

PALAEOVEGETATION AND PALAEOCLIMATE CHANGES DURING THE LATE QUATERNARY IN THE NORTHEASTERN BRAZIL, BASED ON CARBON ISOTOPES IN SOIL ORGANIC MATTER

Pessenda L.C.R.¹; Ribeiro, A.S.²; Gouveia, S.E.M.¹; Aravena, R.³; Boulet, R.⁴ and Bendassolli, J.A.¹

1. Center for Nuclear Energy in Agriculture (CENA), Box 96, 13400-000, Piracicaba-SP, Brazil. pessenda@cena.usp.br, susyeli@cena.usp.br; jab@cena.usp.br

2. Federal University of Sergipe - Department of Biology – Aracaju-SE, Brazil. asr@ufse.br

3. Department of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L3G1, Canada. roaraven@sciborg.uwaterloo.ca

4. IRD, Geoscience Institute/University of São Paulo, 05508-900, São Paulo-SP, Brazil

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INTRODUCTION

Most of the studies on palaeoenvironmental reconstruction during the late Quaternary and the Holocene have been based on pollen record obtained from lacustrine sediments. The regions investigated include, the Amazon (Absy & Van der Hammen, 1976; Van der Hammen & Absy, 1994), central (Ledru, 1993; Salgado-Laboriau et al., 1998) and southeastern and south regions (Roth & Lorscheitter, 1993; Behling, 1995, 1997a, b). Carbon isotopes technique in soil organic matter have also been applied to reconstruct palaeovegetation changes in south, southeastern (Pessenda et al., 1993, 1996a), central (Gouveia et al., 2002) and northern region of Brazil (Gouveia et al., 1997; Freitas et al., 2001).

Few palaeoclimate studies have been developed in the northeastern region, probably due to the difficult to find stable and perennial lakes. One of these studies carried out in the Icatu river valley located in the semi-arid region of Bahia state, documented vegetation and climate changes during the last 11,000 years BP (De Oliveira et al., 1999), with a humid and cold period during the late Pleistocene and drier climate during the early to mid Holocene. Other studies based on pollen data collected at Lagoa do Caçó, Maranhão state, show higher frequencies of *Podocarpus* at the end of the Pleistocene than today, suggesting a late-glacial increase of moist and cool climatic conditions (Ledru et al., 2001). From the early to mid Holocene (ca 6000 yrs BP) the Caçó lake level rose gradually (Sifeddine et al., in press) and the presence of microscopic charcoal fragments (Ledru et al., 2001), indicated that the humid phase was interrupted by dry phases.

In this paper we present the first comprehensive carbon isotope record of vegetation dynamics in the northeastern region of Brazil, covering the late Pleistocene and Holocene. This study is part of a major research program carried out at the Centre for Nuclear Energy in Agriculture (CENA), whose aim is to evaluate vegetation dynamics during the last 20,000 years in Brazil using carbon isotopes (Pessenda et al., 1996a, 1998a, b, c, 2001a; Gouveia et al., 2002; Freitas et al., 2001).

STUDY AREA

A mean annual temperature of around 26°C and a mean annual precipitation of around 1400-1500 mm characterize the climate of the region. The study area is located at an altitude between 100 and 120 m.

Soil samples were collected from eight points on a 78-km transect including Forest (F) and Cerrado (C) vegetations (woody savanna), along the road between the cities of Barreirinhas (referenced as km zero) and Urbano Santos (Fig.1). The sites are denominated F15 (the numbers represent km), F16 (transition), C16 (transition), C17, C20, C25, F46, C54 and F78.

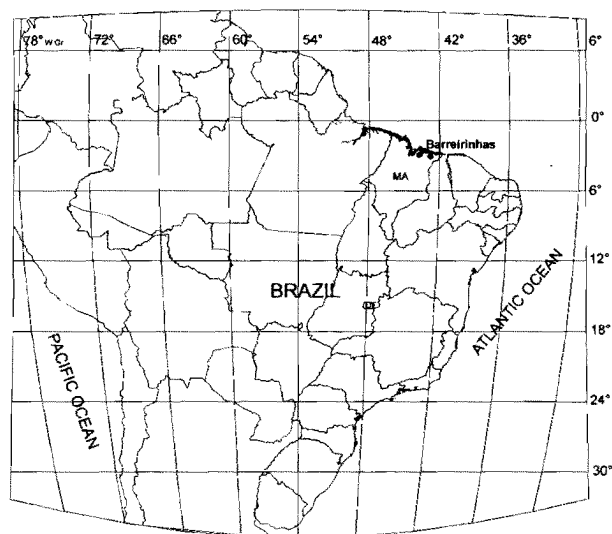


Figure 1. Map of Brazil showing the study site.

