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STUDIES OF PALAEOVEGETATION CHANGES IN THE CENTRAL AMAZON BY CARBON ISOTOPES (^{12}C, ^{13}C, ^{14}C) OF SOIL ORGANIC MATTER

L.C.R. PESSENDA, S.E.M. GOUVEIA
Centre for Nuclear Energy in Agriculture,
University of São Paulo,
São Paulo, Brazil

B.M. GOMES
University of Rondônia, Campus de Ji-Paraná,
Rondônia, Brazil

R. ARAVENA
University of Waterloo,
Waterloo, Ontario, Canada

R. BOULET
ORSTOM, Institute of Geosciences, University of São Paulo,
São Paulo, Brazil

A.S. RIBEIRO
University of Sergipe, Aracajú,
Sergipe, Brazil

Abstract

STUDIES OF PALAEOVEGETATION CHANGES IN THE CENTRAL AMAZON BY CARBON ISOTOPES (^{12}C, ^{13}C, ^{14}C) OF SOIL ORGANIC MATTER.

The paper presents carbon isotope data $\delta^{13}C$ and ^{14}C) on soil organic matter collected along an ecosystem transect in southern Amazon state, north-central Amazon region, that includes three distinct vegetation communities: savannah (Campos de Humaitá), a savannah–forest transition and forest (Manaus). The study sites are located along road BR 319. Botanical identification and ^{13}C analysis of modern vegetation in the savannah and forest sites indicate that most of the vegetation is C_3 plants, although a few C_4 plants are present at Campos de Humaitá. The ^{13}C and ^{14}C data for soil organic matter in the Humaitá region show that significant vegetation changes have occurred in the past, probably associated with climatic changes. During the early Holocene, forest vegetation extended throughout the study region, including areas occupied today by savannah vegetation. Savannah vegetation expanded at least 2 km into the modern forest ecotone during the middle Holocene, suggesting drier conditions. The last approximately 1000 years appear to indicate a recent expansion of forest vegetation,

reflecting a return to a more moist climate. The study illustrates that the transition area between forest and savannah vegetation is quite sensitive to climatic changes, and this region should be the focus of more extensive research related to past climate and vegetation dynamics in the Amazon region.

1. INTRODUCTION

Interaction between climate change and vegetation response is a key question being addressed in palaeoclimate studies in the Amazon basin. Several approaches, including geomorphological, biological and isotopic techniques are being used in these studies [1–4]. Regression of the tropical forest associated with drier periods (60 000, 40 000, 23 000 – 11 000 and 7 000 – 4 000 a BP) has been documented using pollen analysis in lake sediments in Serra dos Carajás, Pará, northern Amazon region [5, 6]. These studies also showed an increase of arboreal vegetation between 9500 and 8000 a BP, indicating an expansion of the tropical forest associated with a more humid phase.

Carbon isotopes (^{13}C, ^{14}C) have been shown to be excellent tracers of vegetation changes during the Holocene in various areas of Brazil [4, 7–11]. The application of carbon isotopes is based on the different isotopic compositions of C_3 and C_4 plants, the preservation of that difference in soil organic matter and the response of these vegetation types to climate changes [12].

This paper presents data collected along a transect covering three different types of vegetation communities, representative of the diverse ecosystem in the Amazon region: savannah, savannah–forest transition and tropical forest. Carbon isotopes were used to evaluate vegetation changes during the Holocene at the forest–savanna boundary. Soils in these areas should preserve a good record of past vegetation changes, contributing significantly to the study of climatic changes and its impact on vegetation communities.

2. MATERIAL AND METHODS

2.1. Study site

The study area is located in southern Amazon state, in north-central Brazil. The sampling sites are located along Road BR 319, near the city of Humaitá (7°31′ S, 63°2′ W). These sites form a transect ecotone including three distinct vegetation communities: a savannah (Campos de Humaitá), a savannah–forest transition (Campos de Humaitá, terra firme forest) and forest.

