CHANGES IN ORGANIC MATTER IN AN OXISOL FROM THE CENTRAL AMAZONIAN FOREST DURING EIGHT YEARS AS PASTURE, DETERMINED BY ^{13}C ISOTOPIC COMPOSITION

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ABSTRACT

The consequences of burning and deforestation on soil organic matter (SOM) content were studied on two managed areas of Oxisol (Yellow Latosol) located near Manaus, in Central Amazonia. The variations of organic carbon (OC) content were studied on the 2 mm sieved fraction of surface soils collected under natural forest, before and after slash and burning, and under pasture of *Brachiaria humidicola* established for one, two and eight years. Under natural forest, OC content reached maximal values of 28 $T.ha^{-1}$ in the 0–3 cm layer, 62 $T.ha^{-1}$ in the 3–20 cm layer, and decreased rapidly with depth. Burning removed about 4 $T.ha^{-1}$ of OC, chiefly from the 0–3 cm soil layer, but this loss was recovered after one year of pasture. Decreases of about 8 $T.ha^{-1}$ after one year and 28 $T.ha^{-1}$ after two years were observed in the 3–20 cm layers, probably because the humification of grass root residues did not balance the decomposition of pre-existing SOM. Contrarily, after eight years of pasture, the initial OC content of surface soil had been almost entirely restored, including the 3–20 cm layer.

Changes in the isotopic ratios $^{13}C/^{12}C$ of SOM were used to determine the respective contribution of OC derived from forest (Cf) and pasture (Cp) in each situation. After one year, the proportion of Cp was already 5% in the whole 0–20 cm layer. After two years, it was of 20%, whereas about 40% of Cf had disappeared. After eight years, the proportion of Cp was close to 40%, whereas almost no further decrease of Cf had been observed between two and eight years of permanent pasture.

Keywords: oxisols, organic matter, deforestation, natural carbon-13, Brazil

INTRODUCTION

The Amazon Basin occupies one third of the South American continent, representing about 5.8 10^6 km^2, of which 75% are covered by tropical rain forest. Although the vegetation is luxurious, the soils developed in *terra firma* are generally poor and acidic, with low retention capacity for nutrients (Schubart and Walker, 1987). However, these soils are almost tight systems, as a large proportion of nutrients are quickly recycled (Luizao and Schubart, 1987).

In the Brazilian Amazonia, deforestation has been increasing since the 1960's, with the intensification of agricultural projects aimed either at annual and perennial crops, use for pasture, or reforestation (Salati and Vose, 1984). In most cases, soil

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productivity drastically decreased after two or three years of cultivation, and fertility was recovered only several years after abandonment (Martins-da Silva, 1987).

The introduction of pastures is considered to be one of the main factors of the alteration of the natural ecosystem (Fearnside, 1979; Meyers, 1982). Before 1960, pastures in Amazonia were restricted to natural areas, whereas Falesi and da Veiga (1986) estimate that about 5.10^4 km^2 of forest have been cut down and burned for pasture purpose in the last 25 years.

How do soils change under permanent artificial pasture in Amazonia? Falesi (1974) at first gave an optimistic answer to this question, but it seems that later more attention was placed on physical and chemical perturbation of soil (Schubart, 1977; Dantas, 1979). In this respect, soil organic matter (SOM) is considerably involved as it carries most plant mineral nutrients, maintains aggregate stability in soil, and protects it against erosion.

Apart from qualitative modifications of SOM due to vegetation changes, the determination of losses of SOM from forest origin and of the rate of its substitution by SOM from pasture origin is of capital importance. In the present work, measurements of total carbon content and isotopic ^{13}C abundances were combined to study such changes of SOM budget with increasing age of pasture in deforested areas of Central Amazonia.

