SIZE-DENSITY AND ISOTOPIC FRACTIONATION OF SOIL ORGANIC MATTER AFTER FOREST CONVERSION

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1. ABSTRACT

The ability to understand soil organic matter dynamics in forest-derived soils is essential in the search for more intensively managed and environmentally sound and sustainable practices. Evaluation of sustainability of newly developed systems requires sensitive methods that allow an early detection of changes in soil fertility before degradation becomes apparent.

Soil samples from under different humid tropical land use systems were obtained from intact as well as recently converted forests, under I) rubber/rice systems and Imperata grassland in Sitiung, Indonesia, and under ii) *Peltophorum dasyrachis* and *Gliricidia sepium* woodlots, *Imperata* grassland and sugarcane plantations at Lampung, Indonesia. Soil was sieved and the 0.15 - 2 mm size fraction was then separated by density (<1.13, 1.13-1.3, > 1.3 g cm^{-3}). The fraction dry weights suggested that land use systems without burning, soil cultivation and intensive weeding can maintain soil organic matter close to forest levels, but in frequently burnt Imperata grasslands stocks are depleted.

The origin of soil organic matter from rainforest and crops was determined by $\delta^{13}C$ methodology for a forest - sugarcane conversion series in Lampung, as well as a pure *Brachiaria humidicola* pasture and a *B. humidicola-Desmodium ovalifolium* mixture after rainforest clearing in Bahia, Brazil. Results showed that rainforest plant species at both sites were mainly C_3 plants differing in ^{13}C content with the C_4 sugarcane and grass pasture, and thus allowed identification of the soil-C origin from the two groups. Loss of rainforest-C after clearing amounted to around 50% under both sugarcane and pastures nine and eight years after rainforest clearing respectively. The contribution of crops to the buildup of new soil organic matter was higher in the pasture systems than under sugarcane presumably due to burning activities and associated loss of organic matter inputs in the sugarcane system.

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$\delta^{13}C$ methodology for a forest - sugarcane conversion series in Lampung, as well as a pure *Brachiaria humidicola* pasture and a *B. humidicola-Desmodium ovalifolium* mixture after rainforest clearing in Bahia, Brazil. Results showed that rainforest plant species at both sites were mainly C_3 plants differing in ^{13}C content with the C_4 sugarcane and grass pasture, and thus allowed identification of the soil-C origin from the two groups. Loss of rainforest-C after clearing amounted to around 50% under both sugarcane and pastures nine and eight years after rainforest clearing respectively. The contribution of crops to the buildup of new soil organic matter was higher in the pasture systems than under sugarcane presumably due to burning activities and associated loss of organic matter inputs in the sugarcane system.

2. INTRODUCTION

When forests are converted into agricultural use, either temporary or permanent, the forest soil provides a rich heritage for the new crops or trees, both by its structure (including 'old tree root channels' VAN NOORDWIJK *et al.*, 1991), chemical content (especially when the litter layer and biomass were turned into ash) and organic matter content. Decline of soil organic matter content is widely seen as a major factor in the decrease of soil fertility and crop yields after forests are converted for agricultural use. The total organic C content of the soil (C_{org}), however, is not a very sensitive indicator of initial changes. Development of improved soil management practices would be easier if more sensitive indicators were available. A number of fractionation methods have been developed for soil organic matter in the past decade. Here we will focus on two of them, one based on size/density fractionation (MEIJBOOM et al., 1995) and one based on the $^{12}C/^{13}C$ isotope ratio (CERRI et al., 1985).

A variety of models are in use for describing soil organic matter turnover by dividing the total C_{org} content into pools with different turnover times. Most of these models involve a small active pool with a short turnover time and one or more pools of greater size and slower turnover rates. Methods to measure the active pool (mainly microbial biomass and byproducts) have been successfully established, but operational definition of slower soil organic matter pools has been less successful. As decomposition depends on both the chemical nature and the physical accessibility of organic pools in the soil, a combination of physical and chemical fractionation methods may be needed to quantify the slow pool in such models.

