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Biological activity of soil under rubber plantations in Côte d'Ivoire

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Soil macrofauna composition and rates of C and N mineralisation were assessed in 5, 10, 20 and 30 year-old *Hevea* stands and in the original forest. The density and the biomass of macroinvertebrates were high in stands 5 to 20 years old and significantly decreased in the 30-year old plantation. In the early stages of the succession, there were large populations of xylophagous termites on dead woody material remaining from the original forest. After 10 years, their abundance decreased and endogeic earthworms became abundant. In 30 year-old stands, the overall biomass of macroinvertebrates dropped. Mineralisation of C increased in the 5-year plantation when compared with that in the original forest and then decreased progressively. N mineralisation was higher in all the plantations younger than 20 years than it was in the original forest but it decreased significantly in the 30-year old stand. In *Hevea* plantations, biological activity was maintained at a high level for 20 years because the dead biomass of the original forest and the legume cover provided food for termites and earthworms. In the oldest stand, exhaustion of these resources resulted in a dramatic drop in biological activity.

1. Introduction

In the humid tropics, soil macroinvertebrates are known to be an important determinant of organic matter dynamic and nutrient cycling (Lavelle 1984, Lee 1985). As a result, the abundance and composition of their communities can be used as indicators of the fertility status of soils (Swift 1986, Lavelle 1988, Paoletti et al. 1991). Previous studies have shown that soil macroinvertebrates are more numerous and diverse in perennial than in annual crops (Lavelle & Pashanasi 1989, Dangerfield 1990). In the humid tropics, *Hevea* plantations are often considered as sustainable systems which, in some cases, might even upgrade the level of soil fertility. The evolution of chemical soil properties have been monitored in a few situations in rubber plantations of different ages (Aweto 1987, Tie Bi & Omont 1987).

Soil biological activities in rubber plantations of different ages were assessed to determine to what extent these artificial ecosystems are capable of conserving high levels of biodiversity and activity of soil communities. The soil fauna composition was determined in rubber plantations and in the original forest, and microbial activity was estimated by measuring soil respiration and nitrogen mineralisation rates in standard laboratory conditions.

2. Sites and methods

2.1. Study site

The study was carried out at Bimbresso in the southern forest belt of Côte d'Ivoire in 5, 10, 20 and 30 year-old rubber plantations and in the nearby original secondary forest. All the sites were sampled at the end of the rainy season (October to November 1990). Annual rainfall is 1 700 mm with four months dry season (December to March).

Study plots of 0.1 hectare were chosen to have homogeneous cultural histories, soil texture, and continous rubber cover. After deforestation, the rubber plots were planted to a legume ground cover (*Pueraria phaseoloides*), which disappeared after the closing of the rubber canopy.

Soils of the 5 plots were oxisols, with a sandy texture (80% sand) and low pH (4.0). Soil organic matter and nutrient contents were higher in the original forest than in plantations. No significant differences were observed among the rubber plantations for soil chemical parameters (C, N, ECC, pH, oligoelements). Total C-content of soil was lower in the plantations (8.8‰ to 11.4‰) than in the forest (12.4‰). In the plantations, total N-content had decreased from 1.17‰ in the forest to 0.88‰–1.10‰ in the plantations (no replicate). The ECC of the soil varied from 1.34–1.68 meq/100g in the plantation to 1.71 meq/100g in the forest.

2.2. Methods

Sampling of soil macrofauna. At each site, 10 monoliths, each 25 × 25 × 30 cm were taken at 5 m intervals on two parallel transects chosen between lines of rubber trees, and hand sorted for macrofauna, i.e. invertebrates with a body length greater than 2 mm (TSBF standard methodology: Anderson & Ingham 1989). The invertebrates were preserved in 4% formalin and separated into 17 broad taxonomic units (orders or families), counted and weighed (weight in formalin, approximately 75% of live weight).

Earthworms were further divided into two ecological categories, i.e. pigmented litter-feeding earthworms (epigeic and anecic) and unpigmented endogeic earthworms. Termites were separated into soil-feeders, wood-feeders and fungus-growers.

Microbial activity of soil. Potential rates of C and N mineralisation were measured in the laboratory on homogenized soil samples, using the standard method described by Dommergues (1960).