MATERIALS AND METHODS

Soils

The soils were located in two flat areas of oxisols — "Latossolos amarelos muito argilosos" in the Brazilian classification — located at 39 km (site 1) and 56 km (site 2) north of Manaus. These soils are characterized by a high content (80%) of iron-poor kaolinite clay minerals in the whole profile, and a low humus content (less than 4% in the 0–10 cm layer). The litter is 4 to 10 cm thick and presents a stratified distribution of various decomposing tree leaves, with abundant fungal hyphea. The upper mineral soil (0–4 cm) has a dark grey colour, a moderate crumbled structure, and abundant fine and very fine pores. In the lower layers, of light yellow colour, the structure becomes massive and the consistence more friable (Cerri and Volkoff, 1987).

On site 1, three areas were chosen: under natural forest (1MF), under forest which had been cut down and burned for less than three months (1MQ) and under a one year old pasture (1MP1). On site 2, three other areas were chosen: under natural forest (2MF), under a two year old pasture (2MP2), and under an eight year old pasture (2MP8), which have been described by Teixeira (1987).

In each soil, from three to four layers were morphologically described within the first 20 cm and sampled.

Total carbon and nitrogen and carbon-13 analysis

Organic C content was determined on air dried, 2 mm sieved and 50 mesh-ground soil sample by dry combustion in a Wösthoff "Carmograph 12" analyzer and total N was determined by Kjeldahl distillation after sulfuric digestion. Carbon 13 natural abundances were measured with a Finnigan mass spectrometer on the purified CO_2 produced by combustion of soil sample at 550°C in sealed pyrex tubes and in presence of CuO, according to the procedure used at the Department of Stable Isotopes of the CENA (Volkoff et al., 1982).

Methods of calculation

For each soil profile, C and N contents of each sampled layer were recalculated in $T.ha^{-1}$ on the basis of their apparent density, and plotted against depth. In order to compare soil layers of equivalent thickness, C and N contents of the 0–3, 3–10 and 10–20 cm layers were then estimated graphically.

The use of isotopic ^{13}C abundances to quantify SOM of two different origins is based on the fact that not all plants discriminate the stable isotope ^{13}C to the same extent during CO_2 assimilation (Bender, 1971; Smith and Epstein, 1971). Carbon 13 natural abundance of each sample (Sp) was expressed in δ units, by reference to the international standard PDB, according to the following equation:

$$\delta^{13}C‰ = [(^{13}C/^{12}C)_{sp} - (^{13}C/^{12}C)_{PDB}] \cdot 10^3/(^{13}C/^{12}C)_{PDB}$$

According to several data reviews, the mean $_{d}{}^{13}C$ values are about –26‰ in C_3 plants (forest), and –12.5‰ in C_4 plants (pasture). On the hypothesis that $\delta^{13}C$ values of SOM reflect that of its parent vegetation, the changes of $\delta^{13}C$ values in soil and soil fractions, due to a C_3–C_4 or a C_4–C_3 succession can provide information about the distribution of SOM of each origin (Deines, 1980). This approach was used, for instance, by Cerri et al. (1985) and Vitorello et al. (1988) under tropical conditions, and by Balesdent et al. (1987, 1988) under temperate conditions, to study SOM turnover under long-term cultivation of gramineaceous crop after deforestation. A similar approach is applicable in the present case, since the Amazonian forest is mainly composed of C_3 plants, while the cultivated pasture of *Brachiaria humidicola*, one of the most commonly used pasture grasses in Amazonia, is of the C_4 type.

In soils under pasture, organic C from forest (Cf) and pasture (Cp) origin are deduced from the equation:

$$Cs \cdot \delta^{13}Cs = Cf \cdot \delta^{13}Cf + Cp \cdot \delta^{13}Cp$$

in which Cs is the total C content of the soil layer, and $\delta^{13}Cs$, $\delta^{13}Cf$ and $\delta^{13}Cp$ are the respective $\delta^{13}C$ values (in ‰ of the soil layer, the forest vegetation, and the pasture.

