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Characterization of organic matter in topsoils under rain forest and pasture in the eastern Brazilian Amazon basin

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Abstract In topsoils under forest and 7-, 12- and 17-year-old pastures, organic matter was characterized by analysing C and N distribution in particle-size fractions, the C decomposition rates of soil and particle-size fractions and by employing density-fractionation of macro-organic matter (>150 μm). The C and N associated with clay fractions increased with increasing age of pasture. The weight (%) of macro-organic matter and its heavy fractions (>1.37 g cm^{-3}) also increased with increasing age of pasture. However, in a long-term incubation (100 days), these changes seemed to involve an increase in the C decomposition rate in the topsoil of the oldest pasture. Using the C decomposition rates of particle-size fractions, it appeared that silt and clay contributed differently to C decomposition in the whole soil. C associated with silt contributed to the C decomposition rate during the first 40 days of incubation, while C associated with clay contributed to C decomposition in the long-term incubation (after 40 days), especially when the clay fraction appeared to reach saturation point with respect to its ability to bind organic compounds and thus protect the soil from C loss.

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Introduction

In the tropics, the clearing of forest for agriculture, notably for the creation of pasture, involves millions of hectares annually. Besides the changes in gaseous emissions and climate (Alvim 1982; Fearnside 1985) caused by this activity, there are also changes in soil properties. These changes may include a decrease in total porosity (Chauvel et al. 1991; Eden et al. 1991), a temporary increase in pH and cation-exchange capacity (CEC) (Serrão et al. 1979; Hecht 1981), and often a decrease in soil organic matter (SOM) (Desjardins et al. 1994). However, in well-managed pastures, an increase in SOM can occur (Choné et al. 1991; Feigl et al. 1995).

Changes in the nature of SOM in these pastures have mostly been evaluated by determining the organic C pool and evaluating the C derived from forest or pasture (Cerri et al. 1985; Bonde et al. 1992; Feigl et al. 1995). Changes in SOM have also been evaluated by chemical procedures (Andreux et al. 1980; Viterello et al. 1989; Andreux et al. 1990; Martins et al. 1991). Thus, in the eastern Brazilian Amazon basin, several changes in soil properties, including an increase in organic C sboek, especially in the topsoil (0.10 m), have been found (Koutika et al. 1997). Koutika et al. (1997) found indirect evidence of a great change in the nature of organic material in the topsoil, both negatively charged surfaces and clay dispersibility increased with increasing age of pasture. In addition, the greater part of the organic material derived from pasture vegetation was located in the topsoil.

Up until now, no integrated studies combining physical fractionation techniques and an evaluation of decomposition rates have been attempted in these forest and pasture systems in order to evaluate changes in the nature of SOM. The aim of this study, therefore, was to characterize the nature of SOM in forest and pastures of various ages by combining: (1) density fractionation of macro-organic matter (>150 μm) the most active organic pool; (2) the C decomposition rate in the whole soil; and (3) the C decomposition of silt and clay fractions to evaluate their contribution to C decomposition of the whole soil.

Materials and methods

Experimental site and soils

The study site is located on-farm (Fazenda Bosque), 10 km north of Paragominas, in the north east (2°25′–4°25′S, 46°25′–48°54′W) of the State of Parà. The mean annual temperature is 27.2 °C and precipitation 1750 mm. The period from July to November is drier with less than 50 mm monthly precipitation (Nepstad 1989). The soils are oxisols developed on tertiary sediments belonging to the Barreiras formation (Nunes et al. 1973). The soil samples were taken in May 1993 from each side of pits (1.50 m wide, 1.50 m long, 1.50 m deep) dug in selected areas. Sampling was carried out at intervals of 0.1 m depth. The soils contain more than 80% clay (mostly kaolinite). They are rich in Fe and AlOH, with CEC and base saturation lower than 0.1 mEq g^{-1} and 20%, respectively (Koutika et al. 1997). The natural vegetation is a tropical forest with a low proportion of palms. As very few tree species remain leafless during the dry season, this forest was designated "tropical moist forest" by Nepstad (1989). Whether this is a primary forest remains uncertain, since most of the area has been strongly affected by clear felling in the last 25 years. The pastures are cultivated under three species of grass. One forest and three pasture topsoils (7-, 12-, and 17-year-old pastures) under *Brachiaria brizantha* (P 7), *Panicum maximum* (P 12), and *Brachiaria humidicola* (P 17), respectively, were selected. The differences in the C/N values of root, stems and leaves of the three grass species were not significant (unpublished results). Thus, we concluded that the soils under the three pasture species were comparable in this respect.

