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$^{13}C/^{12}C$ RATIOS OF SOIL ORGANIC MATTER AS INDICATORS OF VEGETATION CHANGES IN THE CONGO

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ABSTRACT

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The $^{13}C/^{12}C$ ratios were determined for the organic matter of all horizons of a podzol profile and of the A_1 horizons of some ferrallitic soils, in some grass shoots and in a fossil root fragment from the B_{2h} horizon of the podzol. The isotope ratio in the organic matter of the A_1 horizon of the podzol matches those in grass shoots from the present savanna vegetation. The ratios in the lower horizons match those of organic matter in the A_1 horizons of soils under forest and that of the fossil root fragment in the B_{2h} horizon. The ratios thus demonstrate that the humus enrichment of the B_{2h} horizon of the podzol occurred while it was under forest vegetation and that the present grass vegetation did not take part in the podzolization process. The differences also indicate that savanna replaced forest vegetation after the profile had been formed.

INTRODUCTION

The carbon isotope composition of plants is known to differ with the type of photosynthetic cycle employed. All trees and Gramineae of temperate and cold regions using C_3 photosynthesis (Calvin-cycle) have less incorporation of ^{13}C than do plants with a C_4 (Hatch-Slack) photosynthetic cycle. These latter plants are essentially Gramineae of the tropical regions (Bender, 1968, 1971). The C_3-type plants have a $\delta^{13}C$ (see below) ranging between −25 to −28‰ (Deines, 1980).

Soil organic matter has a carbon isotopic composition comparable to that of the source plant material prior to humification (Galimov, 1980), and every change in vegetation between C_3- and C_4-types could thus lead to a

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corresponding change in the ^{13}C value of the soil organic matter. Using this assumption, Cerri et al. (1985) and Balesdent et al. (1986) have studied the organic matter turnover in soils cultivated intensively with C_4-type plants, following forest clearance or long-term C_3-type crops.

In inter-tropical areas where C_3- and C_4-type plants may co-exist as forest and savanna, the carbon isotope composition of the soil organic matter in any one area should thus allow the identification of the type of the source vegetation. The present study is an application of this premise to a tropical giant podzol developed on the Bateke sands at Gangalingolo, near Brazzaville (Fig. 1).

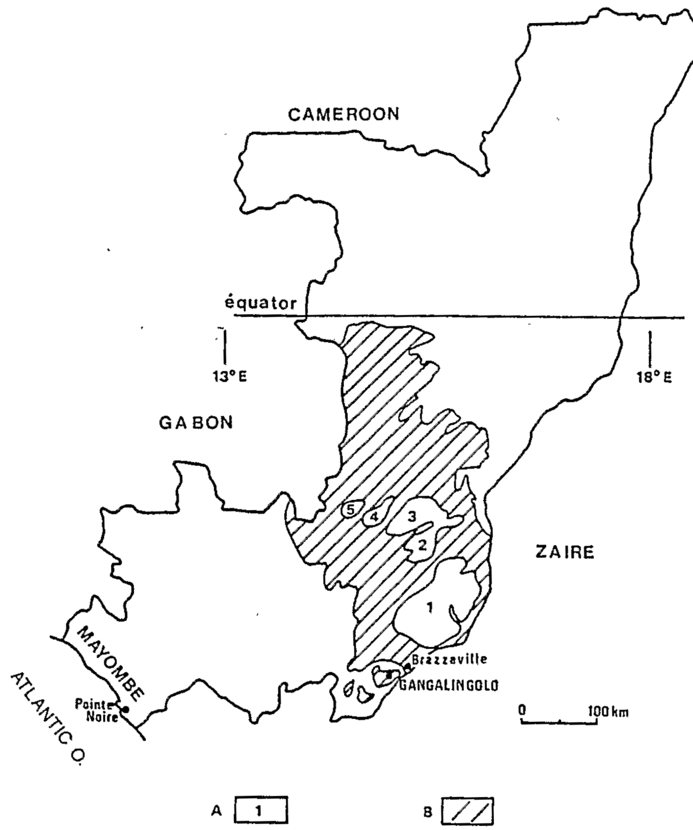

Fig. 1. Distribution of the Batéké sands. *A* = table land areas of (*1*) Mbé, (*2*) Ngo, (*3*) Nsa, (*4*) Djambala and (*5*) Koukouya. *B* = Hill areas.

