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Dynamics of litter and organic matter at the soil-litter interface in fast-growing tree plantations on sandy ferrallitic soils (Congo) (*)

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Abstract

Litter dynamics was studied in plantations of two Eucalyptus hybrids, *Acacia mangium* and *Acacia auriculiformis,* in Congo.

Litter fall ranged from about 5 t. ha^{-1}. $year^{-1}$ under Eucalyptus to 10 t. ha^{-1} $year^{-1}$ under Acacia. Compared to Acacia leaf litter, Eucalyptus leaf litter was poor in nitrogen and lignin. Eucalyptus and *Acacia auriculiformis* leaf litter had a high content of water soluble carbon.

Litter accumulation study showed that the decomposition rate of Eucalyptus litter was low and that Acacia litter decomposed faster. The factors involved are discussed.

The organic matter at the soil-litter interface was studied by particle-size fractionation. Comparisons between tree stand and savanna showed an increase of the light fractions under the trees. No change of the amount of C occurred in the organomineral fraction (from 0 to 50 µm). Eucalyptus and Acacia light fractions showed different features.

Keywords: Eucalyptus, Acacia, litter, litter decomposition, organic matter fractionation, Congo, Africa.

Résumé

La décomposition et l'incorporation au sol des litières ont été étudiées dans des plantations forestières d'Eucalyptus, *Acacia mangium* et *Acacia auriculiformis.*

La chute annuelle de litière est d'environ 5 tonnes par hectare sous Eucalyptus et de 8 à 10 tonnes par hectare sous Acacia. Comparées aux litières d'Acacia les litières d'Eucalyptus sont pauvres en azote et en lignine. Elles sont riches en composés carbonés solubles de même que la litière d'*A. auriculiformis,* mais ces composés ne présentent pas les mêmes propriétés. L'influence de ces caractères des litières sur la vitesse de décomposition est discutée.

La matière organique à l'interface sol-litière a été étudiée par fractionnement granulométrique qui montre sous plantations une accumulation des fractions légères dont les caractéristiques diffèrent entre Eucalyptus et Acacia.

INTRODUCTION

The sandy savanna ferrallitic soils of the south-west Congo are very poor in clay and nutrients and are unfit for agricultural purposes. For about twelve years

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they have been progressively planted with fast-growing trees, mainly Eucalyptus, after intensive forestry research led to the improvement of genetic status and multiplication techniques (DELWAULLE & LAPLACE, 1988).

Intensive exploitation is now carried out, leading to a high level of nutrient outputs. Consequently, the maintenance of soil fertility depends on soil's ability to retain fertilizers and rainfall nutrient inputs within the exchange sites of the clay or of the organic matter. Given the low clay content, soil organic matter is the major nutrient pool, and the improvement of its level is of great importance. Litter decomposition processes and its incorporation into soil organic matter was studied in order to gain information about the evolution of the organic pool.

Comparison with similar studies previously carried out in the Sahelian zone (BERNHARD-REVERSAT, 1987) should reveal general features of exotic Eucalyptus plantations, whose ecology has been less studied than in natural Eucalyptus forests (WOODS, 1974; O'CONNELL & MENAGÉ, 1982; O'CONNELL, 1987).

As an alternative to Eucalyptus, other fast-growing species are undergoing experimentation for afforestation, such as tropical pines or various Australian *Acacia*. Experimental plantations of *Acacia mangium* and *Acacia auriculiformis* on the studied site, allowing comparison of their ability to build up soil organic matter with that of *Eucalyptus*, were worthwhile, as little is known on this subject in Africa.

SITES AND METHODS

Characteristics of sites and stands

The studied site is situated on low coastal hills of sedimentary sands. The soils were studied by JAMET and RIEFFEL (1976), who classified them as ferrallitic soils (arenosol feralic, FAO/UNESCO classification). They are very poor in clay and mineral nutrients. Some analytical data on the studied stands are given in table I.

TABLE I. – *Range values of soil data under savanna.*

	0-10 cm	10-20 cm	20-40 cm
pH	5.7	5.2	5.0
clay %	4-6	4-5	3-5
C °/₀₀	5-8	3.0-3.7	2.9-3.3
N °/₀₀	0.3-0.5	0.2-0.3	0.1-0.2
Exchangeable capacity cmol/kg	5.0-5.5	3.5-4.5	3.1-4.2
Exchangeable cations cmol/kg	0.4-0.7	tr-0.1	tr-0.1

The climate was sub-equatorial. However, the dry season lasted 4-5 months. The mean annual precipitation was 1250 mm.

The native vegetation was savanna, dominated by *Loudetia*, with scattered *Anona senegalensis* shrubs. Rainforest covered the valleys and some hills but tree plantations were exclusively established on savanna.

In the 1970s Eucalyptus hybrids were selected at the CTFT Research Center of Pointe-Noire, (DELWAULLE & LAPLACE, 1988), and two hybrids, described by these authors, are used for commercial planting: one called PF1, and the second, 12ABL saligna (here called HS2).