Soil was moistened at field capacity, placed in a sealed box and kept at 28°C. The CO_2 evolved was fixed with NaOH and titrated with hydrochloric acid. The net amount of CO_2 evolved from the soil was calculated after deducting air CO_2 measured in the air of controls. Results were cumulative over a 17 day-period. After the last respirometric measurement, mineral nitrogen was extracted by a KCl solution; NH_4^+ concentration was measured with a standard NH_4^+ electrode. Three replicates were done for each soil sample.

3. Results

3.1. Soil fauna

Taxonomic richness, based on broad taxonomic units (orders or families) differed little among the 5 plots (15 to 17 units) (Table 1). Litter arthropods (other than termites) had the highest abundance in the forest plot; as a result, the diversity index was maximum in the forest (Table 1). In the 5, 10 and 20 year-old plantations, earthworms and termites comprised a large part of the biomass, which explains the low diversity index. In the 30-year plantation, earthworm populations had a lower biomass; as a result the total biomass included a wide variety of groups and the diversity index was greater.

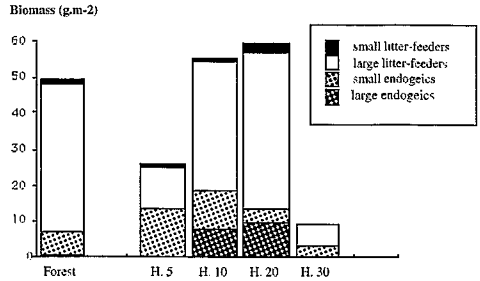

Fig. 1. Distribution of the biomass of earthworms among the ecological categories. H.5 to H.30 are *Hevea*-plantations 5 to 30 years in age.

The secondary forest had high populations of soil invertebrates (5 750/m^2) dominated by termites (4 900/m^2) (Table 2). Biomass was also high (74 g/m^2) because of the abundance of large litter-feeding earthworms (41.5 g/m^2) with an average individual biomass of 3.2 g (Fig. 1).

After five years of *Hevea* cultivation, macroinvertebrate density was 4 times greater than in the original forest (22 400/m^2) mainly due to a large increase of wood-feeding termites from 2 500/m^2 in the forest to 17 000/m^2 in the 5-year old plantation. Earthworm communities were also modified; the abundance of large litter-feeders had decreased whereas small endogeics were more numerous. Biomass of ants was also greater in the youngest plantation than in the original forest.

Communities of the ten and twenty year-old plantations were rather similar (Table 2). The overall density was lower than in the original forest, i.e. 3 500 and 1 800/m^2 respectively in the 10 and 20-year old plantations. Termites were still dominant in number although fungus growing termites replaced wood-feeders which had nearly disappeared (Fig. 2). Total biomass was high with average values of 70 g/m^2 in both plantations. Earthworms comprised more than 75% of the total biomass; large litter-feeders and endogeics were dominant as in the original forest but large endogeics were better represented than in any other situation.

The total fauna biomass in the 30-year old plantation (17.9 g/m^2) was significantly lower than in the younger plots, although total density (2 600/m^2) was comparable to the density in the 10 and 20 year-old rubber plantations. This was the result of significantly reduced numbers of earthworms. Most litter-feeding and large endogeic earthworms had disappeared and no other invertebrate occupied the niche (Fig 1).

Table 1. Taxomomic richness and biological diversity in the 5 plots. The index of diversity is derived from the Simpson index $I = 1/\Sigma p_i^2$, where p_i is the frequency of the taxonomic unit calculated from biomass data.

Plot	Taxa	Diversity
Forest	17	5.17
Hevea 5	17	2.81
Hevea 10	15	2.88
Hevea 20	15	2.37
Hevea 30	16	5.16

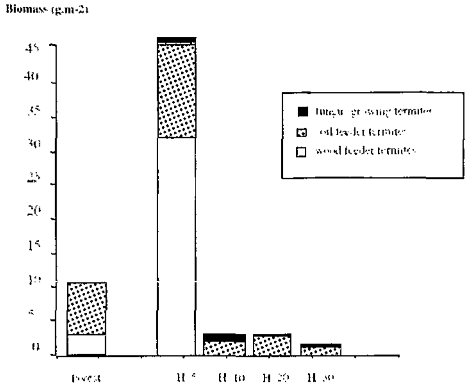

Fig. 2. Distribution of the biomass of termites among the ecological categories. H.5 to H.30 are *Hevea*-plantations 5 to 30 years in age.