VEGETATION AND SOILS

The Bateke sands are a Tertiary continental formation comprising hills and table lands in the center of the Congo. Podzols are formed in alluvial valley bottoms and terraces, forming the lower parts of the landscape with a characteristic gramineous vegetation dominated by *Loudetia simplex* and *Monocymbium ceresiiforme.* The contiguous ferrallitic soils of the surrounding hills and table lands are covered with various forms of savanna with *Loudetia demeusii,* whereas forests are limited to riverside fringes.

The well-differentiated giant podzols are old soils with a complex history and are characterized by impressive translocated humus deposition (Table I and Fig. 2), in which the B_{22h} and B_{23h} horizons constitute a humic hard-pan. Using ^{14}C-dating, Schwartz et al. (1985) demonstrated that this feature developed in the Njilian period (40 000—30 000 BP), a short humid climatic period which was followed by the Leopoldvillian period (30 000—12 000 BP) which was too arid to permit podzolization. The thin and non-cemented B_{21h} horizon developed later at the beginning of the Kibangian period (12 000 BP to present) and in contrast to the underlying humic-pan, has a lower organic matter content which ranges from 0.1 to 1%. These values are much lower than those obtained in the B_{22h} and B_{23h} horizons of podzols on Bateke sands. As a general rule, their organic matter contents range from 3 to 30%.

In certain instances, root remains found in the humic-pan were identified as belonging to several species of *Monopetalanthus,* which are trees found in rain forest (Schwartz, 1985).

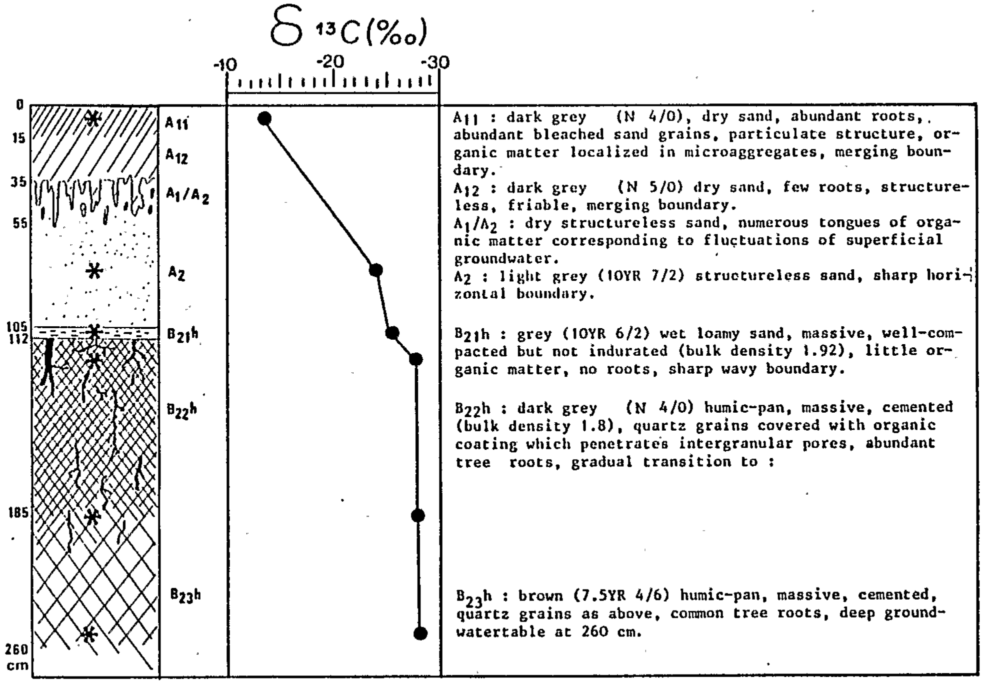

Fig. 2. Schematic representation and description of the giant podzol sampled at Gangalingolo. (Asterisks identify samples collected for C isotope measurements).

