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# Consequences of clearing and tillage on the soil of a natural Amazonian ecosystem

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ABSTRACT

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A comparative study was performed in the Oriental Amazon region of Brazil, on an experimental area of yellow latosol and red-yellow podzolic soils. Taking the forest soil as a reference, the chemical, physical, and micromorphological changes occurring after sequential burning, tillage and fallow-land were studied. Deforestation and tillage were responsible for a decreasing content and qualitative changes in organic matter; fulvic acid content first increased, then humic acid content decreased, giving rise to an increasing destruction of clay/organic complexes in the A horizon. As a result, a greater dispersion and migration of fine particles occurred, causing the obstruction of macropores and an increase in bulk density. Crop production decreased in two years, and the soil had to be abandoned. A secondary vegetation developed, and yielded organic residues which stimulated faunal activity. After three years under fallow, the above observed soil degradation processes were partially reversed.

## INTRODUCTION

In tropical forests, especially in the Amazon Basin, the most traditional form of land use consists of clear felling, removing the economically important trees, and burning the remaining aerial biomass. Besides numerous climatic and ecological alterations (Queiroz Neto and Bentancourt, 1979; Sioli, 1980; Baiardi, 1981; Fearnside, 1982; Salati, 1983), deforestation is also expected to bring about important changes in soil characteristics (Shubart, 1983; Martins and Cerri, 1986b). There is relatively little information about the nature of such changes; most of the data concern forest production and structure, and are generally dispersed and difficult to compare (Klinge, 1983).

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However, it was reported that deforestation induces decreases in the activity of soil microorganisms (Santos and Grisi, 1981; Cerri et al., 1985), in soil porosity (Chauvel, 1982; Chauvel et al., 1991, this volume), and modifies the amount and nature of soil organic matter (Manarino et al., 1982). The absence or modification of plant cover also bring about changes in soil temperature (Mauri, 1979; Diniz and Bastos, 1980; Santos and Grisi, 1981) as well as in water infiltration (Franken et al., 1982).

Among the different kinds of cropping systems, annual crops are probably those which show the most immediate effects, although there are differences according to soil natural fertility. Burning brings about a temporary increase in available nutrients (Brinkman and Nascimento, 1973), but soil productivity often dramatically decreases after two or three years, and the area has to be left under fallow for several years. Up to now, in eastern Amazonia, there was no systematic and integrated study of soil physical and chemical changes due to deforestation and increasing croping time, under low-input agriculture conditions. Results obtained on this topic at the Experimental Farm of the EMBRAPA (Empresa Brasileira de Pesquisa Agropecuaria) in Capitão Poço, Pará State, Brazil, are summarized in the present paper.

## MATERIAL AND METHODS

### *Sampling sites and soils*

Exhaustive site descriptions were previously published by Martins and Cerri (1986a), and Martins (1987). The studied area is located in the eastern Amazon, north east of Pará State, between the Guamá and Irituia rivers, latitude 1°40′S, longitude 47°04′W. This area receives about 2500 mm of precipitation per year, of which 90% is distributed between January and September, with a maximum in March (423 mm), and a minimum in October (45 mm). The average annual temperature is 26.9°C, with a maximum in July (27.9°C), and a minimum in January (25.5°C).

The soils are developed on tertiary sediments belonging to the Barreiras formation (Nunes et al., 1973), and are predominantly medium-textured 'Latossolos podzólicos' and 'Latossolos podzolizados' (Rego et al., 1973). Although the topography is frequently horizontal or very slightly undulating, these soils present, in their upper 1.0–1.50 m, noticeable local changes in texture, bulk density, aggregation, and mottling intensity. They all present an A horizon (subdivided into A11, A12 and A3 sub-horizons), which is about 0.20 m thick, a B1 massive horizon, which is about 1.00–1.50 m thick, and a B2 latosolic horizon, which is often more than 0.70 m thick. The texture is sandy loam in the A horizon (8–10% silt, and 15–25% clay), sandy-clay loam in the B1 horizon (about 10% silt and 25–40% clay), and sandy-clay-loam to

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clayey in the B2 horizon (Martins, 1987). The predominant materials are quartz in the coarse fraction, and kaolinite in the fine fraction.