RESULTS

Main morphological and analytical changes in soils

After burning (1MQ soil), the litter was substituted by a 1 to 3 cm thick layer of charcoal and imperfectly burned twigs and trunk pieces, which were more or less mixed with angular, 0.5 to 2 cm sized aggregates. No change was observed in the underlying layers. Soils under pasture had a slightly darker colour in the surface layer than the corresponding soils under forest and showed a compacted, olive to greyish-brown coloured layer between 2 and 6 cm, in which some mottling was noticeable. This is probably due to the absence of forest cover and limited evapotranspiration, as well as to cattle stamping (Correa, 1985). Coarse residues of charcoal and imperfectly burned wood material still appeared among the decomposing grass residues, although to a lesser extent in the 2MP8 soil. After two years, an increase in the mesofaunal activity was noticed, and a dense root network developed, principally in the 0–20 cm layer.

Analytical data (Table 1) indicate that in the presence of pasture, pH and exchangeable cations tend to increase, at least after

TABLE 1

Chemical characteristics of the studied soils

	Depth	pH		Exchangeable cations (me.100 g^{-1})						CEC	Exchangeable
	(cm)	H_2O	KCl	Ca	Mg	K	Na	Al	H	(me.100 g^{-1})	bases % CEC
Site 1											
1MF*	0–3	4.0	3.5	0.22	0.40	0.15	0.17	2.06	1.15	4.15	22.6
	3.20	4.0	3.8	0.14	0.11	0.06	0.09	1.37	0.7	2.47	16.2
1MQ**	0–3	3.9	3.6	0.37	0.30	0.13	0.09	1.46	1.06	3.41	26.1
	3–17	3.9	3.8	0.13	0.06	0.06	0.10	1.32	0.61	2.28	15.3
1MP1***	0–2	3.9	3.6	0.56	0.16	0.12	0.13	1.74	0.97	3.68	26.3
	2–10	3.8	3.7	0.20	0.07	0.07	0.13	1.67	0.65	2.79	16.8
	10–40	4.3	4.1	0.13	0.02	0.04	0.10	0.87	0.34	1.50	19.3
Site 2											
2MF	0–3	3.6	3.3	0.47	0.32	0.18	0.15	2.53	1.79	5.44	20.6
	3–12	3.6	3.6	0.20	0.13	0.08	0.05	1.78	0.96	3.20	14.3
	12–36	4.2	4.0	0.14	0.04	0.03	0.04	1.09	0.50	1.84	13.6
2MP2***	0–2	5.1	4.6	12.49	5.20	0.50	0.38	0.08	0.24	18.89	98.3
	2–4	4.5	4.0	1.66	0.093	0.16	0.10	0.56	0.44	3.85	74.0
	4–20	4.3	4.0	0.23	0.08	0.06	0.10	1.09	0.48	2.04	23.0
2MP8***	0–3	4.5	4.0	3.70	2.72	0.95	0.28	0.44	0.67	8.76	87.3
	3–5	4.4	4.0	1.43	1.14	0.31	0.12	0.88	0.68	4.56	65.8
	12–30	4.3	4.0	0.32	0.23	0.06	0.11	1.09	0.41	2.22	32.4

*MF = soil under natural forest
**MQ = soil under burned forest
***MP1,2,8 = soils under pasture of 1, 2 and 8 years

TABLE 2

Distribution of total carbon (Cs), carbon from forest (Cf), carbon from pasture (Cp) and nitrogen in the studied soils