Standard soil analyses and macro-organic matter density fractionation

On 0–2 mm air-dried soil samples, particle-size fractionation was carried out using a Na-resin method described by Rouiller et al. (1972). C and N contents of the whole soil (2 mm sieved) and particle-size fractions were determined by combustion (Carlo Erba NA 1500 autoanalyzer).

Fifty grams of soil (2 mm sieved) were washed on two sieves (top sieve, mesh size 250 μm; bottom sieve, mesh size 150 μm). To destroy all macro-aggregates, soil was forced through the top sieve until the water passing through the sieve became clear. The mineral fraction was separated from the organic fraction by decanting the samples. The organic fractions from both sieves were combined, and referred to as macro-organic matter. The macro-organic matter was separated into three fractions: light (organic residues), intermediate, and heavy (dispersible organo-minerals), using silica suspensions with a density of 1.13 and 1.37 g cm^{-3} as described by Meijboom et al. (1995).

Incubation experiments

Next, 15 g of sieved soil (0–2 mm) was moistened to 80% of field capacity (1.8 kPa), and incubated for 100 days at 28 °C in tightly closed 250-ml flasks. There were five replicates for each soil sample. During the incubation, soil moisture was maintained by placing a plastic tube with 5 ml distilled water in each flask. The air in the flasks was sampled periodically with a 1-ml syringe, and flasks were opened for 10 min every third day to allow for an exchange of gases. Measurements of CO_2 were carried out using an infrared LCA-2 ADC analyzer. The amounts of CO_2 released or C decomposition rate (CDR) were expressed in ‰.

For the second incubation experiment, 5 g of sieved soil (0–2 mm), clay and silt fractions were prepared. All samples were reinoculated, moistened with 1 g l^{-1} soil solution to 80% of the field capacity (1.8 kPa for the whole soil and clay and 3.2 kPa for silt) and incubated for 35 days at 28 °C. There were three replicates for each soil sample and fraction.

Statistics

Statistical analyses (notched-and-whisker box plots and ANOVA) were carried out using the Statgraphics package for PC. The notched-and-whisker box plots provide the mean, the median, and the variance of the data. Thus, the variance of CDR under forest and pastures topsoils was tested at each sampling point.

Results and discussion

The topsoils had the same texture (Table 1), with clay as the dominant component (>80%), and silt as the second highest component (>10%). The C contents of the pasture topsoils were slightly lower than those of the forest topsoil, while their N contents were higher. The C/N ratio was lower in the pasture than in the forest topsoils.

An increase in the weight (%) of macro-organic matter (>150 μm) was observed from the forest (9%) to pasture topsoils, and with increasing age of pasture from P 7 (14.9%) through P 12 (17.5%) to P 17 (21%) (Table 2). The same trend was observed in the heavy fraction (>1.37 g cm^{-3}) of macro-organic matter, as its weight (%) increased from 8.4% (forest) to 20.4% (P 17). The high C/N ratios of the light (<1.13 g cm^{-3}) and intermediate fractions (1.13–1.37 g cm^{-3}) reflected the characteristics of undecomposed organic materials. The C/N ratio of the heavy fraction reflected that of the

Table 1 Texture, and C and N contents of the topsoils. *F* Forest, *P 7* 7-year-old pasture, *P 12* 12-year-old P, *P 17* 17-year-old P

Topsoils	Texture			C and N contents		
	Clay (%)	Silt (%)	Sand (%)	C (%)	N (%)	C/N
F	83.9	10.4	5.7	3.33	0.25	13.3
P 7	81.7	12.1	6.2	2.94	0.29	10.1
P 12	83.7	10.5	5.8	2.92	0.26	11.2
P 17	81.0	10.4	8.6	3.17	0.26	12.2

Table 2 Macro-organic matter (>50 μm) distribution into light, intermediate and heavy fractions. For abbreviations, see Table 1

Top-soils	Weight	Weight		Light (<1.13 g cm^{-3})					Intermediate (1.13–1.37 g cm^{-3})					Heavy (>1.37 g cm^{-3})				
				Weight		C	N	C/N	Weight		C	N	C/N	Weight		C	N	C/N
	(g)[a]	(g)[b]	(%)[c]	(g)	(%)	(%)	(%)		(g)	(%)	(%)	(%)		(g)	(%)	(%)	(%)	
F	51	4.76	9.3	0.34	0.66	43.0	1.5	28.7	0.11	0.22	38.5	1.6	24.2	4.31	8.4	3.8	0.27	14.0
P 7	52	7.7	14.9	0.18	0.35	35.6	1.3	28.5	0.15	0.29	26.7	1.3	20.9	7.40	14.2	3.5	0.32	10.9
P 12	51	8.93	17.5	0.15	0.29	36.1	1.2	30.9	0.10	0.20	28.8	1.2	23.6	8.68	17.0	3.1	0.25	12.4
P 17	47	9.89	21.0	0.18	0.21	33.9	1.2	29.5	0.12	0.38	28.9	1.2	24.5	9.59	20.4	3.5	0.28	12.5

