

TENTATIVE DETERMINATION OF THE RESIDENCE TIME OF HUMUS IN TWO  
FERRALLITIC SOILS BY USE OF THERMONUCLEAR AND COSMOGENIC  
RADIOCARBON

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## I INTRODUCTION

The continuous increase of the injection in to the atmosphere of  $\text{CO}_2$  by combustion of fossil carbon and more recently the introduction of  $^{14}\text{C}$  of thermonuclear origin has made it possible to use mathematic models (1) (2) for a better knowledge of the carbon cycle in nature.

A study of the forest tropical soils amounting to about 40% of the active terrestrial biosphere should lead to a determination of the residence time of carbon trapped as organic matter in the various horizons and therefore allow to improve these models.

Also the evolution of the different fractions of organic matter in soils: the successive polymerisation and depolymerisation, the important role of microorganisms, etc, have been extensively studied by the classical methods of pedology.

The use of  $^{14}\text{C}$  of cosmogenic and thermonuclear origin as a world scale tracer can give a better knowledge of these phenomenons.

## II ORGANIC MATTER IN SOILS

The incorporation of atmospheric  $\text{CO}_2$  during plant photosynthesis is the source of organic matter in soils. Plant residues accounts for 90% of organic litter with the rest coming from animal excretions and remains. Microorganisms are responsible for the mineralisation of this litter. Some of the organic components are transformed into more or less polymerised substances which together with microflora and microfauna form the humus.

Chemical treatment with reactive alkalines separates the humus in various fractions:

- fulvic acids (AF) defined as soluble products in the extraction solvents which do not precipitate with acids;
- humic acids (AH) soluble products which precipitate with acids;
- humin (H) remaining residue.

The relative percentage of these fractions in the soil depends of the reactive solvent used (3). These definitions are then rather imprecise. It is possible that two identical humic molecules do not exist (4).

Another problem is the neoformation during the extractions of AF-AH-H from microorganisms and fresh organic matter in the soil.

The importance of the neoformation depends on the method of extraction and also the effectiveness of pretreatment.

In this work, the extraction method of Dabin (5) has been used because it seems to be one of the best adapted for tropical soils. The schematic diagram of the method is shown in figure 1.

