The ^{15}N signals of different ecosystems in Northeast Brazil

E. V. S. B. Sampaio[A], A. D. S. Freitas[B], A. P. S. Ramos[A], M. R. V. Barbosa[C], R. P. Lyra[D] and E. L. Araújo[E]

[A]UFPE, Av. Prof. Luís Freire 1000, Recife, PE, Brazil, 50740-540, Email esampaio@ufpe.br, andresapri@yahoo.com.br
[B]UFRPE, Av D. Manoel de Medeiros s/n, Recife, PE, Brazil, 52171-900, Email ana.freitas@depa.ufrpe.br, elcida@db.ufrpe.br
[C]UFPB, Cidade Universitária, João Pessoa, PB, Brazil, 58051-970, Email barbosamrv@yahoo.com.br
[D]IMA, Av. Major Cícero de Góes Monteiro, 2197, Maceió, AL, 57017-320, Brazil, Email rosalyralemos@gmail.com

Abstract
Measuring the ^{15}N abundance in the plants of a site provides information on two of its important ecological aspects: 1) the openness of its N cycle; and 2) the possibility to measure its biological N fixation (BNF). The variation of δ^{15}N signals in trees of five different ecosystems in Northeast Brazil were measured: 1) a coastal rain forest; 2) a more humid semiarid caatinga; 3) a dry core caatinga; 4) a semideciduous mountain forest within the semiarid region; and 5) one savanna – caatinga transition. The rain forest had a low signal (2.4‰), contrasting with those of the caatinga (6.5 to 10.1‰) and mainly that of the caatinga – cerrado transition (12.6‰). Thus, in these forests, N losses are low, their cycle is relatively close and measuring fixation using the ^{15}N method is not viable. In each of these ecosystems, all the plants of all species had signals varying within a relatively narrow range (±1.6‰), with no significant difference among species, while in the savanna – caatinga transition the differences among species were high (±3.0‰). In the semiarid caatinga and the savanna – caatinga transition the signals are high enough to allow good estimations of N fixation.

Key Words
Semiarid, caatinga, rainforest, N fixation, N-15 abundance.

Introduction
Measuring the ^{15}N abundance in the plants of a site provides information on two of its important ecological aspects: 1) the openness of its N cycle; and 2) the possibility to measure its biological N fixation (BNF). The N inputs from the atmosphere to the large soil pool have δ^{15}N signals very close to 0; gaseous and diffusion losses are higher for the ^{14}N isotope, thus enriching the soil pool in ^{15}N and shifting its δ^{15}N signal to positive values (Shearer and Kohl 1986; Handley and Haven 1992; Handley *et al*. 1999). The higher the relative losses, the higher the δ^{15}N signal. If the soil signal is distinctly different from 0 it is possible to separate plants that obtain their N solely from the soil N pool from plants that obtain part of their N through BNF (Shearer and Kohl 1986). Therefore, knowing the ^{15}N abundance in the plants of a site is valuable information. Several places have had their ^{15}N signals measured in the last decades (Handley *et al*. 1999), allowing some generalizations to be made: tropical forests have higher signal values than temperate ones (Martinelli *et al*. 1999) and areas with low mean annual rainfall have higher values than those with abundant rainfall (Austin and Vitousek 1998). Soil type also influences the signals (Roggy *et al*. 1999). However, many exceptions of these general trends have been verified (Swap *et al*. 2004) and there are few systematic studies of variations along soil and climatic gradients within a single region. The Northeast region of Brazil, with its diversity of rainfall and soil conditions, offers a good opportunity for this kind of study. This paper describes the variation of ^{15}N signals in plants of different northeastern places.

Material and methods
The Northeast region of Brazil has an Atlantic coastal line roughly following a north – south direction. Annual rainfall is abundant in the coastal area (>1800 mm) and decreases westward to a semiarid core area, with low and erratic rainfall (about 500 mm). West of this core area, rainfall increases again to 1000 – 1500 mm, more regularly distributed in a 5-6 months rainy season. Interspersed in the semiarid area there are a few mountains (about 1000 m a.s.l.), where rainfall is higher and temperatures are lower. Soils in the coastal zone are deep, low fertility Latosols; in the semiarid zone are shallow, high fertility Luvisols; and in the western portion are similar to those of the coastal zone. The coastal area was covered by tropical rain forest, a few remnants of which still dot the landscape. Half of the semiarid area is covered by a low dense shrub and tree vegetation, locally called caatinga. Very few fragments remain of the semideciduous tall forest that covered the mountain tops in the semi-arid area. The western portion vegetation is a mixture of caatinga and savanna (cerrado) vegetation.

Eight sites were chosen to be sampled, following roughly three parallel east – west transects, along the states of Paraíba, Pernambuco and Alagoas : 1) one in the coastal forest, in Rio Largo municipality , Alagoas; 2) two in the more humid caatinga of the eastern portion, one in Caruaru, Pernambuco and one in Remígio, Paraíba; 3) three in the caatinga core region, in Santa Teresinha, Paraíba, Serra Talhada, Pernambuco and Pão de Açúcar, Alagoas; 4) one in the mountain forest of Mata Grande, Alagoas; and 5) one in the savanna – caatinga transition at Araripina, Pernambuco. In each site, five to six circular plots of about 20 m radius each and at least 50 m apart were marked in native mature vegetation patches. In each plot, fully expanded healthy leaves of tree species were sampled, excluding species known to obtain part of their N through BNF. The leaves were dried, ground and analyzed for their ^{15}N content, using a mass spectrometer. The results are expressed in $\delta^{15}N$ units, which are calculated as $\delta = (R_{sample}/R_{standard} - 1) \times 1000$, where R_{sample} and $R_{standard}$ are the ratio ^{15}N:^{14}N of the sample and the standard (air), respectively.