TABLE II. – *Description of the main stands studied.*

	Date of planting	years of study	age years	spacing m
Eucalyptus PF1	1979	1986-87	7-8	5 × 5
Eucalyptus PF1	1979	1989-90	9-11	5 × 5
Eucalyptus HS2	1979	1986-90	7-11	5 × 5
Acacia mangium	1981	1987-90	7-10	3.5 × 3.5
Acacia mangium	1984	1987-90	4-7	3.5 × 3.5
Acacia auriculiformis	1981	1987-90	7-10	3.5 × 3.5
Acacia auriculiformis	1984	1989-90	6-7	3.5 × 3.5

Characteristics of the main tree stands studied are given in table II, but some soil sampling was done in other similar stands.

Methods

The methods used for litterfall and accumulation study, fractionations of surface soil and incubations were described earlier (BERNHARD-REVERSAT, 1987) with the following modifications.

Litter traps and sampling surfaces for forest floor (accumulated litter) were 0.25 m^2. Sampled forest floor was sieved at 4 mm (leaves and twigs) and 0.5 mm (fragments).

Litter extracts were obtained by shaking 1 to 3 g of powdered litter in cold distilled water for two hours, followed by centrifugation (tests with hot water extracted only 8 to 15 percent more C). Soluble compounds were obtained by multiplying soluble C content by 2.5, after this factor had been checked by weight loss measurements in some samples. These compounds were mainly organic ones, as shown by their low mineral content (0.2-0.3% of Ca, 0.5-1% of Mg, 0.3-1.3% of K).

For C mineralization measurements, soluble and insoluble fractions were mixed to pure sand and incubated separately.

Soil microfauna was extracted according to the Berlese method by gently drying the samples for three or four days over a flask containing Agallol ® in water solution, following soil sampling with a steel cylinder (54.5 cm^2), taking out litter and the 0-5 cm layer of soil.

Savanna biomass was measured by cutting out the aerial part of grasses on six plots of one square metre which were selected at random. On each plot two soil cores were taken to 20 cm depth for underground biomass determination.

Particle-size fractionations of organic matter were carried out by sieving and floating according to FELLER *et al.* (1983) in order to separate three light fractions (0.5-2 mm, 0.2-0.5 mm, 0.05-0.2 mm) and one organomineral fraction from the sandy fractions.

Carbon determinations were performed by the Walkey and Black method, nitrogen determination by the Kjeldahl method. Lignin was determined by the VAN SOEST (1963) acid detergent method at the IEMVT laboratory. This method, generally used for forage analysis, gives an estimation of the actual lignin content. However, RYAN *et al.* (1989) found a good relation with a more complex method in litter studies.

RESULTS AND DISCUSSION

Litter characterization

Litter fall

Annual litter fall in tree stands is summarized in table III. It indicates the high productivity of *Acacia* stands, which is as high as in most rain forests, and

TABLE III. – *Annual litter production of stands, in t.ha (with standard deviation of the mean) for 10 replicates in tree stands and 6 replicates in savanna.*

	Eucalyptus		*Acacia*			Savanna (annual maximum biomass of standing crops)
plot	PF1	HS2	*mangium*	*auriculiformis*		
age (years)	7	7-8	5-6	6	7-8	
measurement (years)	1	2	2	1	2	1
Leaf litter	4.9 (0.1)	4.5 (0.1)	7.9 (0.3)	5.8 (0.4)	5.7 (0.2)	
Flowers and fruits	0.2	0	1.0 (0.2)	2.1 (0.1)	2.7 (0.2)	
Twigs and bark	1.8 (0.2)	1.0 (0.2)	0.8 (0.2)	0.7 (0.1)	1.6 (0.2)	
Total	6.9 (0.4)	5.5 (0.3)	9.7 (0.5)	8.6 (0.4)	10.0 (0.4)	8.2 (0.1)

higher than in the neighbouring Mayombe forest (SCHWARTZ, 1992). Acacia litter production is about 30 to 45% higher than Eucalyptus litter production.

Annual production of the native savanna was estimated by monthly measurements of the biomass. The maximum aerial biomass was 8.2 t/ha. Primary production in dry savannas is known to range from 15% (BERNHARD-REVERSAT, 1986) to 36% (BILLE, 1976) and 58% (CORNET, 1981) greater than maximum biomass. Thus, in the present study, savanna aerial production could range from 9 to 13 t/ha. The maximum biomass found by MAKANY (1976) in a *Loudetia savana* of the Teke plateau (Congo) was 9 t/ha. However, annual burning of the savanna prevents most of this organic matter from returning to the soil and mainly mineral nutrients are returned.

Litter characterization

The N and lignin content are supposed to control litter decomposition rate (MEENTEMEYER, 1978; BERG & MCCLAUGHERTY, 1987; PARTON *et al.*, 1987; TAYLOR *et al.*, 1989). The average N content of main litter components is given in table IV together with lignin and ash contents, and soluble C content in table V.