TABLE I

Main physical and chemical characteristics of soil horizons

Horizons	pH KCl	Clay < 2 μm (%)	Org. C (‰)	C/N	Fe_d (‰)	Al_d (‰)
A_{11}	3.4	1.1	13.14	31.3	0.2	0.2
A_2	4.9	0.8	0.38		0.2	0.1
$B_{21}h$	3.9	3.1	5.15	18.9	0.5	0.4
$B_{22}h$	3.1	3.2	102.96	65.3	0.2	2.2
$B_{23}h$	4.0	6.4	54.60	52.0	0.2	3.7

Subscript d = extracted with citrate—bicarbonate—dithionite, after the Mehra and Jackson procedure (1960).

ISOTOPIC RATIOS

Carbon isotope ratios of plant and soil organic matter samples were determined by analysing the carbon dioxide resulting from the combustion of a sample in an atmosphere of pure oxygen at 900°C. After purification the gas was analysed on a mass-spectrometer equipped with triple ion collection and a dual inlet system allowing rapid switching between sample and reference. Results were expressed as $\delta^{13}C$ versus a PDB standard, where

$$\delta^{13}C = \left(\frac{R\ \text{sample}}{R\ \text{standard}} - 1\right) \times 1000, \text{ and } R = {}^{13}C/{}^{12}C$$

Results from a perfectly homogeneous organic sample had a precision of about 0.05‰ but the precision with the natural materials (ca. 0.2‰) was determined mainly by the heterogeneity of samples.

RESULTS

The $\delta^{13}C$ values, shown in Table II, ranged from −13.8‰ to −16.5‰ for the shoots of grasses collected at Gangalingolo, indicating a C_4-type of photosynthetic cycle. The shoots were primarily Gramineae but included some Cyperaceae. The range in $\delta^{13}C$ values seems large, but comparable ranges have been noted previously by Smith and Epstein (1971) between species of a single family.

The organic matter in the A_1 horizon of the podzol under these Gramineae and Cyperaceae had a $\delta^{13}C$ (−13.3‰) that is characteristic of soils with a C_4-type vegetation, but the value is slightly greater than those from each plant analysed separately, perhaps explained by differences occurring between the isotopic composition of shoots and roots of the same plant. Deines (1980) shows that such differences are typically of the order of 2‰, but an alternative explanation may be the biological and biochemical transformations occurring during humification (Flexor and Volkoff, 1977). The

TABLE II

$\delta^{13}C$ values from soil samples and plants

Sample No.	Location	Sample	$\delta^{13}C$ (‰)
MC	Gangalingolo	Aerian organs of: *Monocymbium ceresiiforme*, Gramineae,	−13,8
LS	Gangalingolo	Aerian organs of: *Loudetia simplex*, Gramineae	−15,2
BL	Gangalingolo	Aerian organs of: *Bulbostylis laniceps*, Cyperaceae	−16,5
CASC R	Gangalingolo	Roots of: *Monopetalanthus* sp.	−28,8
SCH 1	Gangalingolo	A_1 of fringing-forest soil	−26,6
SCH 5	Mayombé area	A_1 of rain-forest soil	−27,8
SCH 2	Brazzaville area	A_1 savanna soil with *Loudetia demeusii* and *Andropogon* sp.	−14,5
SCH 3	Brazzaville area	A_1 of shrub savanna soil	−15,5
SCH 4	Brazzaville area	A_1 of savanna soil with *Loudetia demeusii* and *Ctenium Newtonii*, and stratum of *Landolphia lanceolata*	−14,3
GASC 1-1	Gangalingolo	A_1 of savanna soil with *Loudetia simplex*, *Monocymbium ceresiiforme* and *Bulbostylis laniceps*	−13,3
GASC1-2	Gangalingolo	A_2 of podzol	−24,3
GASC1-3	Gangalingolo	B_{21h} horizon	−25,2
GASC1-a	Gangalingolo	Humic-pan, upper part (120 cm)	−27,5
GASC1-b	Gangalingolo	Humic-pan, median part (190 cm)	−27,5
GASC1-c	Gangalingolo	Humic-pan, lower part (250 cm)	−27,4