Particle size analysis (TIESEN and STEWARD, 1983; CHRISTENSEN, 1992; BONDE *et al.*, 1992) has shown that organic carbon in the sand size fraction of forests is lost most rapidly after forest conversion. Density separation of this size fraction may reflect early changes in soil organic matter contents under different land use systems even more closely (HASSINK, 1994). The physical density indicates the degree of organic-mineral bonding. Initial results with this method for tropical soils are encouraging (BARRIOS *et al.*, *submitted*).

Isotopic ^{13}C fractionation in plants has been used to trace the fate of recent organic inputs and to follow the decay of soil organic matter (CERRI et al., 1985). The natural ^{13}C abundance of soil organic matter corresponds closely to that of the vegetation from which it originated. Consequently, in tropical forests where most of the trees are C_3 plants the surface soils have $\delta^{13}C$ values between -25 and -30 %o. Many of the tropical grasses currently used for pasture improvement, as well as sugarcane possess a C_4 photosynthetic pathway for which $\delta^{13}C$ values from -8 to -18 %o are common. This isotopic difference thus allows to follow the dynamics of the incorporation of new carbon when a C_4 plant is cultivated on a soil cleared from a C_3 forest or vice versa. The technique also allows to distinguish between grass and legume derived soil organic matter in cases were an appropriate pure grass control is available (CADISCH et al., 1995). Differences in isotopic signature between various soil organic matter fractions together with information on the length of time since the changeover from one vegetation type to the other will allow assessment of relative turnover rates of the fractions and help establish models based on measurable pools.

The objective of the current investigation was to (partially) test the following hypotheses:

1. Size density fractionation methods allow a rapid detection of changes in

functionally important soil organic matter pools after forest conversion,

2. Isotopic fractionation can be used to identify forest SOM pool that resists decomposition after forest conversion,
3. Land use systems without fire and soil tillage allow maintenance of SOM pools close to the original forest soil.

[Table 1]

3. MATERIALS AND METHODS

3.1 Study sites

Data are presented from three study sites, two in Sumatera (Indonesia), one in Brasil. Table 1 gives some soil characteristics of the forest soil before clearing and land use change.

Lampung, Sumatera, Indonesia (4⁰ 30' S, 104⁰ 58' E, elevation 50 m a.s.l., average annual rainfall 2300 mm): The soil was classified as a Grosarenic kandiudult (VAN DER HEIDE et al., 1992). Samples were taken from various experiments and land cleared from (logged over/ secondary) forest by slash and burn in the past ten years for a sugar cane plantation (Bunga Mayang, PTP X).

Soil samples (0-15 cm) for ^{13}C determinations were taken in June 1994 from two nine year old sugarcane fields established after clearing of secondary rainforest. As control samples from a nearby remaining forest were sampled. In each field, three samples consistent of 10 subsamples each were taken from 10x10 m areas 50 m apart. Samples were sieved (2 mm), dried and finely ground before analysis.

Sitiung (Tarantang Panjang village), W. Sumatera, Indonesia (1⁰ 10' S, 101⁰ 42' E, elevation 100 m a.s.l., average annual rainfall 2700 mm): Samples were taken from the 0-20 cm depth layer of a secondary forest, a neighbouring plot cleared by slash-and-burn half a year before sampling and planted with upland rice and rubber (with thick bush regrowth), a neigbouring plot with 3-year rubber (and a dense weedy undergrowth) and a regularly burnt *Imperata* grassland.

Bahia, Brasil (15° 30' S, 39° 00' W, elevation 100 m a.s.l., average annual rainfall 2300 mm): Soils samples were taken in October 1993 from a pasture experiment and from a nearby rainforest (100-200 m away) at the Animal Husbandry Station, ESSUL/CEPEC/CEPLAC; Itabela, Bahia, Brazil . Soil samples (0-15 cm) in the pasture experiment were taken from a pure grass (*B. humidicola*) and from a mixed grass/legume (*B. humidicola/D. ovalifolium*) treatment at a low stocking rate (2 animals/ha) established 1987/88 (PEREIRA, 1990), plot 25) after rainforest clearing in 1985. The soils were classified as Haplorthox (Oxisol), with a pH (H_2O) of 5.3 and 6.1 under the rainforest and the pastures, respectively. The samples consisted of 10 composite subsamples, taken from representative 10x10 m areas. Samples were sieved (2 mm) dried and finely ground prior to analysis.