TABLE IV. – *Some chemical characteristics of litterfall components.*

		Eucalyptus		*Acacia*		Savanna
		PF1	HS2	*mangium*	*auriculif.*	herbs (1)
N %	leaves	0.65	0.67	1.62	1.51	0.45
	flowers + fruits	ND	ND	1.46	1.22	–
	twigs + bark	0.22	0.23	1.18	1.05	–
lignin %	leaves	22	25	31	34	9
	flowers + fruits	ND	ND	27	28	–
ash %	leaves	2.5	3.0	1.7	2.0	5,6
	flowers + fruits	ND	ND	1.7	1.7	–
C/N (2)	leaves	75	72	30	32	105
	flowers + fruits	ND	ND	34	40	–
lignin/N	leaves	34	37	19	22	20
	flowers + fruits	ND	ND	18	23	–

(1) total aerial standing crop.
(2) C = 50% ash-free organic matter.
ND = not determined.

Leaf litter may also be characterized by water-soluble organic matter content, known to be particularly high in Eucalyptus (Wood, 1974; Bernhard-Reversat, 1987).

The content of 24 to 34% of soluble compounds found here corresponded to other data found with Eucalyptus leaves under dry tropical climate (Bernhard-Reversat, 1987) as well as in temperate climate (O'Connell, 1987).

Table V. – *Water soluble C content of recently fallen litter.*

	PF1	HS2	*A. mangium*	*A. auric*	Savanna (1)
number of sample	3	5	3	2	2
soluble C mg/g litter	135	115	76	112	2
mean standard error	1	6	4	–	0
soluble compounds %	34	29	19	28	6

(1) total aerial standing crop.

Abundance of soil microarthropods

The number of microarthropods in the 0-5 cm layer of soil + litter was estimated over two years for savanna and one year for Eucalyptus HS2 and *Acacia mangium* stands, except in July, August and September (dry season). No seasonal variation was indicated during the wet season and a sharp decrease occurred at the beginning of the dry season (May or June).

The global results (table VI) showed a very significant difference between tree stands and savanna.

Table VI. – *Number of micro-arthropods in tree stands and savanna, per dm^2, soil 0-5 cm + litter.*

site	mean (and standard error of the mean)	number of samples	years	% acarians
Eucalyptus HS2 9 years	556 (45)	51	1988-89	63
A. mangium 7 years	601 (83)	18	1988	55
Savanna	320 (23)	67	1987-88-89	66

The distribution diagrams (fig. 1) showed a greater dispersion under Eucalyptus which could be due to the greater variability of soil and litter humidity than under Acacia where the amount or forest floor and the dense canopy were able to buffer humidity changes.

Although no species determination was done, it was observed that species diversity was higher in Acacia stand than in Eucalyptus stand, and low in savanna. In Acacia litter there was also noted a great number and a high activity of macroarthropods, especially cockroaches and ants.

Comparison with data collected by Maldague (1961) in Zaire showed that the present tree stands are in the range of the "artificial tree or shrub stands" (m: 501 per dm^2 with 58% acaria) and somewhat less than natural forests (m: 671 with

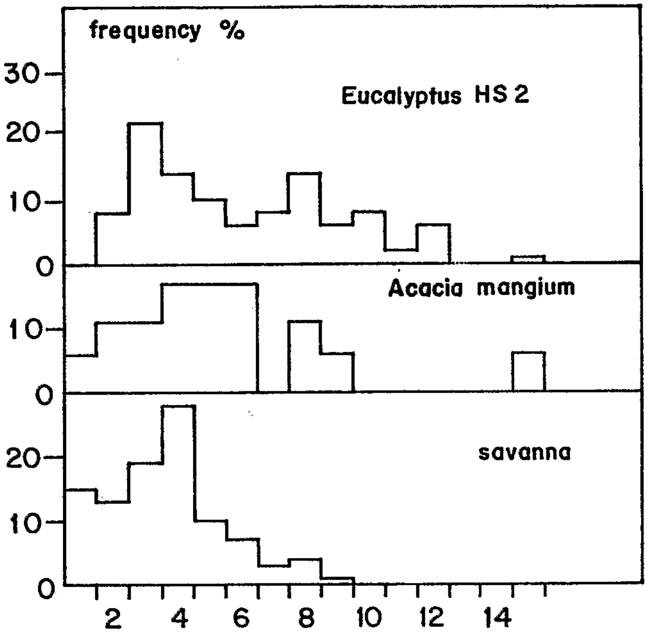

FIG. 1. – Frequency of the number of microarthropods per square cm per sample of soil.

77% acaria). As reported by this author, the present savanna data are higher than ones of the “poor biotopes” such as young *Cecropia* stands and old meadows, but they are much lower than in the wet savanna studied by ATHIAS (1974) in Ivory Coast on a more productive soil.

Litter accumulation and decay

Early decomposition process

Two *in situ* decomposition experiments were carried out with soluble C determinations. The soluble compound content, which was high in litterfall, decreased sharply during the first four weeks (fig. 2A). This decrease was more intensive in Acacia and it must be noted that Eucalyptus had much more soluble C in the 18-week-old litter than Acacia in which hardly any soluble compounds were left. In Eucalyptus loss of litter soluble compounds fitted with weight loss during the first weeks (fig. 2B).

Amounts of mineralizable C (Cm) were determined in the soluble and insoluble fractions of Eucalyptus HS2 and *Acacia auriculiformis*. The Cm obtained from Acacia soluble C was more than twice as high as that of soluble C from Eucalyptus (fig. 3A). The Cm of the insoluble fraction was higher in Acacia during the first weeks and approximately equal to Eucalyptus at 12 weeks (fig. 3B).