Under the native forest, three sites differing by the local drainage conditions were chosen, and designated as poorly, moderately, and well-drained soils. Each site represented an area of about 900 $m^2$ of the forest. The other selected neighbouring sites were as follows: recently burned (50×100 m); one-year cultivated (80×130 m); five-year cultivated (50×50 m); and two-year cultivated then three-year abandoned ('Capoeira', or fallow – 100×100 m) systems. In the last four sites the vegetation was eliminated by axe-cutting and burning. After this process, the branches were jointed and burned. The stems remained in place, except in the site cultivated for one year, where the thinner stems (i.e. those less than 0.80 m in circumference) were sawed and jointed in a 5-m large band in the center of the site, and burned. In the site cultivated for one year, rice and cowpea were planted, respectively three months and eight months after burning. The sites cultivated for three and five years had two annual crops, alterning rice or maize with cowpea.

Soil and crop management were the same in all sites during the cultivation, and included two hoeings per crop without fertilization, and hand-harvesting. Then the crop residues remained on the soil surface. The five-year-cultivated system did not represent an actual field situation, and was designed for experimental purpose only. It did not produce more than 100 kg maize grain $ha^{-1}$ after the third year.

### *Analytical methods*

In each site, the soil samples were collected from a pit, and from three places chosen at random, except in the site cultivated for five years, where only two places were chosen, due to the reduction of the site size to 12×24 m after the fourth year. Undisturbed samples were designated for bulk-density determinations, and thin-sections preparation (Martins, 1987). The loose dry soil material was sieved at 2 mm, and its pH value, exchangeable cations and acidity, and total carbon content were determined. Soil texture was determined after dispersion in 0.1*M* sodium hexametaphosphate solution (hex), and in distilled water (wat), with and without previous destruction of organic matter with hydrogen peroxide, respectively (Martins et al., 1989a,b). The flocculation degree was calculated as follows:

(clay(hex)–clay(wat))/clay(hex)

Soil organic matter (SOM) was fractionated according to particle size by wet-sieving in water. The 0–50-$\mu$m organo-mineral fraction was fractionated into acid-soluble humic acids, alkali-soluble, acid-insoluble fulvic acids, and acid-insoluble, alkali-insoluble humin, according to Dabin's (1971) chemical procedure (Martins et al., 1989a,b).

## RESULTS AND DISCUSSION

### *Soils of the natural ecosystem*

In the study area, the soils present an original pedological organization, characterized by a natural compaction, which increases with increasing clay content, i.e. generally in the 0.20–0.50-m soil layer. The intensity of this phenomenon is variable, and influences drainage conditions. The well-drained profile has a larger proportion of SOM in the whole A horizon, and in the 0–50-$\mu$m fraction, than the two other soil profiles (Table 1). These amounts of SOM are directly correlated with litter production and flocculation degree of clay particles (Martins et al., 1989a). In the 0–50-$\mu$m fraction, the amount of humic acids and their proportion relatively to fulvic acids are maximum in the well-drained profile (Fig. 1). There is, however, an inverse correlation between the humification degree of SOM and the hampering of drainage, as shown by the decrease of humic-acid content with increasing clay content and with decreasing flocculation degree (Martins et al., 1989a).

### *Macro- and micromorphological changes in the modified systems*

In the soil of the recently burned area, no important morphological change was observed, except the disappearance of the litter, which is replaced by a heterogeneous ash layer. After one year of cultivation, the thickness of the