Results and discussion

The ecosystems had different $\delta^{15}N$ signals and N concentrations (Table 1). The tropical rain forest of the coastal area had a low signal (2.4‰), contrasting with those of the caatinga (6.5 to 10.1‰) and mainly that of the caatinga – cerrado transition (12.6‰). The signal of the rain forest is one of the lowest found for tropical forests (Martinelli *et al*. 1999). The low value indicates either a continuous significant input of atmospheric N or low losses of N in gaseous or diffusion forms. No estimation of atmospheric N input in these forests have been made but the number of legume trees of fixing species is relatively low, suggesting that the contribution of BNF is also low. Thus, most likely, in these forests N losses are relatively low and they have a close N cycle, as has been shown to occur with the cycling of other nutrients in tropical forests growing in low fertility soils (Stark and Jordan 1978). A consequence of the low $\delta^{15}N$ signals of the non fixing species is that measuring fixation using the ^{15}N method is not viable. The $\delta^{15}N$ signals of the caatinga – cerrado transition is one of the highest already reported for any vegetation in the world (Handley *et al*. 1999). Indeed, it seems to be the highest reported average for a site. It sharply contrasts with values measured in a cerrado of Central Brazil, with $\delta^{15}N$ varying from -2.9 to 6.5 ‰ (Bustamante *et al*. 2004). The two areas have soils of the same order (Latosols), with low pH and low general fertility. Therefore, vegetation and soil types seem to have no direct and definite influence on the ^{15}N – ^{14}N balance. The northeastern area has a lower and more erratic rainfall regime, which could be responsible for higher N losses. The N concentrations in the leaves (22.9 g/kg) were slightly higher than those in the coastal rain forest but not the highest ones.

The core and the more humid caatinga sites had $\delta^{15}N$ values intermediate between the rain forest and the caatinga – cerrado transition. The averages of the two types, although not far apart, were significantly different, that of the drier caatinga being lower (7.2‰) than that of the more humid one (9.8‰). This seems to contradict the hypothesis that drier sites have higher $\delta^{15}N$ values, reinforced by the fact that the caatinga – cerrado transition has even higher rainfall and the highest $\delta^{15}N$ values. Therefore, generalizations based on a single environmental variable should be made with caution. Bearing this in mind, it seems that all three semiarid ecosystems have higher values than the coastal rainforest and, therefore, more open N cycles. This could be explained by their lower plant biomass, seasonal leaf fall and plant dormancy coupled with heavy rains in the beginning of the rainy period. Under these conditions, flushes on soil N mineralization would not be followed by high N uptake and mineral N would be more prone to be lost. The N concentrations in the leaves were also different, being higher in the hunid caatinga (26.0 g/kg) than in the core caatinga (19.1 g/kg). In both caatinga types, the signals of non fixing plants are high enough and those of fixing plants sufficiently distinct to allow good measurements of fixation (Freitas *et al*., 2010).

In each of the previous ecosystems, all the plants of all species had signals varying within a relatively narrow range (±1.6‰), with no significant difference among species. They were all trees, which probably had root systems deep enough to absorb N from a considerable soil volume and to integrate the signals of distinct soil layers. Other plant forms, like herbs, epiphytes and vines, may have different signals at the same sites. This relative consistency of signals simplifies the choice of reference species and the sampling scheme when studying fixation of the different tree legumes in a site. Tropical vegetation has a large diversity, with many species represented by only a few individuals in a large area. Sampling in plots, as we did in this study, do not include all legume species in a site, unless the number of plots are impractically high. Pairing a legume and a reference plant is a simpler scheme but it is unlikely that the same reference species is found close to each legume and this scheme only works if several reference species can be interchangeably used.

In the semideciduous forest vegetation of the mountain site, the ^{15}N signals of the different species were less consistent than in the other sites. Some species had signals (3.2‰) as low as those of the coastal forest while some others had signals (9.7‰) as high as those of the humid caatinga, the average (6.6‰) being closer to that of the core caatinga. This vegetation occurs as high forest islands surrounded by caatinga and may include some caatinga species together with some that are typical of the coastal forest. There was a tendency for the signals to follow this origin but it was mixed with a tendency of border plots to have higher signals than those deep within the forest fragment and the sampling was not large enough to allow a clear pattern to be seen. The available data indicates that measuring fixation in these sites will be difficult. However, it is recommended to sample other mountain forest before arriving at any conclusion regarding this vegetation type. The N concentrations in the leaves were the highest of all ecosystems (29.5 g/kg). Comparing the $\delta^{15}N$ signals and the N contents of all ecosystems, there seems to be no clear trend.

Table 1. N concentrations and $\delta^{15}N$ signals of leaves from non fixing tree species growing in different ecosystems in Northeast Brazil.

Ecosystem	Number of species	N concentration g/kg	$\delta^{15}N$ (‰) average	minimum	maximum
Coastal rain forest	7	18.9	2.36	1.2	4.0
Humid caatinga	9	26.0	9.78	9.4	11.4
Core caatinga	11	19.1	7.22	5.1	8.3
Semideciduous forest	6	29.5	6.56	3.2	9.7
Caatinga – cerrado transition	7	22.9	12.55	11.4	14.2

Conclusion

The $\delta^{15}N$ signals of all sampled tree species within each ecosystem are relatively consistent, except in the mountain semideciduous forest. The semiarid caatinga and the savanna – caatinga transition signals are higher than that of the coastal forest, indicating the openness of their soil – plant systems. In the semiarid caatinga and the savanna – caatinga transition the signals are high enough to allow good estimations of N fixation.

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