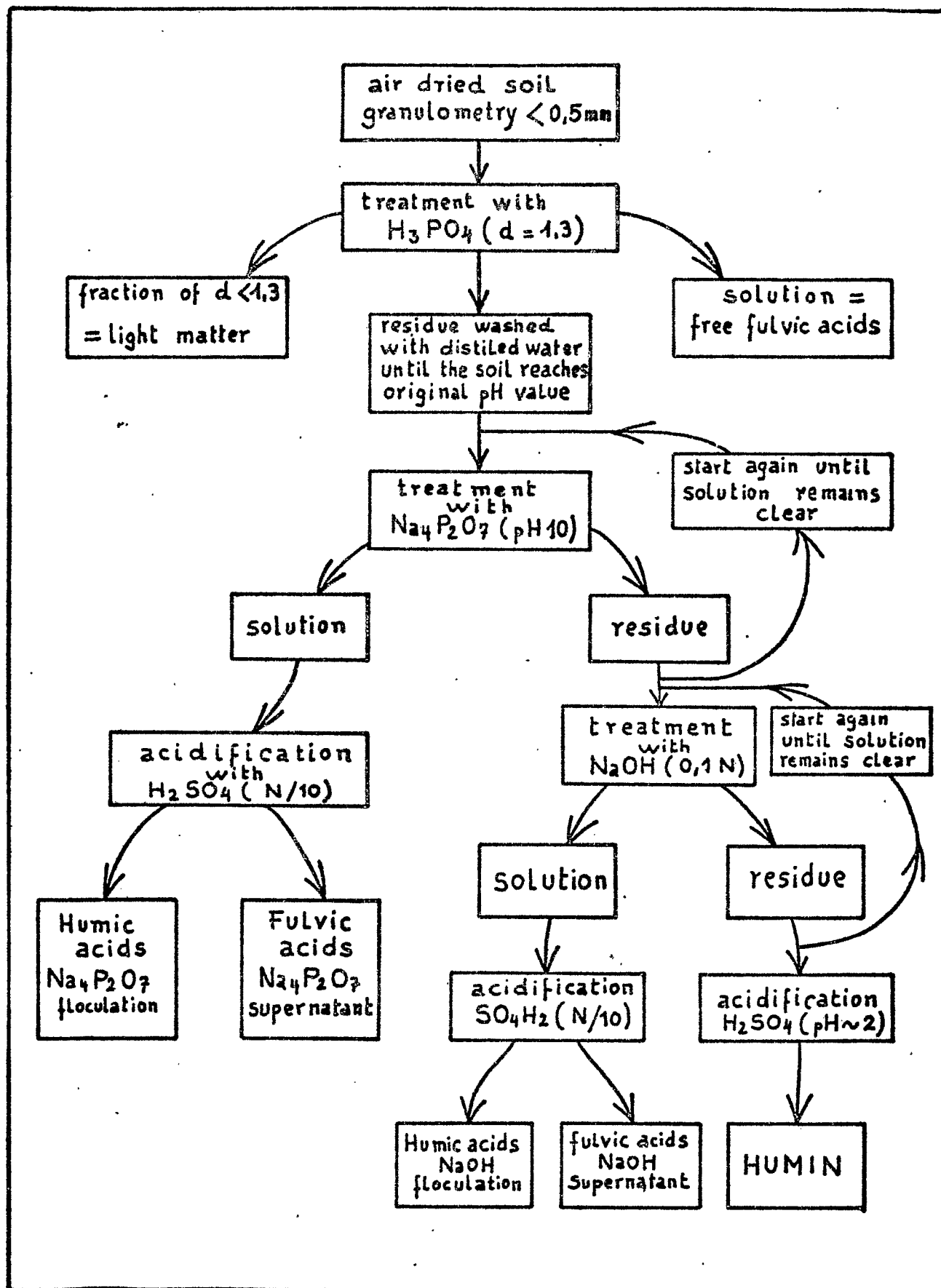


Fig 1 DABIN'S EXTRACTION METHOD

III PEDOLOGICAL DESCRIPTION OF THE FERRALITICS FLORESTAL SOILS STUDIED

ONDINA SOIL:

Ondina soil is located in Salvador (12° 58' 09''S- 38° 31' 11''W) at an altitude of 10 meters at the foot of an hill and is formed under humid tropical climate ( $T= 26^{\circ}\text{C}$  rain = 1800 mm.y<sup>-1</sup>) (6) from granodiorite baserock.

The soil profile has been studied to a depth of one meter.

- Marron red coloration (7.5 YR 5/4) is fairly homogenous all along the profile.

- Organic matter content, measured with Anne's method (7), is 5-4-2% for levels 5-15- 45 cm respectively.

- The soil texture is sandy-clay (20%) at the surface becoming more clayous (42%) at 20 cm.

- With depth the more or less crumbly structure becomes polyedrical; the pH changes from 6.2 to 6.1 and the porosity from good to medium.

- For the 0-5; 5-15; 15-45; cm layers, the exchange capacity is 14- 12- 11 meq%; the exchangeable base sum 11.3- 6.5- 4.6 meq% and the saturation percentage 80- 63- 43 % respectively.