TABLE 1

Organic carbon distribution in the litter and the A horizon (0–0.15 m) in three neighbouring sites affected by different drainage conditions, under native rain forest (1, poorly drained soil; 2, moderately drained soil; 3, well-drained soil)

| Soil fraction | Organic carbon | | | | | |
|---|---|---|---|---|---|---|
| | (kg ha$^{-1}$) | | | (% total) | | |
| | (1) | (2) | (3) | (1) | (2) | (3) |
| Leaf fragments | 1762 | 2373 | 3062 | 27.1 | 49.7 | 43.2 |
| Twig fragments | 3701 | 1936 | 2661 | 57.0 | 40.5 | 37.5 |
| Living roots | 41 | 22 | 128 | 0.7 | 0.5 | 1.8 |
| Unident. fragments | 987 | 447 | 1236 | 15.2 | 9.3 | 17.5 |
| Total litter | 6491 | 4778 | 7087 | 100.0 | 100.0 | 100.0 |
| 200–2000-$\mu$m fraction | 6880 | 7260 | 5240 | 31.0 | 33.0 | 21.0 |
| 50–200-$\mu$m fraction | 3990 | 4180 | 5990 | 18.0 | 19.0 | 24.0 |
| 0– 50-$\mu$m fraction | 11320 | 10570 | 13730 | 51.0 | 48.0 | 55.0 |
| Total A horizon | 22190 | 22010 | 24960 | 100.0 | 100.0 | 100.0 |
| Litter+A horizon | 28681 | 26788 | 32047 | | | |

2b

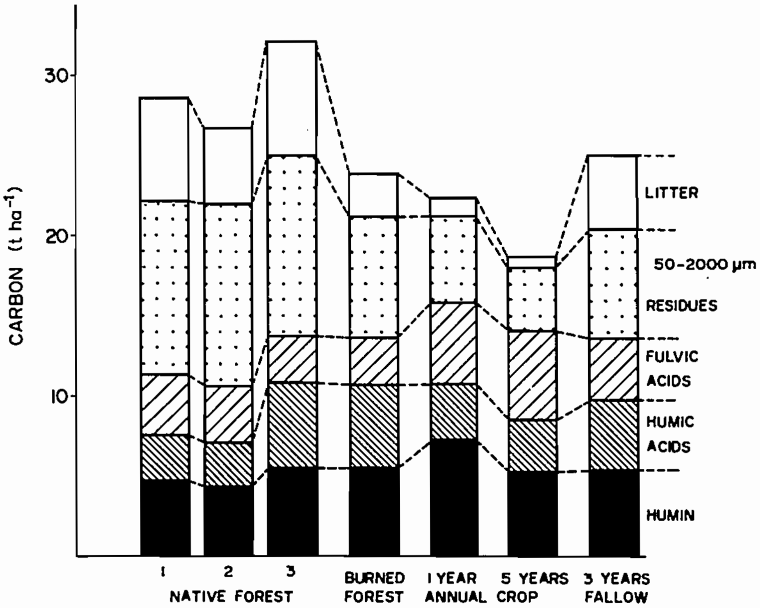


Fig. 1. Comparison of organic carbon distribution in the A horizon of a Latosol from Eastern Amazonia under native forest (1, poorly drained soil; 2, moderately drained soil; 3, well-drained soil) and traditional agriculture.

A11 and A12 horizons decreased by a few cm, and the compaction of the A3 horizon increased. Destruction of micro-aggregates in the A12 horizon and formation of argilans in the A3 horizon were frequently observed. The intensity of these degradation features increased in the soil of the five-year cropped area, in which the differentiation between the A11 and A12 horizons vanished. The presence of mottling features in the A3 horizon, especially the segregation between clay mineral and ferric iron cutans, and an increasing textural heterogeneity in the B horizon matrix, were noticed.

Most of these degradation features were no longer present in the soil abandoned for three years, as observed elsewere under 'capoeira' vegetation (Chauvel, 1982). An incipient A11 horizon was clearly identified, in relation to an intense mesofaunal pedoturbation. Fecal pellets were present in both A and B horizons, fresh residues from the secondary vegetation were incorporated into the soil mineral matrix., and there was no further evidence of clay cutans and textural heterogeneity.