	Depth (cm)	Total carbon T.ha^{-1}	Carbon from forest			Carbon from pasture		Nitrogen	
			T.ha^{-1}	% of Cs	% of initial Cf	T.ha^{-1}	% of Cs	T.ha^{-1}	C/N ratios
1MF	0–3	15.0	15.0	100	100	0	0	1.0	15.0
	3–10	25.0	25.0	"	"	"	"	2.0	12.5
	10–20	26.0	26.0	"	"	"	"	2.2	11.8
	0–20	66.0	66.0	"	"	"	"	5.2	12.7
2MF	0–3	28.1	28.1	100	100	0	0	1.5	18.7
	3–10	31.9	31.9	"	"	"	"	2.4	13.3
	10–20	30.0	30.0	"	"	"	"	2.6	11.5
	0–20	90.0	90.0	"	"	"	"	6.5	13.8
1MQ	0–3	11.5	11.5	100	100	0	0	1.1	10.4
	3–10	21.5	21.5	"	"	"	"	2.2	9.8
	10–20	24.0	24.0	"	"	"	"	2.5	9.6
	0–20	57.0	57.0	"	"	"	"	5.8	9.8
1MP1	0–3	15.0	13.8	92.0	92.0	1.2	8.0	1.0	15.0
	3–10	22.0	20.8	94.5	83.2	1.2	5.4	2.0	11.0
	10–20	17.0	16.6	97.6	63.8	0.4	2.3	2.2	7.7
	0–20	54.0	51.2	94.8	77.6	2.8	5.2	5.2	10.4
2MP2	0–3	35.0	24.5	70.0	87.2	10.5	30.0	1.5	23.3
	3–10	20.0	17.7	88.5	55.5	2.3	11.5	1.9	10.5
	10–20	13.8	12.6	91.3	42.0	1.2	8.7	1.4	9.8
	0–20	68.8	54.8	79.6	60.9	14.0	20.3	4.8	14.3
2MP8	0–3	38.0	12.0	31.6	42.7	26.0	68.4	2.2	17.3
	3–10	30.0	17.7	59.0	55.5	12.3	41.0	2.5	12.0
	10–20	28.0	20.5	73.2	68.3	7.5	26.8	2.5	11.2
	0–20	96.0	50.2	52.3	55.8	45.8	47.7	7.2	13.3

two years, but it is probably that this was also due to fertilization of the pasture with either chemicals or cattle manure.

Changes in soil carbon and nitrogen contents

The two soils under natural forest had very different C contents, mostly in the two upper layers (Table 2). On site 1 (1MQ soil), burning removed SOM, mainly from the 0–3 and 3–10 cm layers, in which C content decreased from 15 to 11.5 $T.ha^{-1}$ and from 25 to 21.5 $T.ha^{-1}$ respectively, as compared with the corresponding layers in the 1MF soil.

In the 1MP1 soil, C content in the 0–3 and 3–10 cm layers was again similar to that of 1MF, but was reduced to 17 $T.ha^{-1}$ in the 10–20 cm layer. Similarly, in the 2MP2 soil, C content in the 10–20 cm layer decreased from 30 $T.ha^{-1}$ to 14 $T.ha^{-1}$ as compared with the 2MF soil. Carbon content of the whole 0–20 cm layer was lower in the 2MP2 soil than in the 2MF soil, but not much higher than in the 1MP1 soil (Table 2). In the 2MP8 soil, the C content of the 0–3 cm layer was higher than that of the 3–10 and 10–20 cm layer. But this last was close to that of the corresponding layer of the 2MF soil.

Under natural forest, the C/N ratio decreased with depth from 15–18 to 11–12. Nitrogen mainly accumulated in the 3–10 and 10–20 cm layers, and to a larger extent in site 2 than in site 1, as for the C (Table 2). Although C/N ratio decreased in the 1MQ soil and increased again in the 1MP1 soil, N content only slightly changed in the 0–20 cm layer of these deforested soils. In the upper layer of soils under older pastures, a slight increase of the C/N ratios was noticed. However, this did not result in a decrease of N content, which had increased again in the 2MP8 soil.