X rays diffractometry shows (fig.2) that the clay fraction

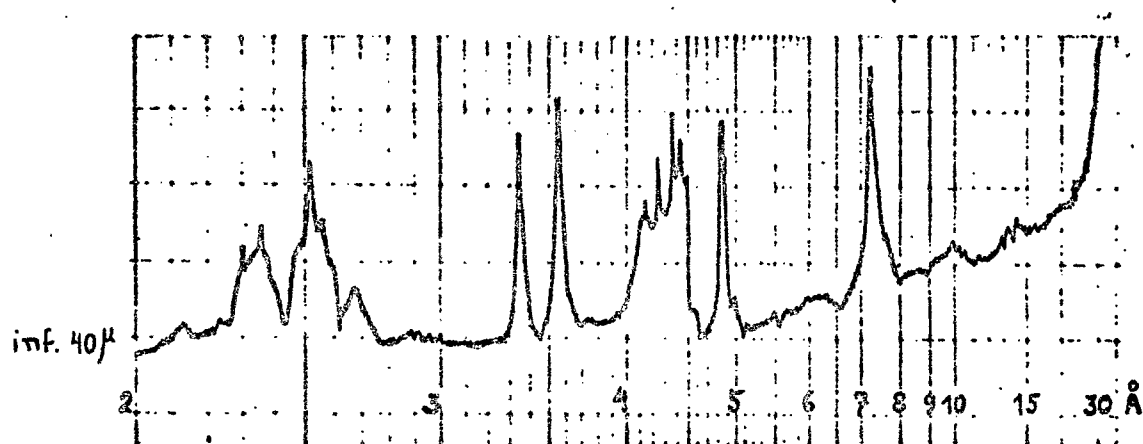


Fig 2 - Powder diffraction pattern - Ondina soil : 15 - 45 cm.

contains b-axis disordered kaolinites, quartz, goethite, a small amount of gibbsite, trace amounts of hematite, illites and swelling clays.

These pedological determinations suggest that this profile shows an A humiferic layer overlying a structural (B) layer and a C layer of weathered baserock.

## SANTO AMARO SOIL

Santo Amaro soil is located on the Camaçari plateau near OPALMA plantation (12° 36' S - 38° 57' W) at an altitude of 200 m and is formed under tropical humid climate ( $T = 28^{\circ}\text{C}$  rain =  $1730 \text{ mm} \cdot \text{Y}^{-1}$ ), from transport materials. Its is at least 10m. thick and has been studied to a depth of one meter.

Litter lays on the surface (3 cm of leaves) followed by a 2-3 cm mattress of roots and rootlets. An intense Lumbricidae's activity takes place and arboricols termites are numerous.

From the surface the coloration changes from dark to light gray (7.5 YR 5/2 to 4/2) and the organic matter content (from Anne's method determination) is 6- 3- 1.5% for 5- 40- 80 cm layers, respectively. The surface texture is sandy clay (23%) and clay sand (37%) at one meter depth. Large rock particles are absent:

From the surface the pH increase regularly from 4 to 5, the exchange capacity changes from 19 to 7.5 meq%, exchangeable base sum decrease from 1.4 to 0.5 meq%.