organic matter of A_1 horizons from other gramineous ecosystems in the Bateke area, including the shrub savanna, also have $\delta^{13}C$ values which indicate a C_4 plant origin (from −14.3 to −15.5‰).

In contrast, the humus from the A_1 horizons of soils under the fringing forest and under rain forest have $\delta^{13}C$ values of −26.6 and −27.8‰, respectively, which are characteristic of C_3-type vegetation. The A_1 horizon under rain forest was sampled near Mayoumbe in southern Congo because no such forest is present on the Bateke sands.

The large difference in isotope ratios of humus between soils under savanna and soils under forest should allow unambiguous identification of the sources of the organic matter in the soils derived from the Bateke sands. The ratios in the podzol clearly show that plant sources of humus were different for the A_1 and for the lower horizons. The organic matter in the A_1 horizons was derived chiefly from grasses, C_4-type plants. Given the age of the humus in the B_h horizon (40 000 to 30 000 BP) and its low $\delta^{13}C$ value, we inferred that the humic pan was a fossil from a previous period of forest vegetation. Moreover, very little modern organic matter has been translocated into the pan. The $\delta^{13}C$ value (−28.8‰) of the root remains of *Monopetalanthus*, at least 30 000 years old according to ^{14}C dating (Schwartz et al., 1985), provides additional strong evidence for a forest origin of the humus accumulated in the B_{2h} horizon.

Following the arid Leopoldvillian period characterized by savanna vegetation (Giresse et al., 1981), the B_{21h} humus was deposited at the beginning of the Kibangian which corresponds to the Holocene in Europe. The organic matter of the B_{21h} horizon, dated as 10 400 BP (Schwartz, 1985), has a $\delta^{13}C$ (−25.2‰) again characteristic of forest conditions, indicating a recovery of this vegetation similar to that detected along the Congo coast (Caratini and Giresse, 1979; Giresse and Lanfranchi, 1984). The timing and reasons for the replacement of the forest by the present savannas during the Kibangian period are unknown.

The A_2 horizon, sampled at a depth of 80 cm, has a low organic matter content (0.2‰) with a $\delta^{13}C$ of −24.3‰, again suggesting a forest heritage for the organic matter, with no major influence from the grass rhizosphere.

DISCUSSION AND CONCLUSION

In temperate regions, the occurrence of ligneous plants (trees and heath) is a prerequisite for podzolization, whereas Richards (1941), and Klinge (1968) have shown that podzols occur under various kinds of vegetation in the tropics. Furthermore, Davies (1970) and Turenne (1977) have postulated that the podzolisation process may occur under grass. The results for the podzol profile clearly show that in the case of soils with a long and complex history, analysis of the system with respect to the present vegetation will not provide an understanding of pedogenesis. In the Bateke sands, podzolisation processes have clearly occurred under forest conditions; tropical podzols of other regions may also have developed under a forest stage. The occurrence of podzols under various types of natural vegetation, e.g. forest, savanna and peat-bog, could simply indicate differences in the evolution of these ecosystems since the formation of the podzols.

In the podzols of the Bateke sands, the $\delta^{13}C$ values are well-differentiated between those from the humic-pan developed under forest and that of the A_1 horizon formed under the present savanna vegetation. Intermediate $\delta^{13}C$ values found in other soils have been interpreted as resulting from isotopic fractionation during humification (Flexor and Volkoff, 1977), but such values may also result from a mixture of humus from C_3- and C_4-plant origins.

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