Isotopic composition and origin of soil organic matter

Delta ^{13}C values in soils from the two experimental areas are shown in Fig. 1. Under forest (1MF and 2MF soils) and in the burned site (1MQ), $\delta^{13}C$ values were close to –28‰ in upper layers, with a scarcely significant increase to –27‰ with increasing depth. After one year of pasture, variations not higher than one Delta unit were observed. Delta ^{13}C values increased with the age of pasture to –23‰ and –17.5‰ in the o–3 cm layer, after two and eight years of pasture, respectively. These values reached –26‰ and –24‰ in the 10–20 cm layers of the soils under two and eight years old pasture, respectively.

Table 2 shows that, after one year of pasture, CP already represented 5% of C of the whole 0–20 cm layer, but was mainly present in the 0–3 cm layer. Obviously, the progressive increase of Cp with time corresponded to a complementary decrease of Cf: after two years, Cp represented 20% of C in the whole 0–20 cm soil layer, but it had increased faster in the surface layer than in the deeper layers. After eight years, Cp represented 47.7% of C in the whole o–20 cm layer, but had increased more slowly in depth than in the surface layer. Its amount in the 10–20 cm layer was less than half of the 0–3 cm layer.

DISCUSSION

One of the difficulties of soil comparative studies is to make sure that the managed soils were similar at zero time to the reference soils. One point which hindered

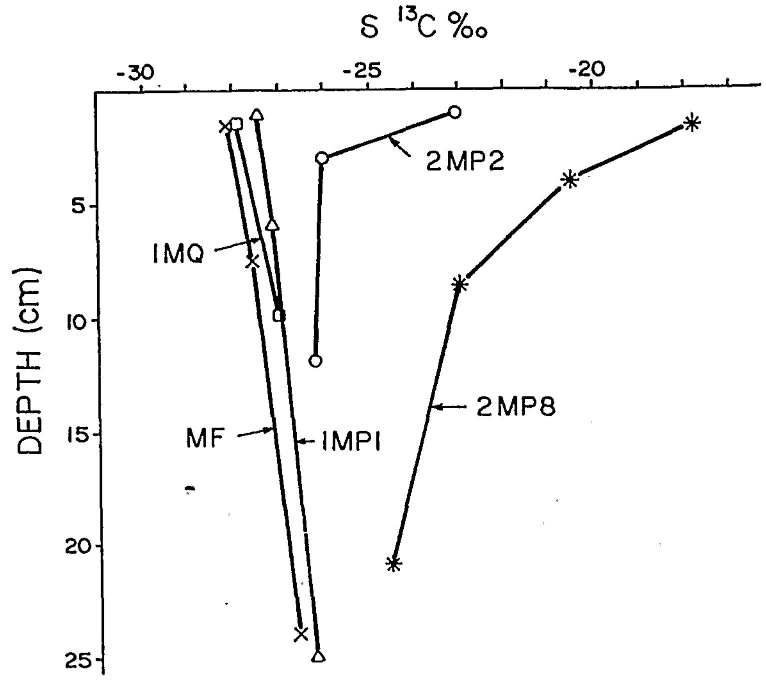

Fig. 1. Variation of soil $\delta^{13}C$ values. MF = soil under natural forest; 1MQ = soil under burned forest; 1MP1, 2MP2, 2MP8 = soils under pasture of 1, 2 and 8 years, respectively.

the present comparison was the difference in soil C content between the two sites under forest. Carbon content of 66 $T.ha^{-1}$ in the 0–20 cm layer of 1MF was close to those obtained by Cerri and Volkoff (1998) and Chauvel et al. (1987), whereas that of 90 $T.Ha^{-1}$ in the corresponding layer of 2MF was probably due to a two times higher litter production (J.C. Correa, unpublished data).

