Nitrogen inputs by rainfall, throughfall and stemflow in Brazilian semiarid

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Abstract
The aim of this study was to quantify nitrogen inputs by the rainfall, throughfall and stemflow, assessing the canopy role in the nitrogen transfers between atmosphere and soil in a rural tropical semiarid region in the Brazilian Caatinga. Samples were collected during two wet seasons, one during an extremely dry year (2012) and one during a year with normal rainfall (2013). The ionic concentrations of $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, dissolved organic nitrogen (DON) and dissolved total nitrogen (DTN) was 0.04 and 0.15, 0.07 and 0.10, 0.49 and 0.48, 0.61 and 0.73 mg l^{-1} in the rainfall for 2012 and 2013, respectively. The canopy enrichment for DON were 3 times for both wet seasons and for DTN were 3 and 2 times in relation to rainfall values for 2012 and 2013, respectively. There were no differences in $N\text{-}NO_3^-$ between rainfall and throughfall. The enrichment for stemflow were 31, 8, 15 and 17 times for $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, DON and DTN for the wet season for 2013, respectively. We report a low bulk nitrogen deposition during both wet seasons and an estimative of about 2.05 kg N ha^{-1} ano^{-1}. We estimated slightly lower annual inputs than previous global estimates, likely due to the low rainfall depths that occurred during the studied years and the lack of measured data for South America. Our findings contribute to the knowledge of nitrogen deposition in the northeastern Brazil by providing information for this poorly studied tropical and semiarid ecosystem.

Key Words
Nitrate, ammonium, precipitation, bulk deposition, South America.

Introduction
The Brazilian semiarid is one of the most water-stressed region in the world and the crescent demand for agricultural and forests products has led to land cover changes with consequences on the nitrogen cycling. These processes are not totally known in this region and it is important to quantify the nitrogen inputs by the precipitation and the canopy contribution through the throughfall and stemflow. By passing through vegetation, precipitation washes the deposited materials in the canopy and trees stem and lixiviates the plant exudates, altering its chemical composition and cycling nutrients within the system.
In this study, we assessed the dissolved nitrogen dynamic in the Brazilian Caatinga, which is located in a tropical semiarid region. Sampling was conducted during two wet seasons, one in 2012, which was an extreme drought year, and one in 2013, which had normal rainfall. The aim of this study was to provide baseline information for the dissolved nitrogen concentrations as well as the nitrogen deposition in the rainfall, throughfall and stemflow.

Methods
Study area
This study was conducted in the Mundaú basin (8° 52' S and 36° 22' W) within a semiarid area in northeastern (NE) Brazil (**Error! Reference source not found.**). The site is located 716 m above sea level, and the straight-line distance from the sampling site to the coastline is 140 km. This area is a region of transition between the coastal Atlantic Forest climate and the inland Caatinga Biome climate, which is dry and xerophytic. The main land uses of this region are agricultural and include cattle grazing, subsistence agriculture and the extraction of fuel wood from natural vegetation areas. The soil in this area is classified as an Entisol according to U.S. Soil Taxonomy (Soil Survey Staff 2014), with pedogenic processes that extend deeper than 1.50 m and a sandy to sandy loam texture (Santos et al. 2012). The soil parent material mainly consists of quartz, and the soil contains low organic matter, available phosphorus and exchangeable cations contents (Sampaio 1995).

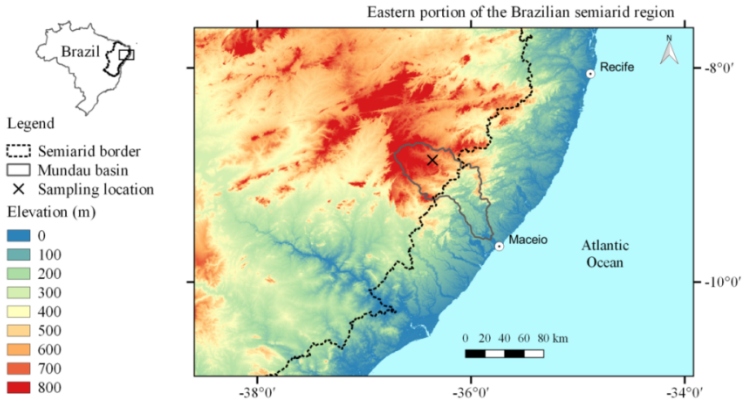

Figure 1. Elevation and location of the study area in the Mundaú Basin and within the semiarid region of the northeastern Brazil. Data source: http://www.relevobr.cnpm.embrapa.br/download/.

