water (NH4W), nitrate in stream water (NO3W), net nitrification rate (NIT), net mineralization rate (MIN), N- NH_4^+ in soil (N-NH4S) and N- NO_3^- in soil (N-NO3S), soil moisture (MOIST) and %N in litterfall.

The vegetation in the AF can reduce soil evapotranspiration, favoring the maintenance of temperature and soil moisture. These factors directly influence the N transformation process. Similar values for net mineralization and nitrification in the AF were found in other preserved areas of Atlantic Forest in southern Bahia (Souza, Pereira, Costa & Silva, 2017) and São Paulo (Silva, 2005). They may corroborate the condition that the vegetation provides a favorable microclimate for the processes. Net mineralization, nitrification, and N concentrations were significantly higher in the AF; however, net mineralization was higher than nitrification in both areas, providing more NH_4^+ to the soil, directly influencing the concentrations of NH_4^+ exported to the streams, the predominant N form in both regions.

Conclusion

Plants in the CR may be assimilating a large part of the N available in the soil (N-NO_3^- and N-NH_4^+), reflecting on the nutritional quality of litterfall. Therefore, there are nutrient conservation strategies in CR plants that enable concentrations in the litterfall to be equal to the AF. In CR soil, mineralization and nitrification processes occur more slowly when compared to AF soil, resulting in low N availability in CR soil and, consequently, low concentrations of NID that are leached to streams, with a predominance of NOD in CR streams.

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