3.2 Soil fractionation

A size density fractionation for soil organic matter was followed from MEIJBOOM *et al.* (1995), based on a silica suspension LUDOX (produced by Du Pont). Soil samples were collected from difference sites and land use systems, and rewetted overnight before it is fractionated. Figure 1 shows a scheme of the procedure. Rewetted soil (500 g) was thoroughly mixed and sieved through a 2 mm sieve and then, with flowing water, through two superimposed sieves of 250 and 150 μm mesh. All materials retained on 250 and 150 μm sieves were washed and swirled to separate macroorganic matter and mineral materials (sand) by decanting. Swirling and decanting was repeated several times until no floating materials remained. The macroorganic matter was placed in a 150 μm sieve and immersed in a ludox suspension (bulk density 1.13 g cm^{-3}) and allowed to sit for about 10 minutes. The floating fraction was collected as light fraction, the material from the bottom of the sieve was transferred to a higher density (1.30 g cm^{-3}) of Ludox suspension. Floating material was collected as intermediate fraction and the material that settled on the bottom as heavy fraction, respectively. Each fraction was dried in the oven at 70°C and weighed. There are thus fractions: (a) Light fraction, which has particle density < 1.13 g cm^{-3} and consists of recognizable plant residues, (b) Intermediate fraction, which has particle density 1.13 - 1.37 g cm^{-3} and is partly humified material, and (c) Heavy fraction, which has particle density > 1.37 g cm^{-3} and consists of undefined (amorphous) organic material.

[Fig. 1]

3.3 Carbon isotope analysis

Carbon isotope ratios were measured on a VG622 mass-spectrometer coupled to an automated CN analyzer (Roboprep, Europa Scientific). The laboratory reference was calibrated against Pee Dee Belemnite (PDB), using the IAEA standard 303. Isotope ratios are expressed as $\delta^{13}C$ values,

$$\delta^{13}C‰ = \left[\frac{(^{13}C/^{12}C)\ sample}{(^{13}C/^{12}C)\ reference} - 1\right] 1000 \qquad 1)$$

where reference is PDB.

Where a C_4 species is cultivated over a native C_3 vegetation its contribution to soil organic matter build up can be directly obtained (CERRI, 1985). The proportion of soil organic matter derived from the C_4 grass *B. humidicola*, $f_{g(G)}$, in the pure grass pasture was calculated using the following relationship:

$$f_{g(G)} = \frac{\delta_{(G)} - \delta_{(RF)}}{\delta_g - \delta_{(RF)}} \qquad 2)$$

where $\delta_{(G)}$ is the $\delta^{13}C$ value of the soil under the pure grass pasture (G), $\delta_{(RF)}$ the $\delta^{13}C$ of the rainforest (RF) and δ_g is the $\delta^{13}C$ value of *B. humidicola* plant material (g).

In order to estimate the legume (*D. ovalifolium*) contribution to soil organic matter build up in the mixed pasture it was assumed that the decay of rainforest organic matter was similar to the one under the pure *B. decumbens* pasture. Thus the proportion of legume derived C in the mixed pasture (GL) be obtained (CADISCH et al., 1995) by maintaining the ^{13}C balance:

$$f_{l(GL)} = \frac{1}{\delta_l - \delta_g} [\delta_{(GL)} - \delta_g + \frac{C_{(G)}}{C_{(GL)}} (\delta_g - \delta_{(G)})] \qquad 3)$$

where δ_l is the $\delta^{13}C$ value of *D. ovalifolium* plant material and $\delta_{(GL)}$ is the $\delta^{13}C$ value of the mixed pasture, $C_{(G)}$ the total amount of carbon in the pure grass pasture and $C_{(GL)}$ the total carbon content of the mixed pasture.