X rays diffractometry shows b-axis disordered kaolinite,

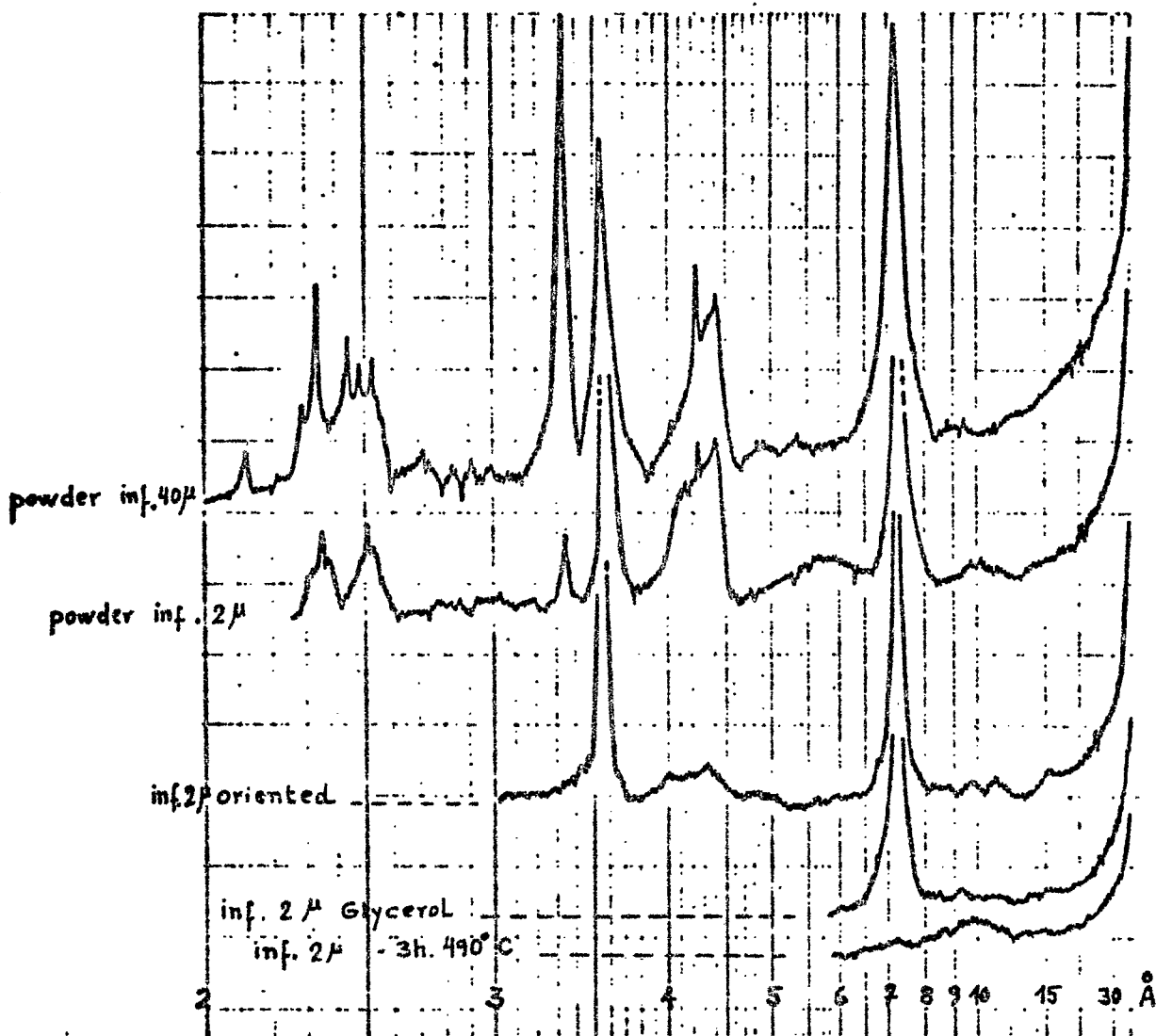
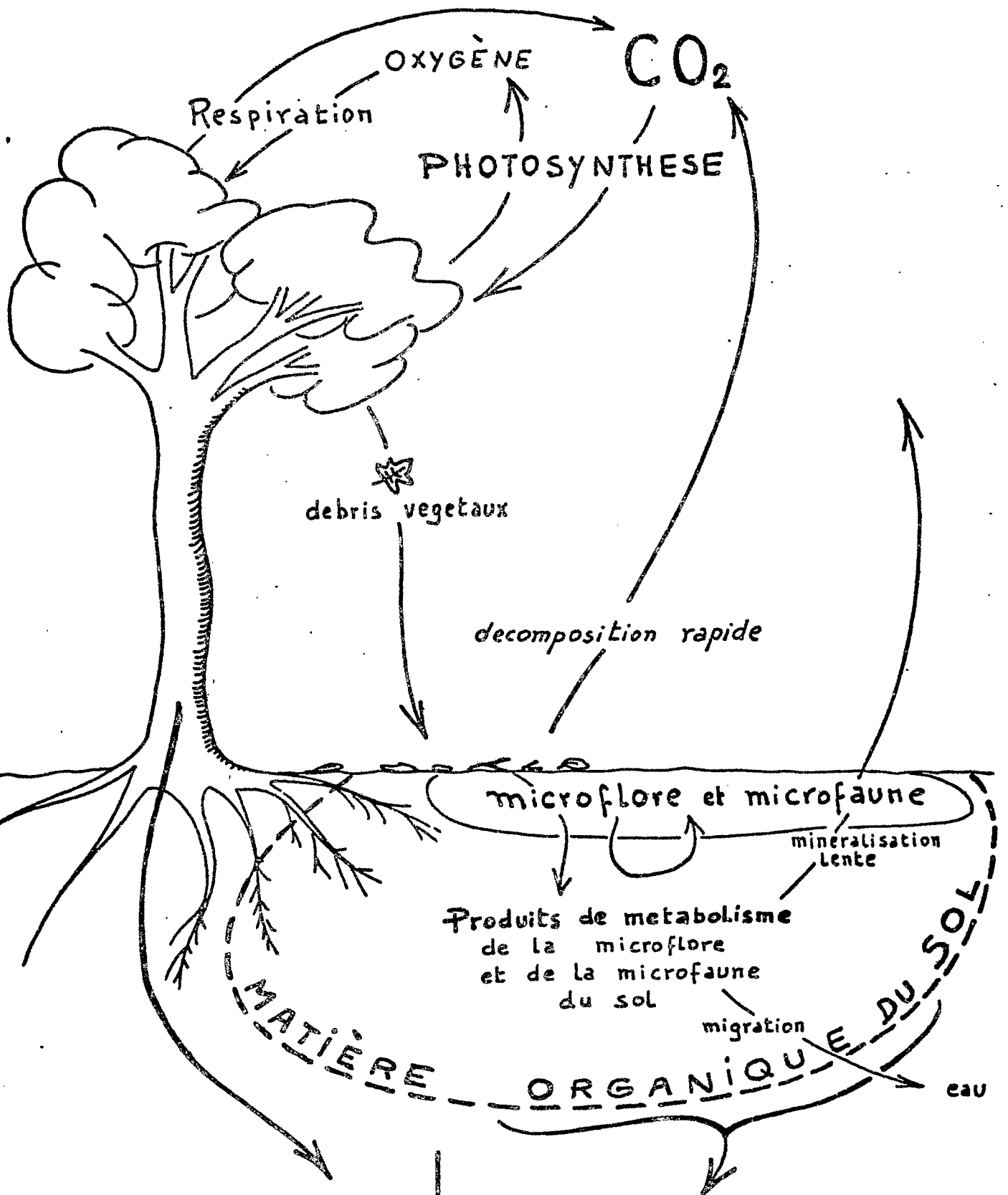