It was shown that during *in vitro* decomposition experiments high amounts of soluble C were found in Eucalyptus litter percolates while low amounts were found in Acacia percolates (unpublished data).

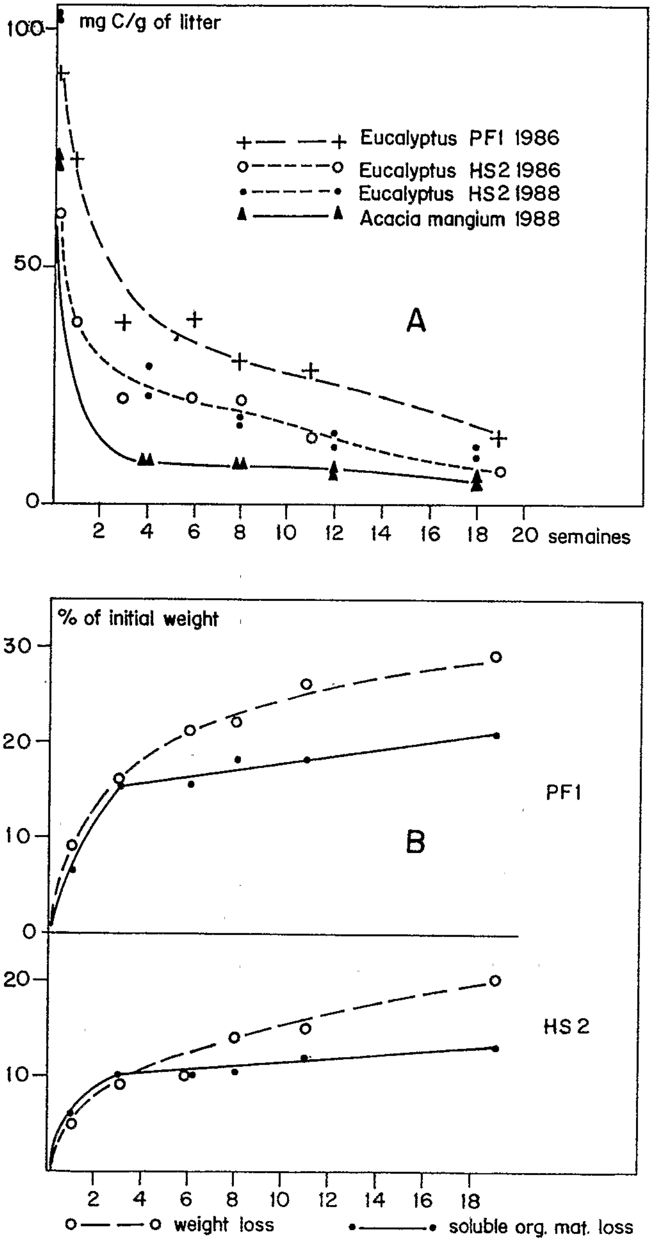

FIG. 2. – A. Soluble carbon content of the litter during *in situ* decomposition.
B. Weight loss and soluble organic matter loss.

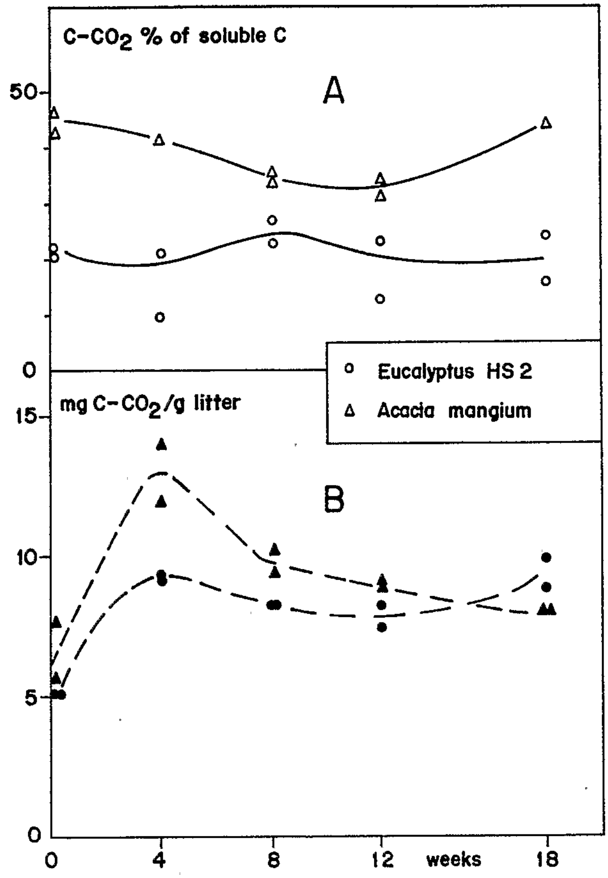

FIG. 3. – *In vitro* carbon mineralization in the soluble (A) and the insoluble (B) fractions of the litter during *in situ* decomposition.