[Fig. 2] Sitiung

4. Results

4.1 Soil Organic Matter Distribution under different Land Use Systems

Results for Sitiung (Figure 2), where secondary forest was converted into rubber with initial rice intercrops but abundant shrub/weed growth, show that the Ludox fractions in the 0-20 cm depth layer may even increase in dry weight compared to the forest soil. Relative increases were highest for the light and intermediate fraction. Data for a nearby site under regularly burnt *Imperata*, after a number of years of intensive food crop production after forest clearance, show that the dry weight of all fractions was greatly reduced.

[Fig. 3]

Data for Lampung (Figure 3) show that topsoil (0 - 5 cm depth) organic matter fractions may decrease when forest soils are compared with nearby converted sites, under woodlots or *Imperata* (provided this is not burnt). In the 5-15 cm depth layer, however, the converted forest sites exceeded the forest. Total content of the Ludox fractions (in g/kg of soil) for this second layer is only 20-50% of that in the top 5 cm. In the 5-15 cm soil layer the heavy fraction is dominant over the light and intermediate fraction in dry weight (and probably also in C content, data forthcoming).

[Fig. 4]

Total soil organic matter content and associated Ludox fractions were obtained from soils under sugarcane with different ages after rainforest clearing in Lampung (Fig. 4). Total soil carbon was highly variable but showed a trend to decline with increasing time after clearing; an exponential regression indicated a 3.6% decrease per year, for the first 9 years. For the Ludox fractions, the forest values were markedly higher than the first point under sugarcane (1.75 years after forest conversion at the time of measurement), especially for the intermediate and heavy fractions (a nearly 50% reduction). After this initial drop, all three fractions continued to decline with 5-7% per year. The relatively small decline of the light fraction suggests that sugarcane contributes primarily to this fraction.

[fig. 5]

4.2 Soil Carbon Disappearance and Build Up after Rainforest Clearing

Soil samples from under sugarcane (Lampung, Indonesia), from under pastures (Bahia, Brasil) and from under the respective nearby secondary rainforests were analyzed for their ^{13}C signature in order to estimated the contributions of the different vegetations to total soil organic matter (figure 5). Soil form under secondary rainforest collected in Lampung, Sumatra and Bahia, Brazil had very variability of the Ludox results. A second problem with the Ludox method is that the decantation step, which removes most of the sand particles, is subject to between-operator variability. This clearly affects the dry weight results for the heavy fraction, but it may be less so if total C content of the fractions is measured (data forthcoming).

Hypothesis 2. 'Isotopic fractionation can be used to identify forest SOM pool that resists decomposition after forest conversion'

Data presented here confirm the value of isotopic fractionation where a C_3 forest is converted to a C_4 grass vegetation. Applying this isotopic fractionation method to the Ludox fractions obtained from the forest - sugarcane series will throw further light on the differences in dynamic behaviour of these fractions (data forthcoming).

Hypothesis 3. 'Land use systems without fire and soil tillage allow maintenance of SOM pools close to the original forest soil'

Forest clearing and cultivation leads to a loss of 53% of native forest soil carbon after eight to nine years (Fig. 5). A rapid initial decline of soil organic matter after secondary rainforest clearing has been observed by SANCHEZ et al. (1983) with 25% lost in the first year confirming preliminary observations at Lampung. CERRI et al. (1985) similarly found a rapid decline in forest soil C of 51% during the first twelve years under sugarcane and a much smaller decrease during the following years. The loss of forest C in the former study appeared to be mainly associated with a loss of C in the sand fractions (88%) while in the clay only 40% of the forest derived C decomposed during the initial 12 years of cropping.(BONDE et al., 1992). This findings support the use of sand size fractions as a basis of a more dynamic soil organic matter pool for further density separation as reported above.