Fig 3 : X-ray diffraction patterns - Santo Amaro soil  
30 - 45 cm.



Graisses et résines .....	6,4	10,4	%
Pentosanes, hexosanes..	28,4%	3	%
Cellulose .....	37,4%	7	%
Lignine .....	14%	8	%
		43%	-- Acides fulviques et humiques
		24%	--- Humines

quartz, trace amount of goethite and more or less degraded illites (broad peak at 10 Å on heating) in the clay fraction (fig.3). Mineralogical description is given by Luz Conceição (8).

The studies show that the soil is chemically very poor.

IV INTERPRETATION OF RESULTS- MATHEMATIC MODEL.

Figure 4 gives the weight of carbon and <sup>14</sup>C specific acti-

Soil	layer cm.			Fulvic acids	Humic acids	Fulvic acids	HUMIN
		(1)	(2)	H <sub>3</sub> PO <sub>4</sub>	Na <sub>2</sub> P <sub>2</sub> O <sub>7</sub> + NaOH	Na <sub>4</sub> P <sub>2</sub> O <sub>7</sub> + NaOH	
ONDINA	0-5	(1)		85 ± 5	305 ± 15	260 ± 15	1060 ± 50
		(2)		+15 ± 1	+25 ± 1	+11 ± 1	+36 ± 1
	15-45	(1)		860 ± 45	780 ± 40	1830 ± 90	1600 ± 80
		(2)		-3 ± 1	-3 ± 1		-29 ± 1
SANTO AMARO	0-10	(1)		770 ± 40	1750 ± 85	285 ± 15	1900 ± 95
		(2)		+8 ± 1	+9 ± 1		+16 ± 1
	70-100	(1)		546 ± 25	590 ± 30	590 ± 30	1600 ± 80
		(2)		-42 ± 1	-31 ± 1		-40 ± 1