Sampling was performed on a ~17-ha cattle ranch that is bordered by a ~4 ha remnant patch of secondary Caatinga vegetation. In this area, the mean annual temperature varies from 18.5ºC in the wet season to 22.6ºC in the dry season (BSh Koppen climate, Peel et al. 2007). The annual climatological rainfall from 1964 to 2014 was 896 mm ± 25%. Pluviometric data were obtained from the nearest meteorological station, which is located in the Garanhuns municipality and is 13 km from the study area (Brazilian Institute of Meteorology 2015). The wettest months are generally from April to August and account for approximately 66% of the annual rainfall. In this study, sampling was conducted during this period due to logistical constraints. In 2012, an unusual drought event with much lower rainfall depth than the historical mean rainfall depth occurred throughout the Northeastern region in association with the anomalously colder subtropical South Atlantic Ocean (Marengo et al. 2013; Rodrigues & McPhaden 2014) . However, the rainfall depth in 2013 was within the range of the historical mean. At the sampling site, 196 and 412 mm of rainfall fell in 2012 and 2013, respectively.

Samplings

Bulk handmade rainfall and throughfall collectors were used to collect the rainfall samples. The collectors consisted of a 706.9 cm^2 polyethylene funnel coupled with a polyethylene 5-l container. The collectors were sheltered with a sun-protective blanket and were attached on top of a pole 1.5 meters above the ground. To avoid contamination from small falling debris, the funnels were loosely covered with nylon mesh (~2 mm) 1 cm below the mouth of the funnel. The sampling set was rinsed three times with deionized water between collections to avoid contamination. At the end of the first sampling period, the sampling set was washed with nitric acid (10%) and then rinsed five times with deionized water.

Three collectors were used simultaneously for rainfall sampling and three collectors were used simultaneously for throughfall sampling. Each sample represented a seven-day rainfall accumulation period, which was considered one event. In 2012 and 2013, rainfall sampling extended from June to September (12 sampling events, 36 samples) and from April to August (16 sampling events, 48 samples), respectively. The total rainfall depths collected in 2012 and 2013 were 116 and 207 mm, respectively, which corresponded to 90 and 84% of the incident rainfall that was measured by the gauge station at the sampling site.

Analytical procedures

The concentrations of ammonium ($N\text{-}NH_4^+$) and nitrate ($N\text{-}NO_3^-$) were analyzed using the liquid ion chromatography (Metrohm 850 Professional IC). Dissolved total nitrogen (DTN) was determined using the total carbon and nitrogen analyzer (Shimadzu, TOC-V_{CPN}/TMN-1). The dissolved organic nitrogen (DON) was obtained from the DTN minus the inorganic forms of nitrogen ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$). These analyses were performed in the Laboratory of Aerosol, Aqueous Solutions and Technologies (LAQUATEC) at the Earth System Science Center (CCST) of the Brazilian Institute for Space Research (INPE).

Results

The volume weighted mean (VWM) concentrations of $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, dissolved organic nitrogen (DON) and dissolved total nitrogen (DTN) for the rainfall, throughfall and stemflow for wet seasons of 2012 and 2013 are presented in the Table 1. Throughfall enrichment were statistically significant for $N\text{-}NH_4^+$ of 5 times ($p = 0.0001$) in relation to rainfall in 2012 and in 2013 no difference were observed ($p = 0.77$). The enrichment factors were 3 ($p = 0.0001$) and 3 ($p= 0.002$) for DON and 3 ($p = 0.0001$) and 2 ($p = 0.0300$)

times for DTN in relation to rainfall for 2012 and 2013 wet seasons, respectively. There were no differences in $N\text{-}NO_3^-$ between rainfall and throughfall ($p = 0.3065$ and 0.9170 for 2012 and 2013 wet seasons, respectively). For stemflow, there were statistically significant enrichment of 31, 8, 15 and 17 times for $N\text{-}NH_4^+$, $N\text{-}NO_3^-$, DON and DTN, respectively, for the 2013 wet season. The higher enrichment values of the stemflow could be due the higher interaction with branches and trunks before the stemflow start than the interaction with the canopy before the dripping start.

Table 1. Volume weighted mean (VWM) concentrations of the dissolved ammonium ($N\text{-}NH_4^+$), dissolved nitrate ($N\text{-}NO_3^-$) organic nitrogen (DON) and dissolved total nitrogen (DTN) (in mg l^{-1}) in the rainfall, throughfall and stemflow for the wet seasons of 2012 and 2013.