2.2. Sampling and analytical aspects

The soil samples were collected from excavations from Campos de Humaitá type vegetation (km 5 and km 17 of BR 319) to tropical forest, km 50. The soil types are Plintossolo, according to the Brazilian soil classification, and Tropaquept in the Soil Taxonomy of the United States Department of Agriculture (USDA) at km 5; Litossolo (Troporthent, USDA) at km 17; Cambissolo Álico (Dystropept, USDA) in the savannah–forest transition, km 18; Cambissolo Álico at the forest site (km 20) and Ferralítico Amarelo-Vermelho (Hapludox, USDA) at the forest site (km 50).

Soils were sampled at 10 cm intervals to a maximum depth of 2 m. Samples were dried at 60°C to constant weight, and root and plant remains were discarded by hand picking. Any remaining plant debris was removed by flotation in 0.01M HCl, dried and sieved. The soil fraction less than 0.210 mm (total soil) was used for ^{13}C and ^{14}C analyses. The humin fraction was extracted from 1.5–2.0 kg of total soil fraction. A detailed description of the chemical treatment for the humin samples is given in Refs [4, 10].

The ^{14}C analyses on total soil were carried out at the Radiocarbon Laboratory, Centro de Energia Nuclear na Agricultura (CENA), following the standard procedure for liquid scintillation counting [13]. The ^{14}C analyses on humin samples with low carbon content (<0.1 g) were carried out at the Isotrace Laboratory, University of Toronto, using accelerator mass spectrometry. The ^{13}C analyses on soil and plant samples and soil carbon contents were carried out at the Environmental Isotopes Laboratory, University of Waterloo, Ontario, Canada. Radiocarbon data are reported as per cent modern carbon (pmC) and radiocarbon ages as years BP. Carbon-13 data are expressed in δ per mille (‰) units. Uncertainty in $\delta^{13}C$ results is 0.3‰, as determined by repeated analysis of natural samples.

3. RESULTS AND DISCUSSION

3.1. Soil properties

Grain size analysis indicated that the study soils are mainly composed of clay, silt and sand fractions [14]. Clays comprise 26–45% of the shallow soil horizons and increase to 55% in the deeper part of the soils representative of savannah (km 5, BR 319), forest (transition, km 18) and forest (km 20 and km 50). The savannah site (km 17) shows higher clay content, ranging from 60% to 64% in the shallow zone and 56% to 47% in the deeper strata.

The carbon content data show the typical soil profiles of decreasing carbon content with depth. They range from 1.64% to 0.48% in the shallow soil horizons to as low as 0.09% in the deeper soil horizons [14].

TABLE I. RADIOCARBON DATING OF TOTAL SOIL ORGANIC MATTER AND HUMIN SAMPLES IN RELATION TO SOIL DEPTH, IN THE TRANSECT ECOTONE SAVANNAH–FOREST TRANSITION–FOREST IN HUMAITÁ, CENTRAL AMAZON REGION

Depth (cm)	Total soil		Humin	
	Modern carbon (%)	Radiocarbon dating (a BP)	Modern carbon (%)	Radiocarbon dating (a BP)
	km 5, Savannah (Campos de Humaitá)			
0–10	107.54 ± 0.78	Modern	—	—
20–30	91.90 ± 0.69	680 ± 60.0	—	—
90–100	44.87 ± 0.58	6440 ± 110.0	—	—
	km 17, Campos de Humaitá			
0–10	115.81 ± 0.85	Modern	—	—
20–30	92.34 ± 0.71	640 ± 60.0	—	—
90–100	—	—	49.97 ± 1.47	5570 ± 240
180–190	—	—	27.23 ± 1.60	10450 ± 940
	km 18, Transition			
0–10	113.93 ± 0.08	Modern	—	—
20–30	96.26 ± 0.73	310 ± 60.0	—	—
90–100	64.10 ± 1.05	3570 ± 130.0	47.60 ± 1.54	5960 ± 260
	km 20, Forest			
0–10	109.57 ± 0.80	Modern	—	—
20–30	102.05 ± 0.95	Modern	—	—
90–100	74.58 ± 0.60	2360 ± 60.0	53.39 ± 3.54	5040 ± 530
180–190	46.62 ± 0.52	6130 ± 90.0	36.18 ± 1.93	8170 ± 430
	km 50, Forest			
10–20	111.12 ± 0.86	Modern	—	—
20–30	95.63 ± 0.70	360 ± 60.0	—	—
90–100	55.27 ± 0.50	4760 ± 70.0	—	—