(1) C = g.m<sup>-2</sup>      (2) δ<sup>14</sup>C %

Fig 4 : Weight of carbon and specific activity of various fractions of Organic matter in layers of studied profiles.

activity of the organic matter, in the different extracts with Dabin's method, for two layers of these soils. Various interpretations of radiocarbon measurements are possible (9) (10) (11). We can:

- Give an <sup>14</sup>C age following the more classic definition. For example, humin of 15- 45 cm layer of Ondina soil (δ<sup>14</sup>C% = - 29) would be an age of 2 750 years.

- Extend this notion to the surface layer marked with <sup>14</sup>C from thermonuclear origin. For example, humin of the 0- 5 cm layer in the same soil (δ<sup>14</sup>C% = + 36) would be 8 years old because the 1963 atmospheric carbon at the sampling site showed the same activity.

- Define an mean age by the arithmetic average of the values obtained for the upper and lower part of the studied layer. For example, humin of the 0- 45 cm layer of Ondina soil would have a mean of 1380 years.

- Take into account the carbon weight which would give an age of 1660 years for the same fraction.

We prefer, as Nikiforoff did in 1954 (12), to consider a constant weight of organic matter in the soil with equal quantities being formed and decomposed. This steady-state would be reached in  $10^3$  to  $10^6$  years following the  $1 - e^{-\lambda t}$  law (13). However, in Cameroon two soils were studied (14) on the same base rock, under the same climate and only 10 km. apart. The first ( $10^4$  years) has an organic matter content twice that the second ( $10^6$  years). We know that the steady-state can be broken in many ways: fires, climatic variations like that of Würm etc. Nevertheless, a mathematic model giving residence time of organic matter in soil can be established (15).

Let Q and F be the amount of carbon present in the soil and the amount subceptable to enter, respectively; a the percentage of F which enters per unit time and b the percentage of Q which leaves the soil during the same time interval; then,

$$-\frac{dQ}{dt} = aF - bQ \quad (I)$$

The same argument can be used for  $^{14}\text{C}$  atoms

$$-\frac{dQ}{dt} = aF - (b+\lambda)Q \quad (II)$$

with  $\lambda$ , desintegration constant of  $^{14}\text{C}$ .

Noting that,

$$\frac{Q}{Q} = Q^* \text{ and } \frac{F}{F} = F^*$$

may be represented by specific activities and that for the hypothesis  $\frac{dQ}{dt} = 0$ , the relationship becomes:

$$-\frac{dQ^*}{dt} = bF^* - (b+\lambda)Q^* \quad (III)$$

Before 1954 starting of the mesurable effects of thermonu clear tests,  $-\frac{dQ^*}{dt} = 0$  then,

$$\frac{1}{b} = \frac{1}{\lambda} \left( \frac{F^*}{Q^*} - 1 \right) \quad (IV)$$

After 1954  $-\frac{dQ^*}{dt} \neq 0$ . The integration of III gives

$$Q^* = b \int_0^T F_t^* e^{-(b+\lambda)(t-T)} dt \quad (V)$$



This can be resolved numerically in the following form

$$Q_T^* = Q_0^* e^{-(b+\lambda)(T-T_0)} + b \sum_{n=1}^{T-T_0} F_{(T_0+n)}^* e^{-(b+\lambda)(T-T_0-n)} \quad (VI)$$

with  $n = 0$  in 1954 taken as the year  $T$ ;  $Q_0^*$  and  $F_0^*$  being constant and  $T > T_0$ .