*Changes in soil physical and chemical properties*

The stability of the A horizon is strongly affected by the removal of the forest cover, and subsequent exposure of soil to sun radiation and rain-drop impact (Martins et al., 1986; Martins, 1987). Although this effect does not appear immediately following burning, the decreasing clay-mineral content and flocculation degree in the A11-A12 horizons, and the increasing bulk density in the underlayer horizon were very striking after one year of cultivation (Fig. 2). Increasing cropping time brings about increasing dispersion and eluviation of clay minerals, and affects the characteristics of the B horizon; in the A3 and B horizons, total porosity changed from values between 0.40 and 0.60 $cm^3$ $cm^{-3}$ under native forest, to values lower than 0.40 $cm^3$ $cm^{-3}$ in the five-year cultivated soil (Martins, 1987). As a result, temporary waterlogging appears, which favors lateral evacuation of clay-mineral particles. However, in the soil under fallow, all these parameters return to values close to those found in the non-cultivated system, in agreement with morphological changes.

Soil cation exchange complex is strongly affected by forest burning. In the A11-A12 horizons, the pH values increased from 4.2–4.9 to 6.7–7.2, and remained higher than 5.5, even after five-year cropping (Martins et al., 1986; Martins, 1987). At least till the first year of cultivation, the exchangeable bases liberated by the ash material are translocated through the soil profile (Brinkmann and Nascimento, 1973). These bases induce pH-dependent charges which contribute to increased soil cation exchange capacity and clay mineral dispersion (Gombeer and d'Hoore, 1971). However, this effect does not appear beyond 0.25–0.35-m depth, and the input of saturating bases is much more restricted after five-year cropping, as shown on Fig. 3. After crop interruption and installation of the fallow secondary vegetation, biological cycles resume; the values of cation exchange capacity and exchangeable bases are slightly lower than in the soil cultivated for one year. However, chemical

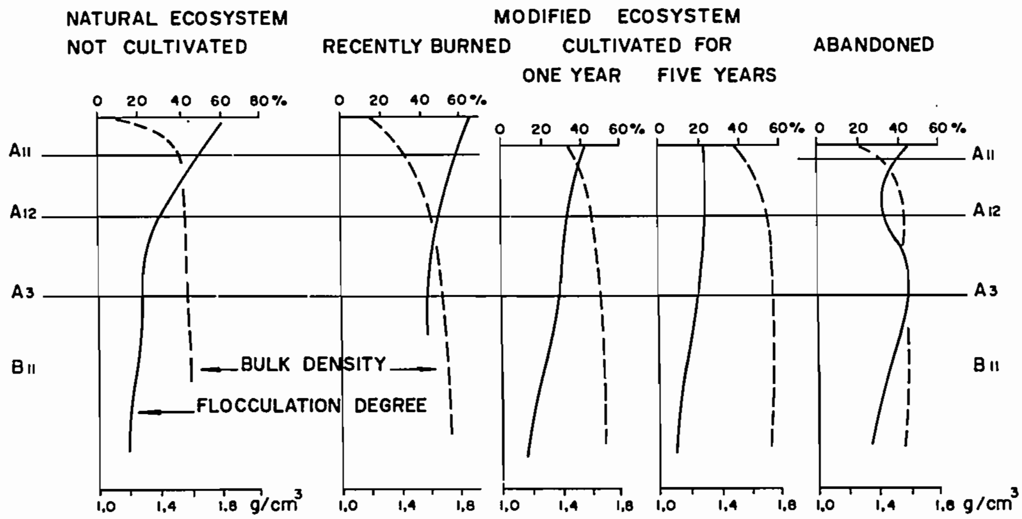


Fig. 2. Comparison of variations in bulk density and clay flocculation degree in soil profiles under native forest (well-drained soil) and traditional agriculture.