The loss of soil organic matter was only partly compensated by the build up of new carbon derived from the crops. Pastures and particularly sugarcane crops induced a lower equilibrium level of soil organic matter, partly because of reduced organic inputs and removal of the harvest. Sugarcane contributed less to organic matter build up compared to the pastures. This is probably not due to a lower primary production rate of the sugarcane, but to the different management practices. Under sugarcane in Lampung intensive soil tillage is performed at planting time and the leave biomass is burned at harvest, while structural carbon from the stems is only occasionally returned to the fields as filter cake. Thus after nine years under sugarcane the total soil carbon amounted only 64% of the amount under native forest. In contrast under grass pastures the build up of new carbon leads to a restoration of original soil carbon level of 78%. In the mixed pasture the legume contributed about 40% to newly formed organic matter. This is consistent with a high (30-50%) legume proportion in this pasture achieved due to the low stocking rate used (J.M. Pereira, personal communication). Lower over all organic matter contribution from mixed pastures compared to pure grass pastures may be mainly due to the lower productivity of the legume component.

The Ludox data show that forest conversion into rubber plantations under extensive management (allowing large amounts of weeds and shrub undergrowth) does allow to maintain the soil organic matter content of the secondary forest. *Imperata* fallows may maintain or even restore soil organic matter content, as long as they are not frequently burnt (Fig. 3). Where the *Imperata* fallow is frequently burnt (Figure 2+3), its contribution to soil organic matter amelioration appears to be low.

Development of soil management strategies which conserve organic material within the system, e.g. by avoiding burning practices at harvest in sugarcane plantations as currently promoted in Brazil, will help to maintain higher soil organic matter levels and may even maintain them at values close to those of forest soil.

6. Acknowledgements

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7. References

BARRIOS, E., R.J. BURESH and J.I. SPRENT (1995?) Organic matter in soil particle size and density fractions from maize and legume cropping systems. Soil Biol. Biochem. (*submitted*)

BONDE, T.A., B.T. CHRISTENSEN, and C.C. CERRI (1992): Dynamics of soil organic matter as reflected by natural ^{13}C abundance in particle size fractions of forested and cultivated Oxisols. Soil Biol. Biochem. 24, 275-277.

CADISCH, G., H. IMHOF, S. URQUIAGA, and K.E., GILLER (1995): Carbon ($\delta^{13}C$) turnover and nitrogen mineralization potential under different land use systems after rainforest clearing. Soil Biol. Biochem., *in press.*

CERRI, C.C., J. BALESDENT, C. FELLER, R. VICTORIA, and A. PLENECASSAGNE (1985): Application du tracage isotropique naturel en ^{13}C à l'étude de la dynamique de la matière organique dans les sols. Comted Rendus de l'Acad. des Sci. de Paris., T. 300, Serie II 9, 423-428.

CHRISTENSEN, B.T. (1992): Physical fractionation of soil and organic matter in primary particles and density separates. Adv. Soil Sci. 20, 2-90.

HASSINK, J. (1994): Active organic matter fractions and microbial biomass as predictors of N mineralization. in: J.J. Neeteson and J. Hassink (eds.) Nitrogen mineralization in agricultural soils. Proc. Symp. Haren (Nl), 19-20 April 1993. AB-DLO, Haren, pp 1-15.

MEIJBOOM, F. W., J. HASSINK and M. VAN NOORDWIJK, (1995): Density fractionation of soil macroorganic matter using silica suspensions. Soil Biol. Biochem., in press.

PEREIRA, J. M. (1990): PhD Thesis, University Federal de Viçosa, Brasil.

SANCHEZ, P. A., J.H. VILLACHICA, and D.E. BANDY (1983): Soil fertility dynamics after clearing a tropical rainforest in Peru. Soil Sci. Soc. Am. J. 47, 1171-1178.

TIESEN, H and J. W. B. STEWARD (1983): Particle size-fractions and their use in studies of soil organic matter. II. Cultivation effects on organic matter composition in size fractions. Soil Sci. Soc. Am. J. 47, 509-514.

VAN DER HEIDE, J., S. SETIJONO, SYEKHFANI, E.N. FLACH, K. HAIRIAH, S. ISMUNANDAR, S.M. SITOMPUL AND M. VAN NOORDWIJK (1992): Can low external input cropping systems on acid upland soils in the humid tropics be sustainable? AGRIVITA 15: 1-10

VAN NOORDWIJK, M., WIDIANTO, M. HEINEN and K. HAIRIAH (1991): Old tree root channels in acid soils in the humid tropics: important for crop root penetration, water infiltration and nitrogen management. Plant Soil 134: 37-44.