The measure of  $b$  is  $T^{-1}$  unit's being the inverse residence time of carbon in soil. The magnitude of  $b$  is independent of specific activity and thus must satisfy simultaneously equations IV and VI. We have also  $b = -\frac{q}{Q}$  where  $q$  is the amount of organic matter entering or leaving annually the soil.

The equations are general. For example,  $Q_T^*$  is the measured specific activity of humin for a given layer  $H_x$  for the year  $T$ . The specific activity,  $F_t^*$ , of the humin which enters yearly this  $H_x$  layer may come from various fractions and various layers so that the sum of those contributions  $a_{ij}$  is equal to 1. We then obtain:

$$F_t^* = \sum Q_{ij}^* a_{ij}$$

Taking in account our measurements, in order to simplify the model, assumptions have led to determine some parameters.

#### V RESIDENCE TIME OF AF, AH, H IN THE UPPER PART OF THE SOILS.

We suppose that:

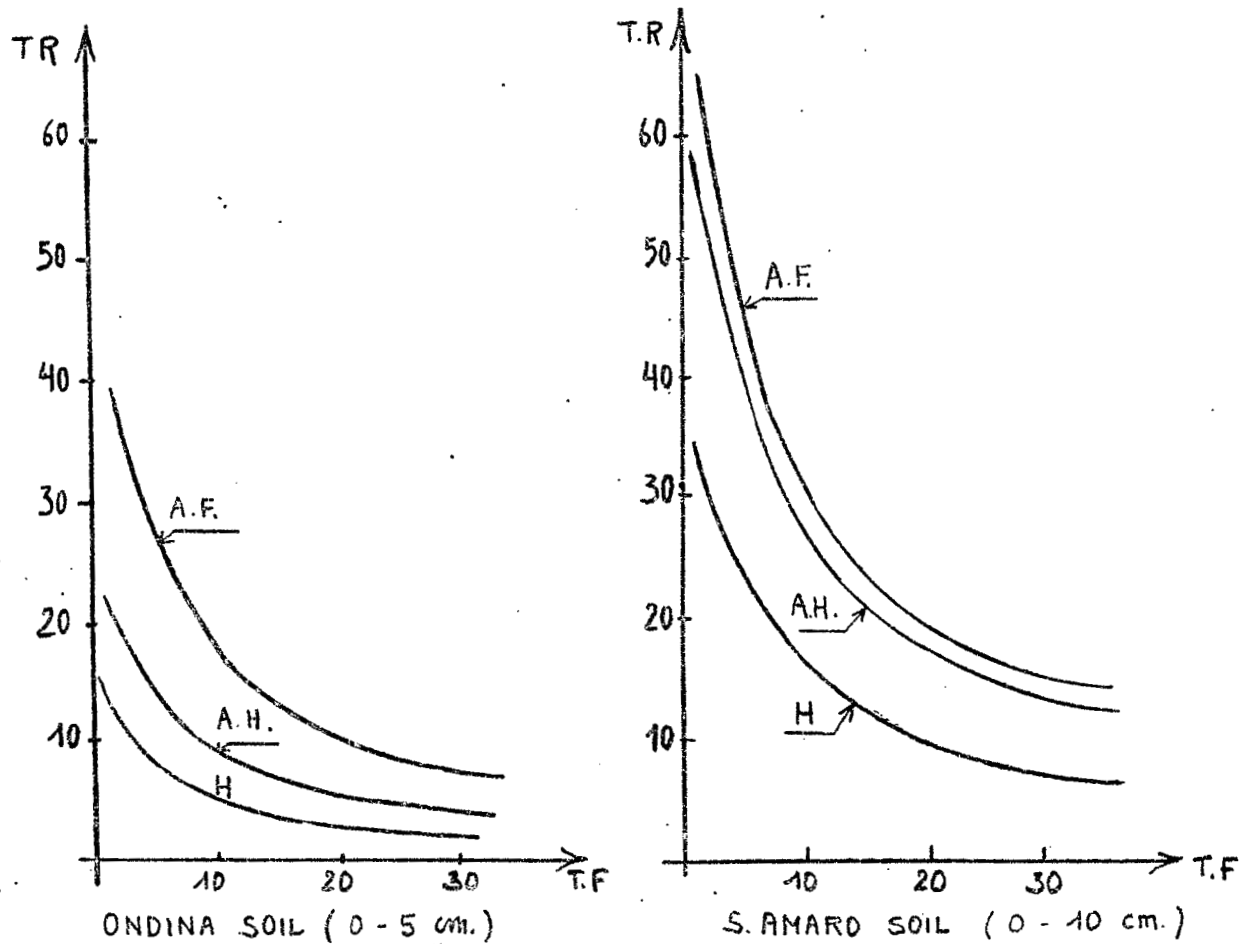
- The upper layer of soils is quickly homogenised (16) due to biological action.
- The various fractions are formed directly and solely from the litter:
- The carbon specific activity of the litter is that of the atmospheric  $CO_2$  at the sampling site.