3.2. Metabolic activity of soils

The amounts of C and N mineralized from soil samples incubated in the laboratory decreased with depth (Fig. 3). The potential metabolic activity of the soil was greatest in the upper ten centimeters, where soil organic matter, roots and soil fauna are concentrated.

Mineralisation of C was lower in the 10 to 30 year-old plantations than in the original forest at all depths; the difference was significant for the three plantations at the depth 10–25 cm (*t*-test, $P < 0.05$). The mineralisation rate decreased with the age of the plantation. The 5 year-old plantation was the only plantation with a mineralisation rate significantly higher than in the original vegetation at all depths. This may be related to the abundance of termites (21 000/m²) and the associated biological activation.

The mineralisation rate of N was significantly higher in the 5, 10 and 20 year-old plantations than in the forest at all depths. Conversely, N mineralisation rate of the soil in the 30 year-old plantation was significantly lower than that of the original forest in the 25 upper cm.

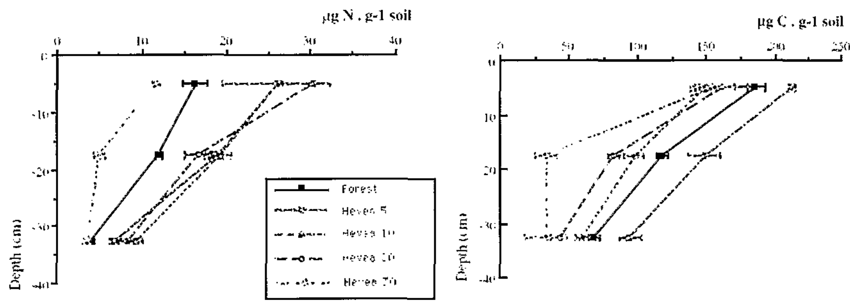

Fig. 3. N mineralisation (left) in µg NH_4^+-N/g[1] soil, and C mineralisation (right) in µg CO_2-C/g[1] soil for 17 days of incubation.

Table 2. Density and biomass (mean ± *SE*, ind./m² and g/m²) of macroinvertebrates in the 5 plots.

	Forest		Hevea 5		Hevea 10		Hevea 20		Hevea 30	
Earthworms	171.2	± 22.4	339.2	± 61.1	489.6	± 54.9	150.4	± 18.3	97.6	± 7.7
	52.3	± 31.9	27.7	± 6.9	52.0	± 19.8	59.5	± 23.7	9.2	± 6.2
Termites	4920	± 1107	21011	± 7633	2080	± 586	1334	± 676	1976	± 701
	10.9	± 3.3	45.3	± 15.1	3.3	± 1.1	3.5	± 3.2	2.7	± 1.3
Ants	100.8	± 44.6	374.2	± 241.9	27.2	± 9.1	24.0	± 11.9	28.8	± 14.6
	0.48	± 0.33	2.44	± 1.63	0.33	± 0.22	0.18	± 0.10	0.13	± 0.08
Coleoptera	88.0	± 23.2	41.6	± 4.5	28.8	± 7.0	83.2	± 15.0	164.4	± 39.4
	3.71	± 3.31	0.20	± 0.07	0.57	± 0.38	1.08	± 0.52	2.13	± 0.61
Dermaptera	27.2	± 9.8	20.8	± 11.3	6.4	± 4.5	6.4	± 5.2	16.0	± 10.1
	0.05	± 0.02	0.03	± 0.02	0.01	± 0.01	0.15	± 0.15	0.10	± 0.08
Arachnida	41.6	± 9.8	22.4	± 7.2	16.0	± 5.6	17.6	± 7.3	40.0	± 9.2
	1.08	± 0.76	0.38	± 0.21	0.30	± 0.17	0.17	± 0.08	1.15	± 0.46
Chilopoda	81.6	± 22.1	20.8	± 7.1	19.2	± 6.6	70.4	± 17.3	24.0	± 5.8
	1.23	± 0.95	0.15	± 0.07	0.23	± 0.07	0.23	± 0.07	0.12	± 0.05
Diplopoda	142.4	± 37.4	121.6	± 30.7	35.2	± 14.0	38.4	± 7.2	51.2	± 10.3
	3.00	± 1.33	1.44	± 0.28	6.81	± 3.32	7.69	± 6.72	1.59	± 0.63
Isopoda	33.6	± 9.2	6.4	± 3.79	1.6	± 1.7	27.2	± 9.1	28.8	± 10.0
	0.98	± 0.81	0.37	± 0.29	0.01	± 0.01	0.79	± 0.46	0.27	± 0.19
Mollusca	22.4	± 6.7	14.4	± 6.9	9.6	± 3.7	8.0	± 3.8	4.8	± 2.6
	0.33	± 0.10	0.57	± 0.22	0.30	± 0.14	0.40	± 0.27	0.14	± 0.10
other	118.4	± 34.6	436.8	± 139.1	755.2	± 190.9	59.2	± 15.1	169.6	± 37.8
	0.22	± 0.08	5.48	± 5.21	1.16	± 0.25	0.43	± 0.18	0.43	± 0.16
Total	5747	± 1143	22414	± 7522	3469	± 5293	1819	± 693	2602	± 694
	74.24	± 31.24	84.10	± 16.37	65.00	± 19.53	74.09	± 23.49	17.87	± 6.82