VOLKOFF, B. and C.C. CERRI (1987): Carbon isotopic fractionation in subtropical Brazilian grassland soils. Comparison with tropical forest soils. Plant Soil 102, 27-31.

Table 1: Soil pH, texture and total C of soil from under rainforest from the three different locations (0-15 cm depth)

	Soil pH H_2O	Tot. C %	Soil texture		
			Sand %	Silt %	Clay %
Lampung	4.6	1.4	68	12	20
Sitiung	4.6	1.5	38	14	48
Bahia	5.3	1.9	81	2	17

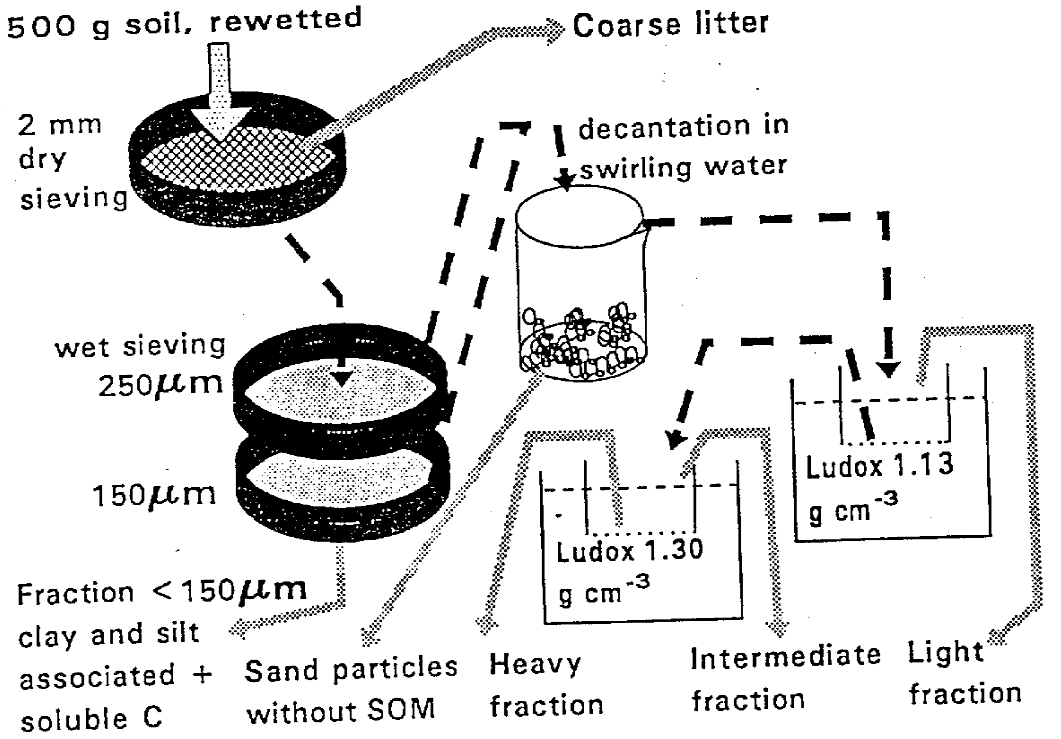

Figure 1: Scheme for fractionation of soil organic matter (SOM) based on size (0.15 - 2 mm) and physical density, based on MEIJBOOM *et al.* (1995)

Figure 2: Soil fractions from the 0-20 cm depth layer of a secondary forest, a neighbouring plot cleared by slash-and-burn half a year before sampling and planted with upland rice and rubber (with thick bush regrowth), a neigbouring plot with 3-year rubber (and a dense weedy undergrowth) and a regularly burnt *Imperata* grassland in Sitiung, Indonesia