These results indicate that the studied litters have high amounts of soluble organic matter. Eucalyptus PF1 has somewhat higher contents than Acacia species, but the main difference between the two genera is the great ability of Acacia soluble compounds to be mineralized, while Eucalyptus soluble compounds are mainly leached.

The low mineralization ability of soluble C from Eucalyptus suggests an antibiotic effect which would be in agreement with the low decomposition rate of the litter, and with the allelopathic effect reported previously (BERNHARD-REVERSAT, 1991*a*). Current observations about the good conservation of litter extracts in the laboratory confirm this possibility and antibiotic compounds were found in *Eucalyptus macrocarpa* by MURATA *et al.* (1990).

Litter accumulation

Eucalyptus PF1 and HS2 were compared for the amount of accumulated litter on the soil (forest-floor), once in the studied 7-year-old stands and once in 10-year-old stands. In the 7-year-old stands amounts of leaf litter (leaves + fragments) were respectively 11.1 and 7.8 t/ha under PF1 and HS2 with a significant difference related to a higher litter production. Total litter was 14.0 and 10.3 t/ha respectively. However, in 10-year-old stands a significant inverse ratio was observed with respectively 8.6 and 12.9 t/ha of leaf and fragments, and 15.5 and 17.2 t/ha of total litter. These results were in agreement with a known sharp decrease in growth of PF1 after seven years, while the growth of HS2 is known to continue for a longer time.

The seasonal variations of litter accumulation were measured for one year under Eucalyptus HS2 and two years under *A. mangium* and *A. auriculiformis.*

Change of accumulated litter with time is shown in figure 4. In one year the increase in Eucalyptus leaf litter was 12 per cent. This allows an estimation of 7.1 t/ha in a 10-year-old stand, a value in agreement with the 7.6 t/ha measured. However, the 16 per cent increase for leaf + fragment accumulation overestimates the value for the 10-year-old stand, showing that increase of the fragment fraction did not continue.

In *Acacia mangium* stand litter accumulation appeared to have reached a balance, and the amounts mesured in June 1988, 1989 and 1990 (7.3 t of leaves and 12.0 t of total litter per ha) are nearly the same.

Litter decomposition rate

Litter accumulation results from litterfall and litter decomposition, which can be estimated with these two parameters, calculating the decomposition coefficient k.

For Acacia where L was constant we used the equation $k = \frac{A}{L}$ and for Eucalyptus $k = \frac{A-(L2-L1)}{L}$, where A is the annual litterfall, L the mean litter accumulation, L_1 and L_2 respectively litter accumulation at the beginning and the end of the year (Bernhard-Reversat, 1981). Although these equations involve a theoretical decomposition pattern (Olson, 1963) which does not always occur in reality, they allow comparisons. The results are given in table VII.

A relation between litter characteristics and decay rates has been reported by several authors. Lignin content was reported by Meentemeyer (1978) to control decomposition rate, together with macroclimate expressed by AET (actual evapotranspiration). According to his equations (with AET estimated by Riou, 1975, to be 950 mm at Brazzaville, Congo) k should be as given in table VIII compared to actual k. Decay rate for Acacia is not very far from the actual one, but the rapid decay which should be expected from the low lignin content of Eucalyptus leaves contrasted with the observations.

Taylor *et al.* (1989) claimed that N content and C/N ratio were better predictors of decay than lignin content, but the range of lignin content of their material was low. Nevertheless, the very low N content of Eucalyptus litter may be responsible for its low decay rate.

Bignand and Schaefer (1988) pointed out the role of lignin but also the main influence of the nature of soluble organic matter and the inhibitory effect of polyphenols on the decomposition process. Antibiotic or inhibitory compounds may account for the low decay rate of Eucalyptus leaves.

For Parton *et al.* (1987), the lignin to nitrogen ratio (Li/N) is inversely related to the amount of metabolic fraction in plant residue, while the amount of structural