3.2. Carbon isotope data

3.2.1. Radiocarbon data

The data presented in Table I correspond to about 65% of the samples selected for radiocarbon analysis. The other samples, which correspond to total soil fraction (two samples) and humin fractions (five samples) of the deeper part of the profiles, are still being analysed. The ^{14}C data, with values between 115.8 pmC and 102.05 pmC, clearly show the influence of bomb ^{14}C in the first upper 20–30 cm of the soil profiles. Penetration of the carbon is more pron(inced at the forest sites, probably because of the lower soil density in the upper 30 cm (1.12–1.21 g/cm^3) than in the savannah (1.54–1.56 g/cm^3) and the savannah–forest transition (1.45–1.60 g/cm^3).

The ^{14}C profiles obtained in the total soil and humin fractions predictably show increasing age with depth (Table I, Fig. 1). The total soil in the 20–30 cm horizon of the Campos de Humaitá sites, km 5 and km 17, show radiocarbon ages of 680 a and 640 a, respectively. The transition forest and forest sites (km 18, km 20 and km 50) show radiocarbon ages of 310 a BP, modern and 360 a BP, respectively. For the 90–100 cm interval, the savannah site shows an older radiocarbon age of 6440 a BP, as against 3570 a BP, 2360 a BP and 4760 a BP, observed in the transition and forest