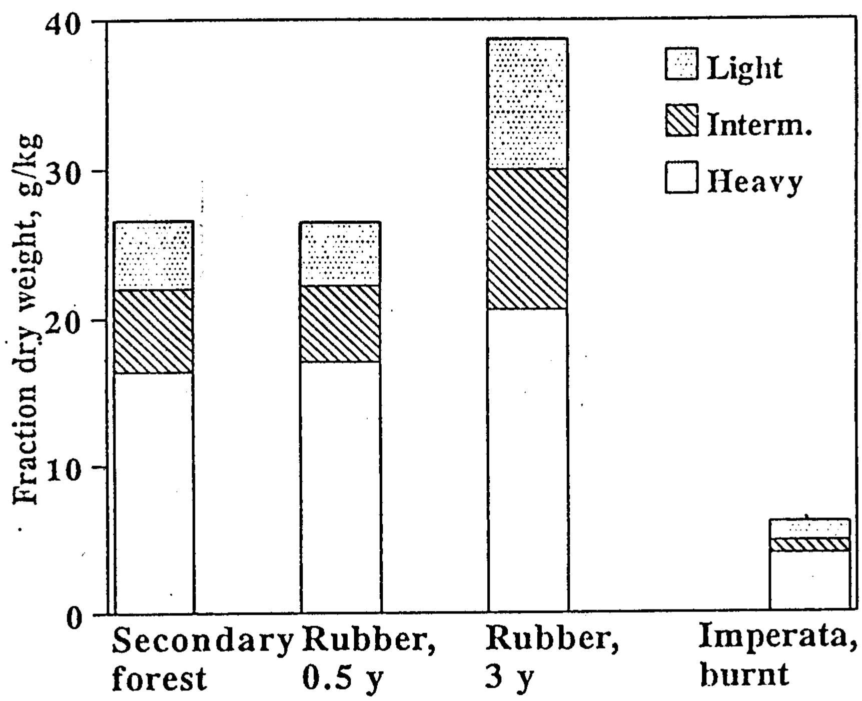

Figure 3: Soil fractions from the 0-5 and 5-15 cm depth layers under different land uses in Lampung, Indonesia (note the difference in scale of the Y-axis)