The study transect is located between the coordinates 2°52'S/45°55'W, corresponding to km 15 covered by "Restinga", the steppe vegetation along Brazil's coast which is dominated by *Manikara* sp, *Capaifera martii*, *Platonia insignis* and *Dimorphandra gardneriana* in the arboreal extract and 3°11'S/43°22'W in the km 78, covered by a Cerradão - semi deciduous forest (Pessenda et al., 1998). The sandy "Cerrado" savanna vegetation is located between the km 16 in an ecotone with Restinga vegetation and km 54, and is characterized by short trees (< 10 m) as *Curatella americana*, *Byrsonima*

verbascifolia, *Annona coriacea* Mart. and grasses as *Andropogon bicornis* L., *Aristida longifolia* Trin., *Panicum* sp and *Paspalum* sp. Soil samples and buried charcoal fragments were also collected in a semi deciduous forest located 200 m (F200) from Caçó lake (2°58'S/43°25'W), and approximately 10 km northwestern from the ecosystem transect of 78 km.

METHODS

The soil of the study sites was classified as sandy soil (Typic Quartzipsament) over eolian sand. Soil samples were collected from trenches or with a hand-auger.

From trenches, up to 5 kg of material were collected in 10 cm increments to a maximum depth of 300 cm. For $\delta^{13}\text{C}$ analysis, about 0.5 kg of soil and about 0.2 kg in case of samples collected by a hand auger was sieved (5 mm), dried at 50°C to a constant weight and root fragments were discarded by hand picking. The dry samples were sieved again (210 μm) and any remaining debris was removed by flotation in hydrochloric acid 0.01 M and wet sieved (210 μm). For ^{14}C analysis, the buried charcoal fragments in the soil received the conventional acid-alkaline-acid treatment (Pessenda et al., 1996a) and dried to a constant weight.

The grain size analyzes were carried out at the Soil Science Department of the Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba, Brazil, on sieved through a 2 mm samples of dry soils. The results are expressed in percentage (%).

The carbon analyzes on soils ($\delta^{13}\text{C}$, total C) were carried out at the Stable Isotope Laboratory of CENA. Results are expressed as $\delta^{13}\text{C}$ with respect to PDB standard using the conventional δ (‰) notations:

$$\delta^{13}\text{C} (\text{‰}) = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000$$

where, R_{sample} and R_{standard} are the $^{12}\text{C}/^{13}\text{C}$ ratio of the sample and standard, respectively. Analytical precision is $\pm 0.2\text{‰}$.

The ^{14}C analyzes on charcoal fragments collected at site F 200 were carried out by AMS at Isotrace Laboratory, University of Toronto, Canada. Radiocarbon ages are expressed in years B.P, normalized to a $\delta^{13}\text{C}$ of -25‰ PDB.

RESULTS

SOIL PROPERTIES AND TOTAL ORGANIC CARBON CONTENT

The grain-size analyzes showed that the clay content was low (around 6 to 14%) in the six locations, with exception to km 46 (forest) that presented up to 28% of clay. The carbon content data show a general decrease with depth, similar to that observed in other studies in distinct regions of Brazil (Pessenda et al., 1998a, b, c). Values range from 1.42% in the shallow part of the soil to 0.04% in the deepest sample levels (Pessenda et al., 2001b).