Macro-organic matter fractions (>150 μm)

[a] Weight used for density fractionation
[b] Weight of macro-organic matter
[c] Percentage of macro-organic matter

whole soil (Tables 1, 2). This result confirmed the finding of Hassink (1995) showing an increase in the degree of decomposition of organic materials from light through intermediate to heavy fractions. Thus, with increasing age of pasture, the changes in SOM were due to an increase in the weight of macro-organic matter and its heavy fraction and a decrease in the weight of its light fraction.

In all the topsoils, the proportions of C and N associated with clay were higher than 60% and 40%, respectively, and increased with increasing age of pasture (Table 3). It appeared that the local climate (monthly precipitation lower than 50 mm from July to November) enhanced the increase in organic materials associated with clay in the pasture systems. At the same time, the proportion of organic materials in the sand fractions decreased. This result confirmed the finding of Boissezon et al. (1973) showing the accumulation of organic materials in soil clay fractions. In this study, the accumulated organic material seemed to be humified, probably due partly to the increase in the heavy fraction of macro-organic matter and to local climatic conditions.

The CDR of the four topsoils during 100 days of incubation are shown in Fig. 1. During the first 40 days, the CDR was higher in the forest (20.9‰) than in all the pasture topsoils (18.3‰, 17.6‰, 18.9‰ for P 7, P 12 and P 17, respectively). However, after 100 days of incubation, the CDR was higher in P 17 (43‰), and lower than 34‰ in the other topsoils. Besides the changes in the nature of SOM with increasing age of pasture (Koutika et al. 1997; this study), there was also a decrease in the biological stability of SOM in the oldest pasture soil (P 17). This result suggested that the increase in the weight of macro-organic matter, which constitutes the most active organic pool, might have been partly responsible for the high CDR of this topsoil. It has been observed that organic C in macro-organic matter is much more labile than organic C in

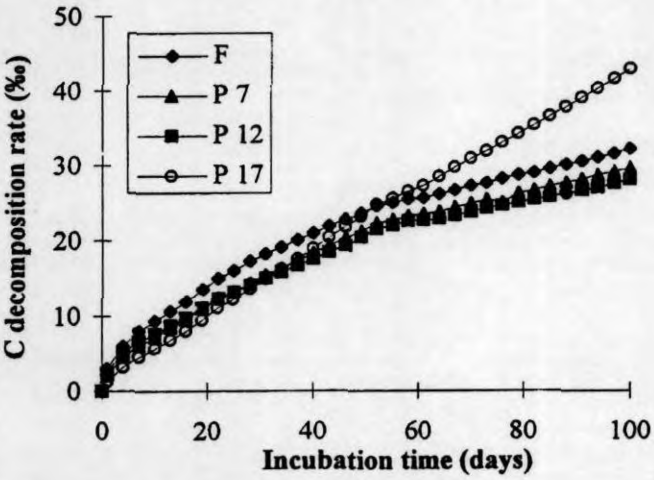

Fig. 1 C decomposition rate of the soil during 100-day incubation at 28 °C. *F* Forest, *P 7* 7-year-old pasture, *P 12* 12-year-old P, *P 17* 17-year-old P

Table 3 C and N contents, and C and N associated with particle-size fractions. For abbreviations, see Table 1

Top-soils	C and N contents of clay fractions			C and N associated with clay in the soil		C and N contents of silt fractions			C and N associated with silt in the soil		C and N associated with sand in the soil	
	C (%)	N (%)	C/N	C (%)	N (%)	C (%)	N (%)	C/N	C (%)	N (%)	C (%)	N (%)
F	2.5	0.20	12.5	63.1	63.7	6.1	0.42	14.5	19.2	17.2	17.7	19.1
P 7	2.3	0.18	12.8	61.6	48.6	4.8	0.43	11.2	19.3	17.3	19.1	34.1
P 12	2.3	0.20	11.5	65.4	63.6	5.3	0.41	12.9	19.1	16.1	15.5	20.3
P 17	2.7	0.22	12.3	68.4	67.3	5.6	0.39	14.4	19.0	15.6	12.6	17.1

clay and silt fractions (Tiessen and Stewart 1983; Dalal and Mayer 1987). In addition, the increase in the heavy fraction of the macro-organic matter in the oldest pasture soil might also have been responsible for the high CDR, especially after 40 days.