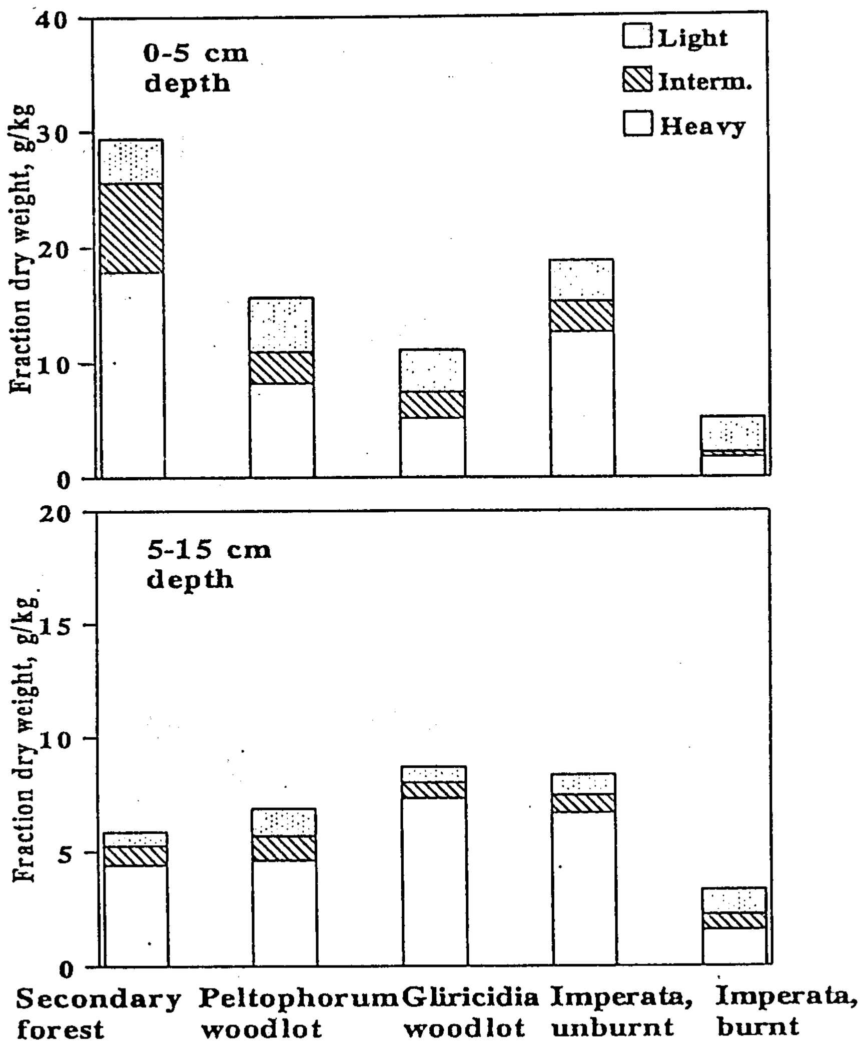

Figure 4: Soil fractions and C_{org} content of the 0-.. cm depth layer of sugarcane land derived from secondary forest at different times in Lampung, Indonesia

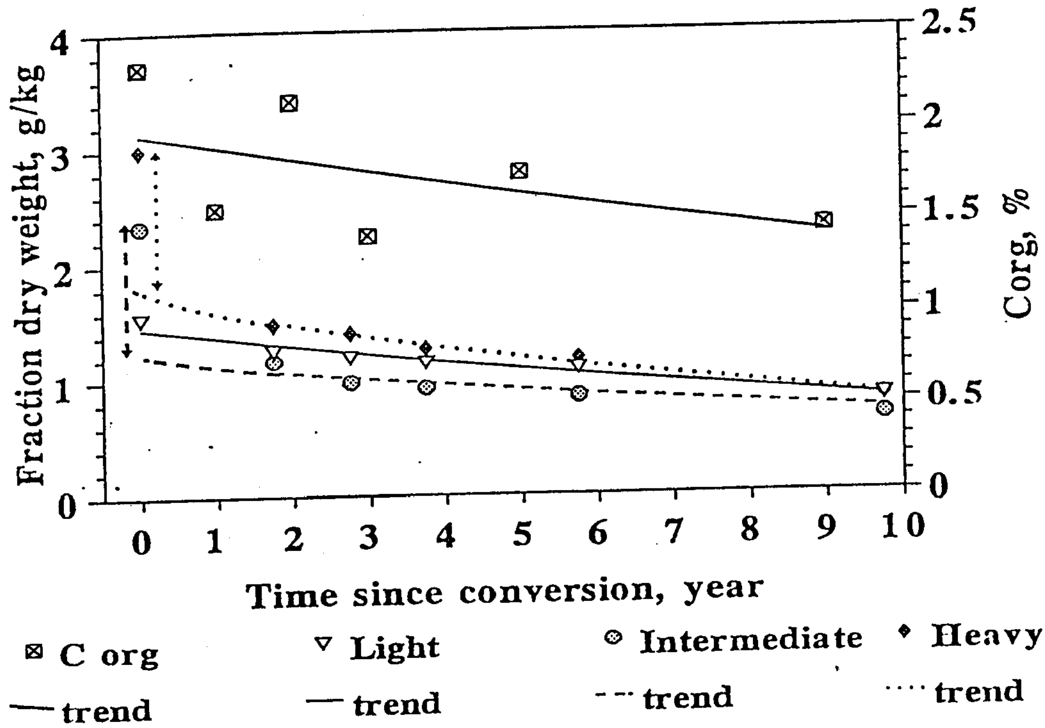

Figure 5: Soil organic matter derived from the forest and from the vegetation after forest clearing, estimated from the $\delta^{13}C$ value. Left: nine years after forest - sugarcane conversion in Lampung Indonesia; Middle: eight years after forest - pasture conversion in Bahia, Brasil; Right: *idem*, in the presence of a legume component in the pasture. Values in brackets represent total soil carbon content of undisturbed rainforest control samples