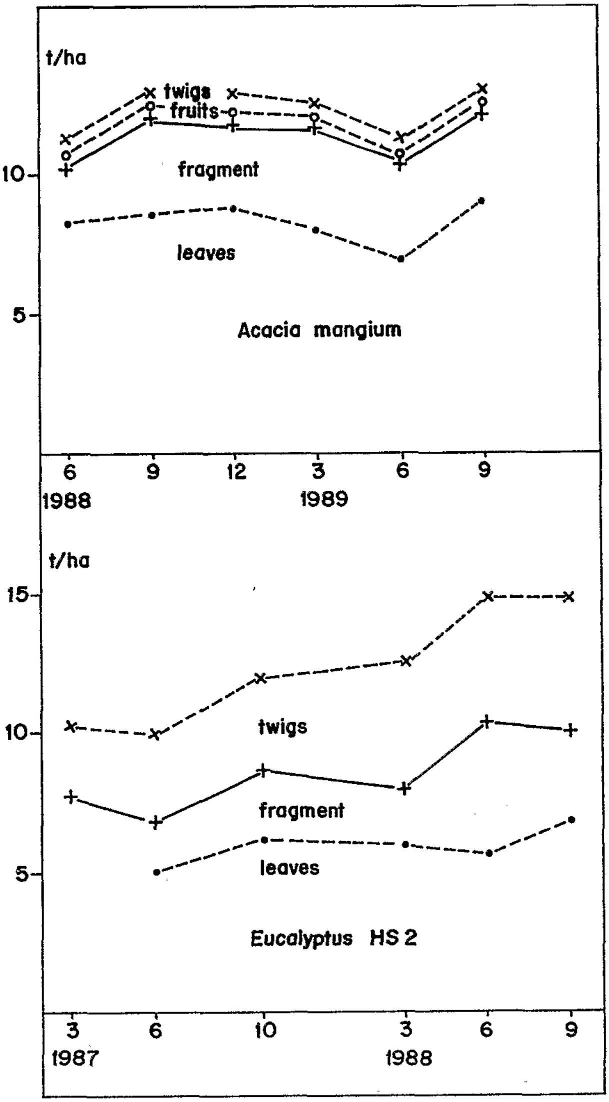

FIG. 4. – Litter accumulation on the soil under plantations.

fraction increases with increasing Li/N ratio. As a result, the decomposition rate is inversely related to Li/N. The values of this ratio quoted in table IV agree with this assessment and suggest a low decomposition rate in Eucalyptus litter.

In their native environment Eucalyptus of various species have been studied for decomposition rate. In temperate climate decomposition rate falls in the same range as in the present study and was higher than in exotic species (BAKER & ATTIWILL, 1985; O'CONNELL, 1987). In tropical and subtropical climates decomposition rate

TABLE VII. – *Annual decomposition coefficients.*

	Eu HS2	*A. mangium*	*A. auric.*
leaves (> 4 mm)	0.61	0.96	1.20
leaves + fragments (> 0.5 mm)	0.35	0.69	0.73 (1)
total litter	0.24	0.76	0.69

(1) as pod litter was important for this species, the fragments fraction was corrected proportionally for k calculation.

TABLE VIII. – *Decomposition coefficient and calculated annual disappearance, using the Meentemeyer equation or the decomposition coefficient.*

	k		annual disappearance %	
	Meentemeyer	actual	Meentemeyer	actual
Eucalyptus HS2	0.81	0.35	56	30
A. mangium	0.59	0.69	48	50

was higher than in Congo, as reported by ROGER and WESTMAN (1977) and SPAIN & LE FEUVRE (1987).

The general trend suggests the occurrence, in Eucalyptus native ecosystems, of an adapted biotic environment which is lacking in young overseas plantations.

Acacia magium and *A. auriculiformis*, although also being exotic species, exhibited a contrasting high turnover of litter organic matter in the studied environment. The high level of N content and the lack of toxic polyphenols lead to a fast decomposition and consequently a high productivity on a poor soil. The occurrence of white rot fungus in the forest floor under Acacia may contribute to the leaf brown pigment degradation (TOUTAIN, 1987) and improve decomposition rate. White rot fungus was not observed under Eucalyptus.

Organic matter at the soil-litter interface

The organic matter of the 0-2 cm layer of soil was investigated by fractionation into three light fractions (0.05-0.2 mm, 0.2-0.5 mm, 0.5-2 mm) and one or two organomineral fractions below 0.05 mm.

Characterization of the fractions

The fractions were characterized by their morphology, by their C/N ratio, and by their susceptibility to degradation measured by CO_2 release during incubation.

Morphological observation of the fractions was performed with a binocular microscope. The 0.2-0.5 mm fractions were very different under Acacia and Eucalyptus: the Eucalyptus fraction consisted mainly of plant fragments, pieces of leaf epiderm, veins and roots, with a few feces and aggregates. The Acacia fraction consisted mainly of feces, with a few plant fragments, veins and roots (fig. 5). The savanna fraction comprised plant fragments (mainly roots) charcoal pieces, and a few feces. The 0.5-2 mm fractions consisted mainly of vegetal and animal fragments, but the Acacia fraction comprised mainly feces. The 0.05-0.2 mm fractions showed few recognizable fragments and differed among stands by their colour.

The average C/N ratios of the fractions are shown by figure 6. The light fractions of Eucalyptus stands contrasted with that of Acacia ones and savanna by their high C/N ratio. However, the tree stand fractions between 0.025 mm had the same 15-16 C/N ratio which was somewhat higher than the savanna one.

In vitro mineralization measurements showed the CO_2 production rate to be higher in the 0.2-0.5 mm light fraction of Eucalyptus soil than in either the same fraction of Acacia soil, or the other light fractions of Eucalyptus (fig. 7).