The CDRs of the two higher particle-size fractions of the topsoils were determined in order to clarify their contribution to the CDR of the whole soil (Fig. 2). During 35 days of incubation, the CDRs of the whole soil and clay fraction of the forest were higher than those of the pasture topsoils. The CDR of the silt fraction of P 17 was higher than that of the others. Even though the silt fraction represented less than 15% (w/w) of each topsoil, and the proportion of C was low compared to that of the clay fraction, it contributed highly to the CDR during the first 40 days of incubation. The decomposition of organic materials associated with silt was rapid in this study. Thus, in the 100-day incubation, the organic material associated with clay was responsible for the high C decomposition rate of the oldest pasture topsoil, especially after 40 days. At this point, the saturation point of the clay fraction with respect to its adsorption of organic compounds could have been reached, as argued by Hassink (1995), due partly to high levels of C associated with clay and to high levels of macro-organic matter in this topsoil.

Finally, this study confirmed the changes in SOM occurred in the topsoils after pasture creation and with increasing age of pasture by increases in both negative charges and clay dispersibility (Koutika et al. 1997). With increasing age of pasture, increases in C, associated with the different clay fractions, and increases in macro-organic matter, especially in the heavy fraction, were found. These changes seemed to be responsible for the high CDR in the oldest pasture soil. Thus, the density fractionation of macro-organic matter combined with the CDR can be used to evaluate changes in the nature of SOM in the topsoil of pastures created from clear-felled tropical forest.

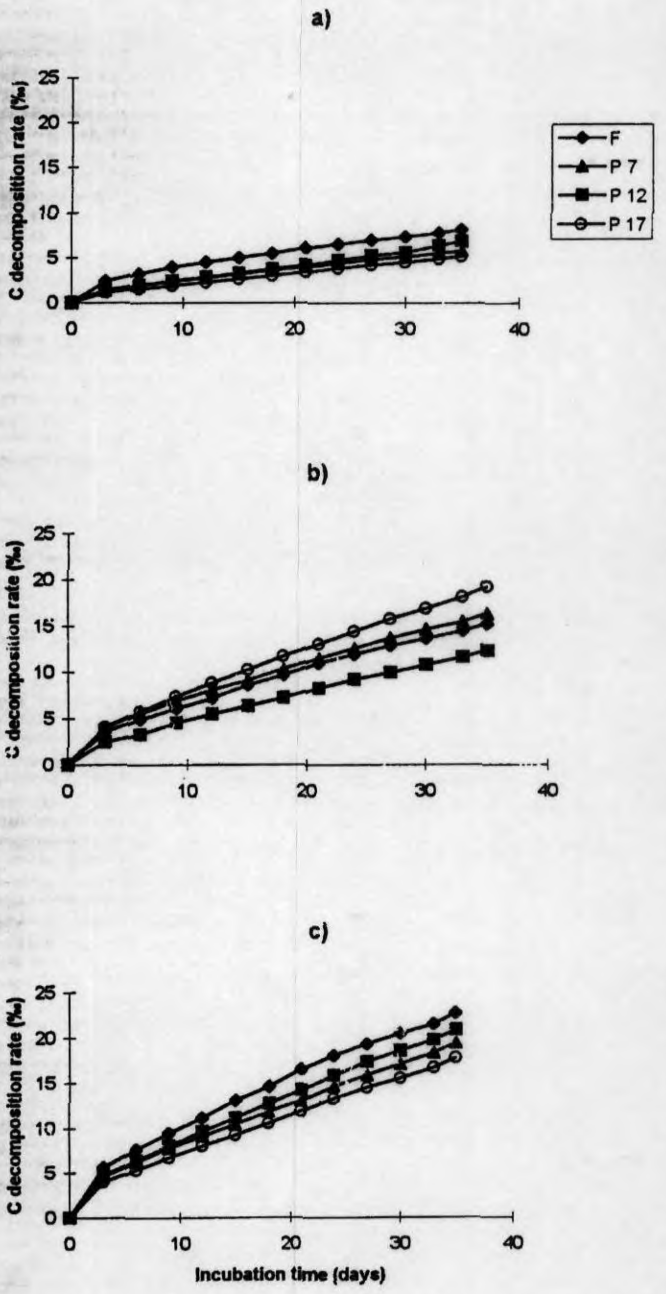

Fig. 2 C decomposition rate of the soil (**a**), silt (**b**), and clay (**c**) fractions during 35 days of incubation at 28 °C. For abbreviations, see Fig. 1

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