CHARCOAL CHRONOLOGY AND SOM $\delta^{13}\text{C}$

These data are presented in Fig. 2. The radiocarbon dates range from about 1890 yrs BP (30-40 cm) to about 9000 yrs BP at 230-240 cm soil depth. Significant carbon isotopic variations were observed in some points of the study transects. The $\delta^{13}\text{C}$ values of soil surface characterized very well the distinct vegetation cover. $\delta^{13}\text{C}$ values of -27‰ to -25‰ represent the predominance of C_3 forest vegetation (F15, F16, C16). The $\delta^{13}\text{C}$ values of -21.4 to -17.7‰ showed the contribution of C_4 plants (C20, C25, C54), and soil under cerrado vegetation (C78) characterized by a $\delta^{13}\text{C}$ value of -25.3‰ . Litter samples from each location presented more depleted $\delta^{13}\text{C}$ values up to 0.9‰ (C54) and 3.5‰ (C78) compared to the shallow soils.

The cerrado sites (C17, C20, C25 and C54) show a wide range in isotopic composition that varies between -26.1‰ and -16.9‰ . The forest sites (F15, F46 and F78) also show a wide range, with more depleted values, from -29.6 to -21.9‰ . The soil at transition sites (F16 and C16) show more enriched values (-22.1 to -20.2‰) at the lower section (100-90 to 80-70 cm) than in shallow depth.

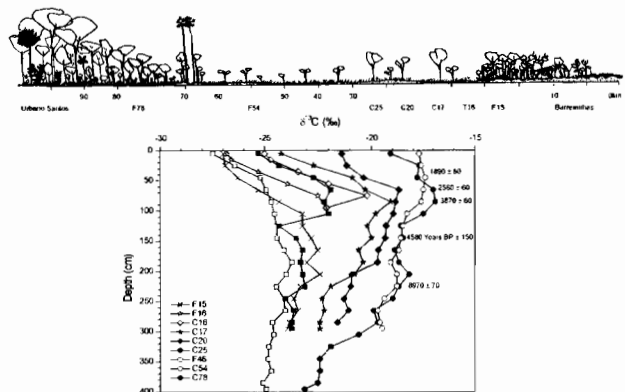


Figure 2. $\delta^{13}\text{C}$ variation of SOM of ecosystem transect and ^{14}C age of charcoal fragments.

DISCUSSION

CHARCOAL CHRONOLOGY AND $\delta^{13}\text{C}$ VARIATIONS

Based on extrapolation of the radiocarbon dates obtained with the charcoal fragments, it is possible to postulate that the carbon isotope record represents the last 15,000 yrs BP.

It was observed that since 330-320 cm (approximately between 12,000-11,000 yrs BP) up to approximately 70-60 cm (around 3000 yrs BP), there was a tendency of isotopic enrichment in several points of the soil transect. This is clearly observed in the locations of more dense cerrados in the km 17, 20 and 25 (-26.1‰ up to -16.9‰) and in the open cerrado in the km 54. The enrichment trend (-28.9‰ up to -21.9‰) in case of in km 78 is observed from approximately 4600 yrs BP until approximately 3000 yrs BP. The exceptions occurred in the forest in the km 15 and the forest LCF46, located around 10 km southeast of cerrado site km 54.

The results also indicated that mainly from 250-240 cm (approximately 9000 yrs BP) up to 70-60 cm (around 3000 yrs BP) the $\delta^{13}\text{C}$ values were clearly more enriched (up to -17‰), indicative of the presence of C_4 plants in several points of transect, aspect that can be associated with a drier climate in the region.

It is interesting to emphasize that the value of -19.5‰ at 300 cm for C54, probably characterize the presence of an open vegetation from late Pleistocene/early Holocene. The isotopic enrichment up to -17.4‰ at 50 cm soil depth (around 2500 yrs BP) followed the general tendency and reinforces the presence of a paleocerrado in that location.

In terms of vegetation dynamics it was verified that approximately since the late Pleistocene up to the early Holocene, arboreal vegetation probably related to forest, covered most of the ecosystem transect of 78 km constituted of forest-cerrado-restinga ecotone on the Barreirinhas region. Afterwards, since approximately 8000 yrs BP until around 3000 yrs BP the cerrado expanded, probably related to the presence of a drier climate. From 3000 yrs BP to the present, more depleted $\delta^{13}\text{C}$ of SOM in several points of soil transect were interpreted as a forest expansion over the cerrado, due to the return to a humid climate and probably similar to the present.

The paleoclimatic interpretations for this study is in agreement with the article of De Oliveira et al. (1999), where a probable dry period dominated the north region of Bahia from the early Holocene (around 9000 yrs BP) up to mid-Holocene (4000-3000 yrs BP), following a more humid period and probable similar to the present.