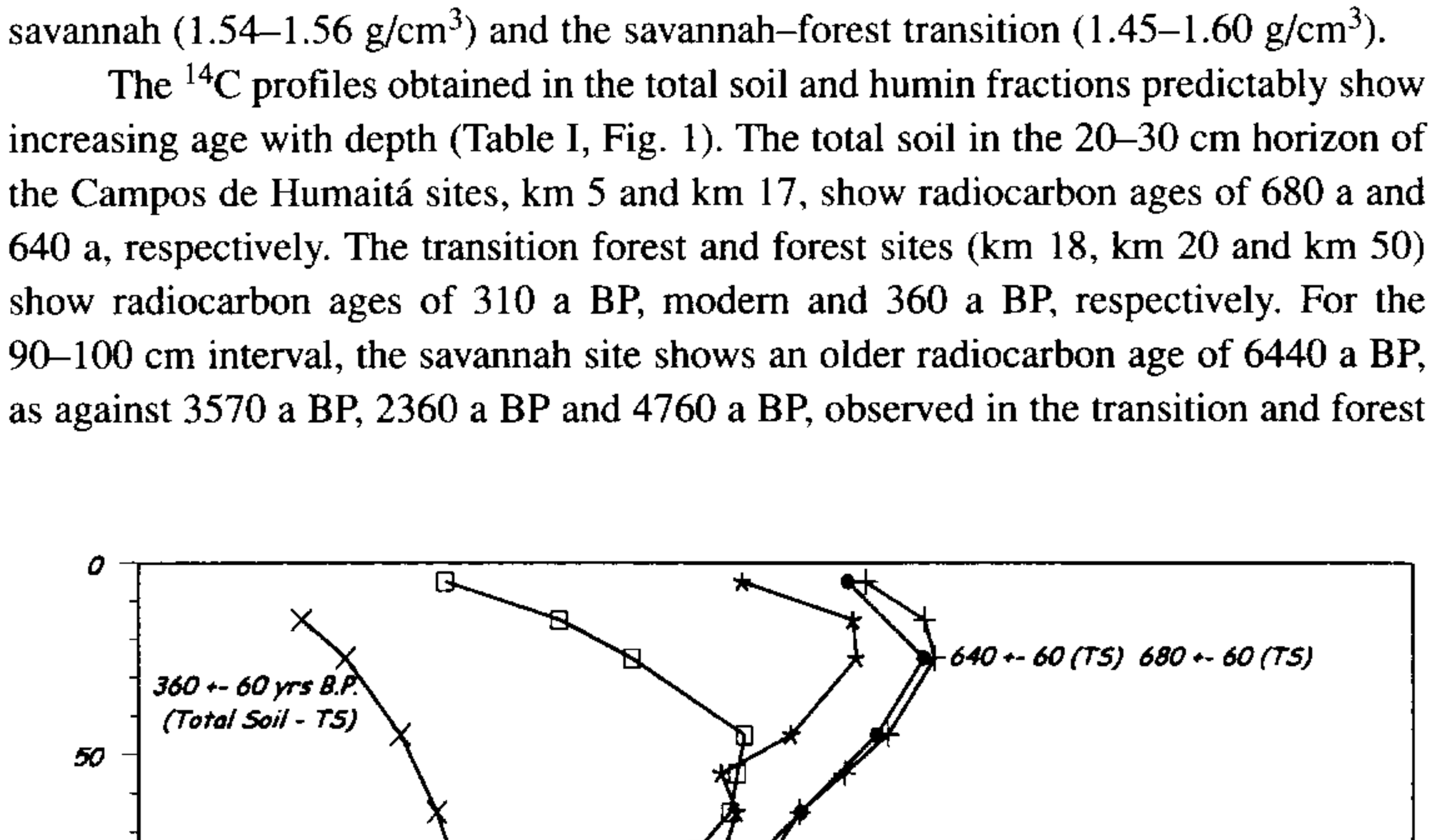

FIG. 1. Radiocarbon dating and carbon isotopic ($\delta^{13}C$) composition of SOM in relation to soil depth, in the study area.

sites. These data indicate a greater influence of the recent carbon pool in the total soil fraction in the transition and forest sites than in the savannah site. Older soil age–depth profiles were also obtained in the Cerrado (a wooded savannah) vegetation site than in forest sites in an ecosystem transect Cerrado–Forest in Rondônia state, southwestern Amazon region [15]. The radiocarbon ages of the humin fraction are roughly 2000–2500 years older than the total soil fraction for the two samples for which both fractions were measured. Soil age–depth profiles obtained on humin samples in other study sites in Brazil (including a site in the Amazon basin) yield an age of about 10 000 a BP for the 2 m soil horizon [4, 10, 11].

3.2.2. ^{13}C results

Botanical identification and ^{13}C analyses of modern vegetation at the savannah and forest sites indicate that the majority (>95%) of the vegetation is C_3 plants in the study area.

The $\delta^{13}C$ values for soil organic matter (SOM) at the two forest sites range from –26.7‰ to –23.1‰ and –30.6‰ to –24.8‰, respectively (Fig. 1). This profile should represent the effect of decomposition of soil organic matter in the shallow part of the soil, which enriches the remaining carbon in ^{13}C [16, 17], and a slight change in the isotopic composition of the plant communities in the deeper part of the soil profiles. This isotopic pattern is typical for SOM generated by type C_3 vegetation [4, 18]. Data for the deeper part of the five soil profiles (200–150 cm) show $\delta^{13}C$ values (about –23‰ to –24‰) typical of C_3 plants, suggesting that forest vegetation covered the study area from the early Holocene (~10 000 a BP) until 7000 a BP. Between 150 and 50 cm, significant enrichment occurs in all profiles except at km 50. This trend is interpreted as reflecting an increasing presence of C_4 plants in areas that are today covered by forest and forest–savanna vegetation, probably in response to a drier climate. Radiocarbon data suggest that this interval represents the middle Holocene (7000–3000 a BP). The ^{13}C data in the shallow part of the soil profiles are characteristic of the modern vegetation cover. The vegetation dynamics inferred from C_3 data, namely early Holocene forest expansion followed by middle Holocene regression and recent expansion, is similar to that in other forest–savanna boundary areas in the Amazon region [15, 19].

4. CONCLUSIONS

The ^{13}C and ^{14}C data collected in soils in the Humaitá region show that significant vegetation changes occurred in the past, probably associated with climate change. During the early Holocene, forest vegetation covered the study region, including areas occupied today by savannah vegetation. Forest regression to at least

km 20 northeast of the modern forest–savanna border occurred during the middle Holocene, suggesting drier conditions in this region. The remainder of the record may indicate a more recent expansion of the forest. This study shows that the transition areas between forest and savannah vegetation are sensitive to climatic changes, and such areas should be the focus of more extensive research dealing with climate and past vegetation dynamics in the Amazon region.

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