Soil C content and distribution were clearly modified under pasture: after the first year, the decrease in total C was not much higher than that due to burning, but about 5% of Cp were already incorporated in the 0–20 cm layer. The main decrease in soil C occurred during the second year of pasture, principally in the 3–20 cm layer. Isotopic measurements showed that this was due to the decrease of Cf, which was faster than the incorporation of Cp during this period. This can be explained by the fact that the graminaceous vegetation stimulated microorganisms which decomposed residues and even humified material from the forest. In the meantime, the entrance of Cp proceeded mainly from the soil surface, which suggests that the contribution of aerial parts was higher than that of root deposits. After eight years, total C content had returned to its initial value, mainly due to the increase of Cp in the 3–20 cm layers, suggesting a higher contribution of pasture root deposits during the last years. It is noticeable that Cf had decreased very slowly in the meantime, and still represented about 50% of C in the 0–20 cm layer. These results contrast with those obtained by Cerri et al. (1985) in forest-sugar cane successions on red oxisols from Southern

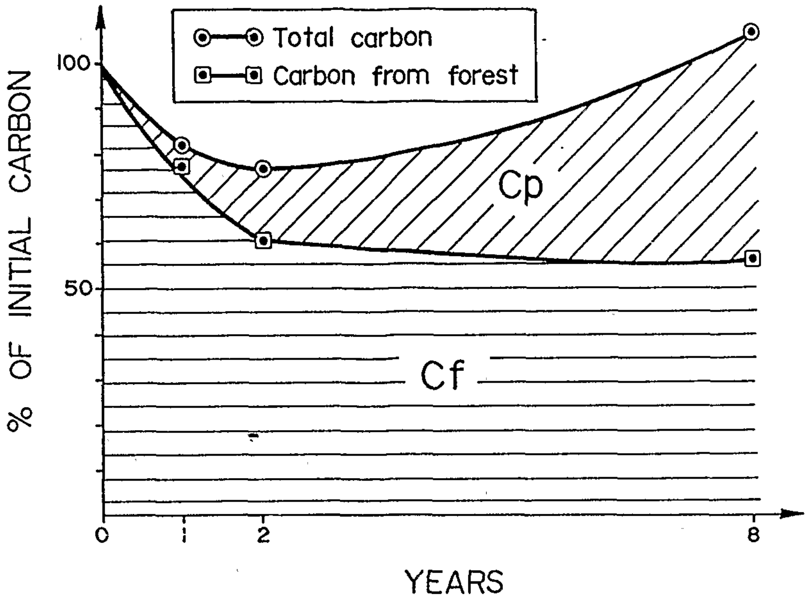

Fig. 2. Dynamics of total carbon, carbon derived from forest (Cf) and carbon derived from pasture (Cp) in the 0–20 cm soil layer.

Brazil, in which more than 75% of the initial Cf was decomposed in 10 years, with no complete compensation by humified C from the crop.

When plotted against time on a graph (Fig. 2), these data show a satisfactory coincidence between the time at which the decomposition of Cf slows down and that at which total C content starts to increase again, due to Cp accumulation. It is remarkable that soil Cp increased in the presence of grazing cattle, and despite a tendency to a return of C_3 invading plants (Dantas and Rodrigues, 1980). This is probably due to the fact that the selected experimental area represents an ideal accomplishment of soil management.

CONCLUSION

The chosen set of sites under native tropical forest and new cultivated pasture seems to provide an ideal example of a complete reconstitution of soil organic matter content within a relatively short time. However, these sites were located in a well-managed, flat area, and the considered period of eight years is probably too short to provide a long-term prediction of soil organic matter content. It can be stressed from this study that:

- The first two years of use for pasture are decisive, as soil organic matter from forest origin undergoes an active phase of decomposition. The mineralization of these materials supplies nutrients to the growing pasture. In the meantime, poorly humified carbon from pasture origin is deposited mainly in the form of residues from aerial parts.
- After two years of pasture cultivation, the mineralization of remaining soil organic matter from forest origin decreases. Such a stabilization has not

been explained, but it is probable that this organic matter contains large proportions of charcoal. When the establishment of the pasture has been successful, the humification of the secondary material begins. After eight years of pasture, there is a great contribution of carbon from both aerial parts and root deposits of the pasture, and soil carbon content is then again close to that observed under natural forest.

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