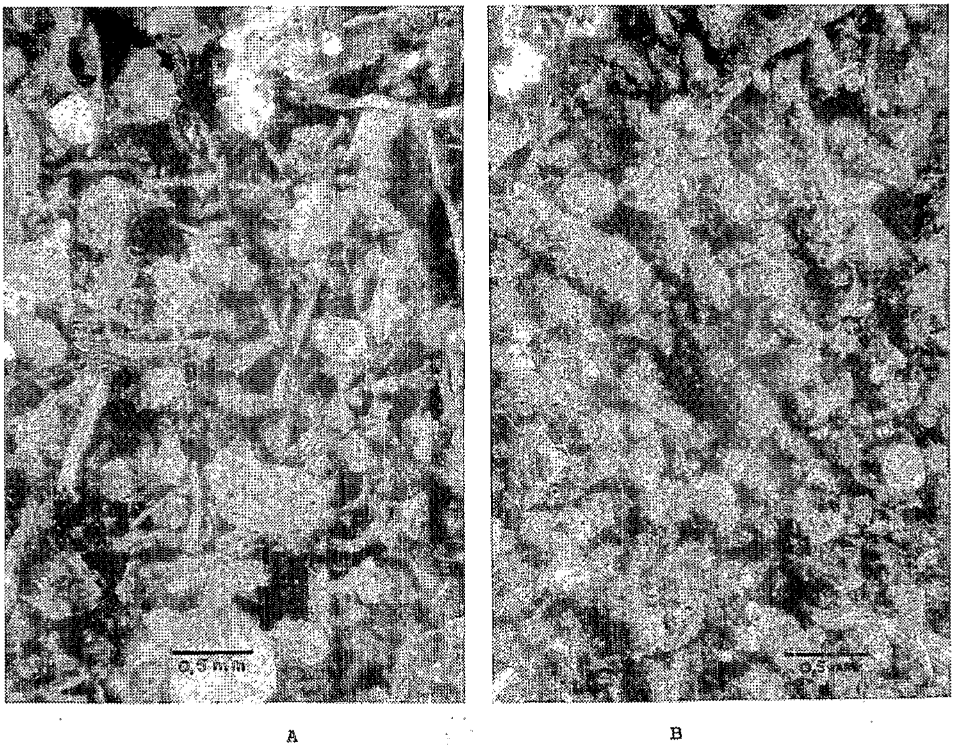

Fig. 5. – The 0.02-0.5 mm light organic matter fraction of *Eucalyptus* PF1 (A) and *Acacia auriculiformis* (B).

Particle-size fraction distribution

The amount of carbon in each particle-size fraction (fig. 8) showed an increase in all light fractions under the trees compared to savanna and compared to the zero point which was the soil tilled for tree planting. The coarser fraction (0.5-2 mm) increased the most and did not show any significant difference among tree species.

The main significant difference among species was observed for the 0.2-0.5 mm fraction, the amount of which was twice as high under Acacia as under Eucalyptus.

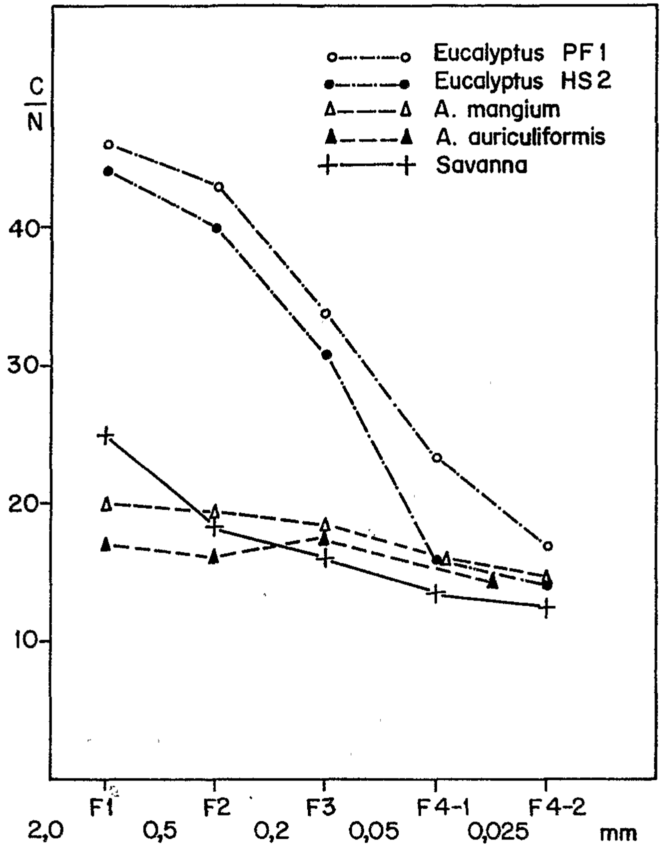

FIG. 6. – Average C/N ratio of the particle-size fractions.

In the organomineral fraction (< 0.05 mm), equal amounts of organic matter were found in savanna and tree stands. As shown previously the amount of carbon in this fraction under Eucalyptus did not increase significantly with age in the studied fractions (BERNHARD-REVERSAT, 1991*b*).

The evolution of organic matter

The high lignin content of plant residue, according to PARTON *et al.* (1987), leads to a high content of the "structural" fraction compared to the "metabolic" fraction in soil organic matter, and therefore to material which will be resistant to degradation. Thus the Acacia litter could evolve into more resistant organic matter than Eucalyptus litter. Besides, the observed increase of N content of Eucalyptus light fractions can stimulate their decomposition by decreasing the lignin-/nitrogen ratio.