Under these conditions, for a given fraction, we have:

$$F_t^* = F_{(t-1)}^* (1 - a) + A_t^* a$$

$A_t^*$  is the specific activity for the atmosphere in the year  $(t)$  estimated from different works (2) (17);  $F_{(t-1)}^*$  is the specific activity of the litter for the year  $(t-1)$ ; and  $a$  is the probability of formation of a given fraction per unit time, or the inverse of decomposition time of litter.

The simultaneous solving of IV and VI equations shows for the same value of the decomposition time of litter that the residence time of the various fractions is always greater for St Amaro soil than for Ondina soil ( fig 5).



VI ESTIMATION OF THE AMOUNT OF CO<sub>2</sub> CROEVED BY THE MINERALISATION OF AF - AH AND H.

We suppose that the organic matter which enters a given layer:

- has been formed within one year from the litter ( polymerisation of soluble compounds)
- is mineralising in its formation layer.

In these conditions,  $F_t^* = A_t^*$  .

Extrapolating for the whole profile the weight and the specific activity of various fractions, we can calculate for each of them the residence time in successive layers of constant thickness (18).

Remembering that  $T_r = \frac{Q}{q}$  and summarizing q we see that more than 90% of the carbon so mineralised occurs in the top 30 cm for Ondina soils. For St Amaro, the same result is obtained for a double thickness. The global residence times for layers 0-45 cm are respectively 30 and 115 years.

VII ESTIMATION OF THE MAXIMUM VELOCITY OF AF - AH - H MIGRATION  
IN THE UPPER LAYERS

We suppose that organic matter which enters yearly a layer H comes from two sources (1) the immediately upper level (H-1) and (2) the litter. The specific activity is then given by:

$$F_H^* = aQ^*(H-1) + (1-a)A^*$$

where a is the percentage entering H by migration from H-1.

If on the other hand, biological activity decreases with depth, the residence time ( $T_r$ ) of organic matter in successive layers of the profile must increase. At the limit, we should have

$$T_r(H-1) = T_r(H)$$

which corresponds to a maximum percentage of migration.

We can see ( layers 0-5 and 5- 10 cm) that for St Amaro soil ( more sandy than Ondina ), that these percentages for AF and AH are 2.5 times larger. Humus seems to have the same behaviour. Migration velocities are of the same order: 0.1 to 1 mm.Y<sup>-1</sup>.

VIII CONCLUSION

All the results given depend on the validity of a mathematic model. As pointed out by Dommergues and Mangenot (19), even the most sophisticated mathematic models are approximative because of the number of parameters being neglected for numerical resolution.

The model used in spite of its approximations shows the different nature of the two studied profiles ( residence time- origin of CO<sub>2</sub> from mineralisation of AF, AH, H - percentage of migration of these fractions into the upper layers).

<sup>14</sup>C from cosmogenic and thermonuclear origin used as a tracer of organic matter in soils can thus be an useful complement to the classical techniques used by soil scientists.

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