In Carajás (PA), central Amazon region, around 1400 km west from Barreirinhas region, Sifeddine et al. (1994) verified through pollen analysis em lacustrine sediment, a dry period between approximately 7000 yrs BP and 4000 yrs BP, reinforcing the interpretations.

Other studies based on used carbon isotopes of SOM in an ecosystem transect of a ecotone forest-savanna in the Humaitá region, southern part of Amazonas State, approximately 3000 km west from Barreirinhas) verified that in the period of 17,000 yrs BP to 9000 yrs BP the transect was covered by forest vegetation (Gouveia et al., 1997; Pessenda et al., 1998a, c, 2001a; Freitas et al., 2001). From about 9000-8000 yrs BP up to approximately 3000 yrs BP, several locations in the study transect were substituted by savanna vegetation (C_4 grasses), probably due to the presence of dry climate. Since approximately 3000 yrs BP up to the present, the isotopic data indicated the predominance of C_3 plants, related with the presence of a humid climate. Similar palaeovegetation and palaeoclimatic reconstruction were documented by Pessenda et al. (1998d) in the southeastern part of Rondônia State, south Amazon region.

It is important to high light different palaeovegetation and palaeoclimatic signals were observed in the southeast and south regions of Brazil, in the late Pleistocene/early Holocene.

Isotopic data of Salitre, western region of Minas Gerais State (Pessenda et al., 1996a, 1998d), Piracicaba, São Paulo State and Londrina, Paraná State (south) (Pessenda et al., 1996b, 1998d) and Jaguariúna, São Paulo State (Gouveia et al., 1999, 2002) indicated the significant presence of C_4 grasses since approximately 11,000 yrs BP till about 4000 yrs BP, that was associated to the presence of a dry climate. Palinological data from lake sediments also indicated a dry climate in similar period in sites located in the south of Brazil (Ledru et al., 1996; Behling, 1997a, 1998).

A hypothesis for the occurrence of these climate changes could be related with the position of Intertropical Convergence Zone (ITCZ) between 12,400 and 8800 calendar yrs, which correspond to approximately 10,500 yrs BP and 7300 yrs BP. According with Martin et al. (1993), the present precipitation over the South America continent is amply controlled by seasonal movements of ITCZ. During the summer, the ITCZ moves to the south due to the heating of continent. In the period 12,400 yrs and 8800 yrs, the east part of the Amazon received substantial humidity, while in the Bolivian Altiplano (located more in the south and to the east) was arid. The authors suggested this pattern was related to the ITCZ position more in the north during the summer, in relation to the present days. In similar form in the mentioned period, the northeastern and Amazon regions presented higher precipitations than the south region, occurring situations of more humid climate in the north and drier in the south, between approximately 10,500 yrs BP and 7300 yrs BP.

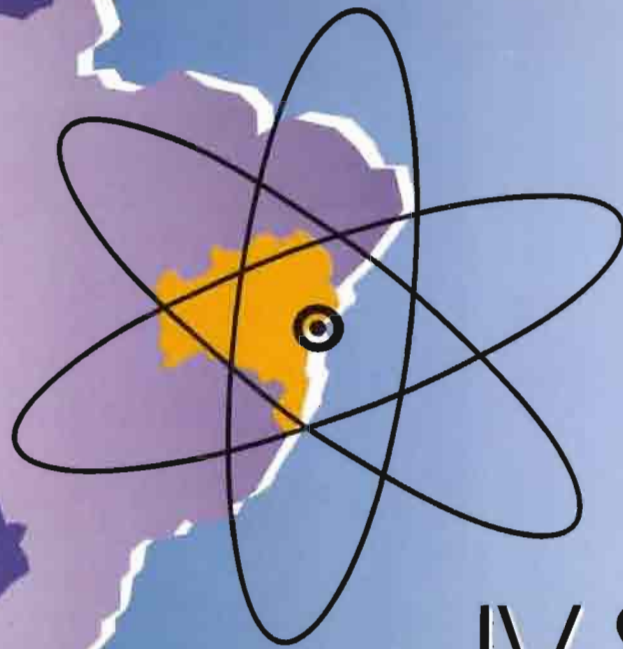
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