	2012				2013			
	mg l^{-1}				mg l^{-1}			
	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	DON	DTN	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	DON	DTN
Rainfall	0.04_a	0.07_a	0.49_a	0.61_a	0.15_a	0.10_a	0.48_a	0.73_a
Throughfall	0.21_b	0.07_a	1.61_b	1.89_b	0.20_a	0.10_a	1.46_b	1.76_b
Stemflow					4.69_b	0.83_b	7.01_c	12.53_c

The estimated atmospheric deposition, throughfall deposition and stemflow deposition of the nitrogenous species for the wet seasons of 2012 and 2013 and an annual estimative of DTN for atmospheric deposition are presented in Table 2. The estimated atmospheric depositions were 0.05 and 0.30 kg $N\text{-}NH_4^+$ ha^{-1} and 0.08 and 0.24 kg $N\text{-}NO_3^-$ ha^{-1} for the wet seasons of 2012 and 2013, respectively. The estimated depositions for DON were 0.60 and 1.27 kg N ha^{-1} and for DTN were 0.73 and 1.81 kg N ha^{-1}, for the wet seasons of 2012 and 2013, respectively. Higher depositions were estimated for throughfall, except for the $N\text{-}NO_3^-$ of 0.05 and 0.15 kg $N\text{-}NO_3^-$ ha^{-1}, for the wet seasons of 2012 and 2013, respectively. Despite higher concentrations of all nitrogenous species in stemflow the estimated depositions were lower than rainfall and throughfall depositions, probably due to the low flows in this pathway. The net depositions were calculated as the sum of throughfall deposition and stemflow depositions (when available) minus the atmospheric deposition. The net depositions values were positively, which indicates canopy lixiviation of exudates and/or washout of the deposited materials for major nitrogenous species, except for $N\text{-}NO_3^-$. The net depositions for $N\text{-}NO_3^-$ were -0.03 and -0.07 kg ha^{-1} and these negative values indicate canopy uptake or retention of this nitrogen species.

Table 2. Atmospheric deposition (show as rainfall), throughfall deposition and stemflow deposition of the dissolved ammonium ($N\text{-}NH_4^+$), dissolved nitrate ($N\text{-}NO_3^-$) organic nitrogen (DON) and dissolved total nitrogen (DTN) (kg ha^{-1}) for the wet seasons of 2012 and 2013 and an annual estimative (kg ha^{-1} ano^{-1}).

	2012				2013				Annual
	kg ha^{-1}				kg ha^{-1}				kg ha^{-1} ano^{-1}
Deposition	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	DON	DTN	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	DON	DTN	N-total
Rainfall	0.05	0.08	0.60	0.73	0.30	0.24	1.27	1.81	2.05
Throughfall	0.13	0.05	1.28	1.46	0.24	0.15	2.40	2.79	-
Stemflow	-	-	-	-	0.08	0.02	0.18	0.28	-
Net	0.08	-0.03	0.68	0.73	0.02	-0.07	1.31	1.26	-

Net depositions were calculated from the sum of throughfall and stemflow depositions minus the atmospheric deposition (when available). Negative net deposition indicates uptake of the nitrogenous species by the canopy and positive net depositions indicates lixiviation and/or washout by the canopy.

In the Atlantic Forest of northeastern Brazil, Henriques (2009) reported similar values for the wet season of 2013, with 0.4 kg $N\text{-}NH_4^+$ ha^{-1} and 0.2 kg $N\text{-}NO_3^-$ ha^{-1} . In the Atlantic Forest of southeastern Brazil higher values of 8.09 kg $N\text{-}NH_4^+$ ha^{-1} and 0.78 kg $N\text{-}NO_3^-$ ha^{-1} , respectively, were reported (Forti et al. 2005). These higher deposition estimates potentially resulted from urban anthropogenic contributions, i.e., vehicles, industries and sewage.

The estimated annual nitrogen deposition was 2.05 kg N ha^{-1} yr^{-1}. Similar depositions of 2 - 3.4 kg N ha^{-1} yr^{-1} were reported in a nitrogen budget of dry African savannas sites with an inter-annual variation of ± 25% (GALY-LACAUX & DELON, 2014). A higher value of 3.6 kg N ha^{-1} yr^{-1} was also estimated for a semiarid region of western India (Rastogi & Sarin 2006). In the framework of the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW), Vet et al. (2014) modelled the nitrogen deposition surrounding the São João and indicated that it was 1 - 2 kg N ha^{-1} yr^{-1}. This estimate is similar to the estimate reported here, which indicates that the estimates from WMO/GAW reasonably describes the deposition that ocurred in our study area. However, our data set should be assessed with attention, since our sampling occurred only in the wet season and were extended for the whole year.

Conclusion

In general, there was an enrichment of the throughfall by dissolved organic and total nitrogen when passing though canopy, but there was no differences for inorganic nitrogen species. For stemflow, there was statistically significant enrichment for all nitrogenous species, probably due to the higher retention time of the rainfall in the branches and trunks before the stemflow start. Our results show that the dissolved organic nitrogen is an important component of the total nitrogen deposition and it is the main component of the deposition. Nevertheless, the dynamic of the DON as well as the nitrogen cycling are poorly understood in the Brazilian semiarid. Global climatic changes and land use and cover changes, such as deforestation and expansion of urban areas can impact the N cycle by altering N deposition and bringing severe consequences to such fragile ecosystem.

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