Moreover, comparison of fractions suggested the hypothesis that macro and mesofauna were mainly responsible for the disappearance of the N-rich Acacia litter and that once converted into feces the organic matter was more resistant to

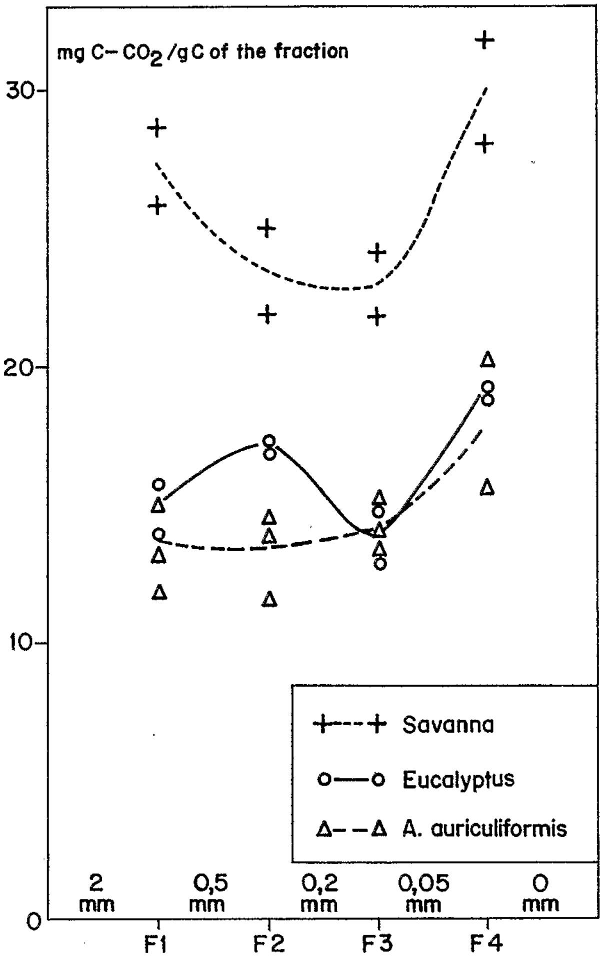

FIG. 7. – *In vitro* carbon mineralization in the particle-size fractions of the 0-2 cm layer of soil.

microbial action, either by humification (FELLER *et al.*, 1983) or by sequestration of labile materials inside the aggregates (GREGORICH *et al.*, 1989). The result was a relative accumulation in the fraction. Under Eucalyptus and savanna there was less consumption by macro-fauna and the fragmented litter was more suitable for microbial activity.

CONCLUSIONS

Regarding the process studied, the two Eucalyptus hybrids showed similar behaviour. Differing from them, the two Acacia species resembled each other.

The Acacia and Eucalyptus stands, although having similar high productivity (BERNHARD-REVERSAT *et al.*, in prep.), showed different functional processes.

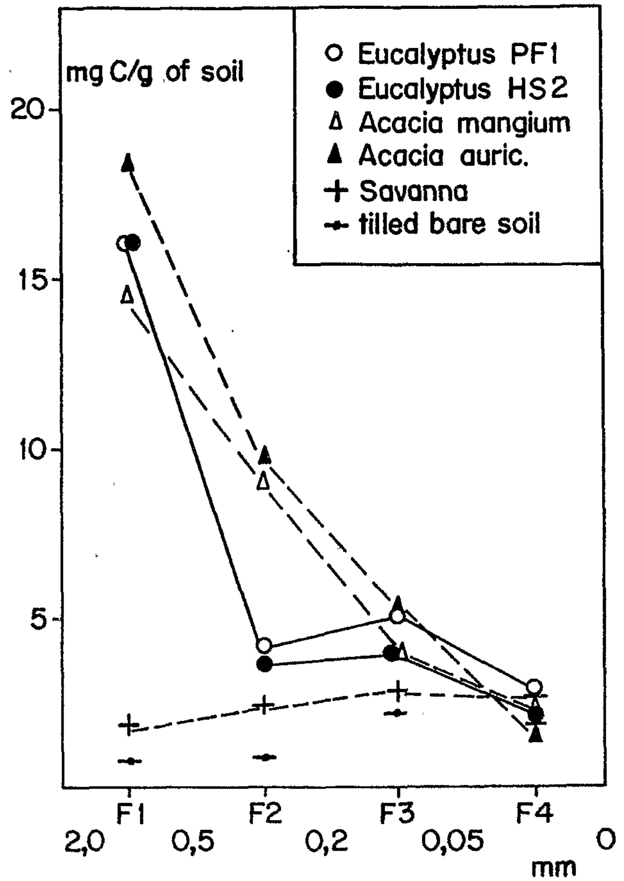

FIG. 8. – Carbon distribution in particle-size fractions of the 0-2 cm layer of soil.

Acacia litter disappeared more quickly in spite of its higher lignin content. Its high N content led to a high rate of consumption by the meso and macrofauna.

However at the soil-litter interface, observation on organic matter fraction suggested an inverse relationship, with a better stability of organic matter under Acacia. This was confirmed by the observation of the 0-10 cm layer of soil in 7-8-year-old stands whose organic matter had increased under Acacia compared to savanna, while no increase was observed under Eucalyptus.

Previous studies on *Eucalyptus camaldulensis* compared to *Acacia seyal* led to a similar hypothesis (BERNHARD-REVERSAT, 1987) concerning the low humification rate of Eucalyptus residues. Regarding soil improvement, Eucalyptus appears to be less adapted to sandy soils than Acacia species.

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