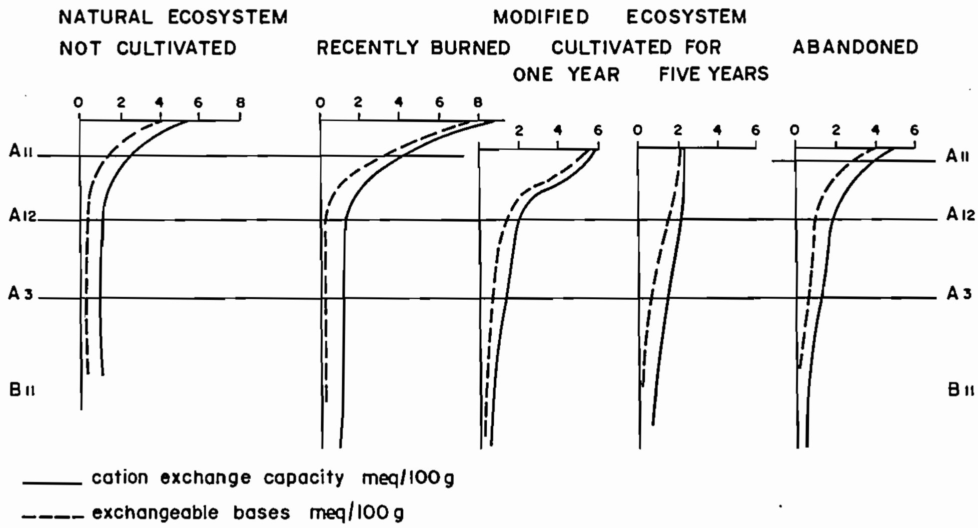


Fig. 3. Comparison of variations in cation exchange capacity and base saturation in soil profiles under native forest (well-drained soil) and traditional agriculture.

conditions, especially base saturation in the upper horizon, seem to be better than in the native forest soil.

*Changes in soil organic matter content and composition*

Figure 1 indicates that only the quantities of coarse (200–2000 μm) and medium (50–200 μm) organic residues decrease as a consequence of burning. After one-year cropping, surface residues had partly decomposed, and the amounts of total soil carbon and humic acid carbon decreased, due to the low level of organic restitution to the soil. This is confirmed in the five-year cropped system, in which soil fulvic acids were the predominant humus fraction. The increasing proportion of fulvic acids with increasing cropping time is no doubt related, as in the soils under natural vegetation, to drainage hampering. It is therefore probable that these acidic, acid-soluble molecules would favour the processes of soil degradation through the dispersion and downwards and/or lateral migration of clay mineral particles, as suggested by experimental studies (Dixit et al., 1975; Shanmuganathan and Oades, 1983).

In the abandoned soil, organic residues derived from the secondary vegetation increased again, and total soil carbon was about 80% that in the well-drained soil under natural forest. The proportion of fulvic acids decreased relative to that of humic acids, which indicates a reversion of humus degradation processes. Such a recovery of SOM chemical properties is in agreement with the enhancement of the mesofaunal activity, which seems to be a characteristics of soils under 'capoeira' vegetation (Chauvel, 1982).

## CONCLUSIONS

In spite of bringing about no immediate damage to the soil, and even improving soil nutritional properties, burning has been shown to create adequate conditions for the alteration of soil physical properties. Such alterations are dominated by the destruction of soil structure, the increase of bulk density, and the subsequent decrease of total porosity, sometimes leading to strong hydromorphic features. There changes appear as an emphasis of soil natural tendencies, but are shown to be reversible after a sufficient fallow period.

The main factor that affects the clear-felled soils is probably the removal of the natural vegetation cover, rather than the crop itself. Two facts seem to prevail: (1) the decrease in soil organic matter and the proportional increase in the fulvic acid fraction; and (2) the increasing dispersibility of clay mineral particles. It is thought that, as in other soil types, the decrease in soil biological activity negatively affects aggregate stability (Tisdall and Oades, 1982), and that acid-soluble molecules, such as fulvic acids, are involved in the processes of clay mineral dispersion and redistribution throughout the soil profile.

In this work, it was attempted to determine and quantify simultaneously all soil changes in a selected sequence of shifting agriculture. The above results indicate that soil organic matter integrates most of these changes. According to not only its amount, but also its – still very poorly known – chemical nature, soil organic matter can therefore be questioned as one of the leading factors in soil degradation, as well as in soil reclamation.

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