4. Discussion

At Bimbresso, in the tropical rain forest belt of West Africa, the secondary forest had an abundant macrofauna community. Density and biomass (5 750 ind./m^2, 75 g/m^2) were 1.5 to 4 times higher than in other tropical rain forests sampled in Peru (Lavelle & Pashanasi 1989), Mexico (Lavelle & Kohlmann 1984) or South East Asia (Collins 1980).

The composition of the soil macrofauna communities and the potential mineralisation activity of soil in the 5-year plantation differed greatly from the original forest and the older plots. The increase of biological activity in this plot may have been simply a consequence of the deforestation rather than of substitution of original forest trees by *Hevea*. Deforestation induced a reorganisation of soil fauna based on modification of the resources. Suitable microclimatic conditions were soon restored as the disappearance of the canopy was rapidly compensated by the development of a legume cover and soil macrofauna did not seem to have been greatly damaged by the land clearing. After clearing the forest, dead trunks and large root systems were not removed and they represented a huge amount of resources for wood-feeding termites. Decrease in the populations of large litter-feeding earthworms may have resulted from the low input of litter during the establishement of rubber cover and from competition with termites.

The observation of soil fauna communities in the 10 and 20 year-old plantations suggested that the first stage of great modification of the environment due to the establishment of the new vegetation had come to an end. A new equilibrium had been reached with a rich litter layer allowing the development of an important litter-feeding fauna. On the other hand, it is likely that wood feeding termites had eaten up all the dead wood material and transformed it into humified soil organic matter, which was further used as a feeding resource by large endogeic earthworms.

The disappearance of large litter-feeding earthworms in the 30-year old plantation resulted in a wider diversity of faunal groups; the index of diversity was as high as in the forest plot. The modification of biological activity of soil is also demonstrated by significant changes in the potential mineralisation rate of C and N. Nonetheless this decrease in biological activity can be partly the result of a deterioration of the quality of litter inputs due to ageing of the trees. Indeed, the exploitation of rubber trees generally ends after 20–25 years because of the decrease of latex yield and a high mortality rate of trees broken by the wind.

This decline in biological activity may indicate a modification of soil fertility although no significant difference of soil organic matter and nutrient contents was observed with increasing age of the plantation. As observed by Aweto (1987), the main modifications of soil chemical parameters, the decrease in C, N and other nutrients, occurred during the years following the establishment of the rubber plantation. Several studies have shown that land clearance enhances mineralisation of organic matter which is rarely compensated by the organic input of the crop (Ghuman et al. 1991, Eden et al. 1991, Yoro 1989). However, the initial association of the tree plantation with a dense legume cover soon restores suitable conditions for an active soil fauna. When the disturbance linked to the forest clearance has lost its initial impact, soil communities are abundant, with a biomass comparable to that in the original forest, and microbial activity is high. After more than 20 years of intense biological activity, the ageing of the trees and the deterioration of the litter system lead to a decrease in biological activity.

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