Chapter 3.

Litterfall, Litter Quality and Decomposition Changes with Eucalypt Hybrids and Plantation Age

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Introduction

Litterfall serves three main functions in the ecosystem: energy input for soil microflora and fauna, nutrient input for plant nutrition, and material input for soil organic matter development. The first two functions are completed through decomposition and mineralisation, and the third through decomposition and humification. Those functions are related to main soil processes, especially microbiological activity and soil fauna activity, litter quality and quantity. Annual litterfall in the Congolese eucalypt plantations was previously shown to be low compared to many natural tropical forests or to other fast growing trees (Loubelo 1990; Bernhard-Reversat 1993), and to have high content of phenolic compounds (Bernhard-Reversat 1999) which are known to affect many biological processes. The hypothesis of the control of litter quality, quantity and decomposition by plantation age, management, and hybrid was studied.

Studied Plots and Methods

Litter measurements

Litterfall was measured in 6, 13, and 19-year-old plots of *Eucalyptus* PF1 and an 8-year-old plot of *Eucalyptus urophylla* x *E. grandis* hybrid referred to as *E.* urograndis (plots Ep, Er, Et, Eu, Ev). As the plots were logged every 7 years, the trees were 6-7 years old in all plots except in the 19-year-old plot, where half of the area was never logged and the trees were 19 years old, and the other half was coppiced. The 8-year-old plot of *E.* urograndis (clone 18-85) referred to as (plot Ev), was also sampled to compare its litter production with that of PF1. In the 6-year-old PF1 (plot Ep), litterfall was sampled every week in 15 quadrats of 0.56 m^2. In the other plots, litterfall was sampled in 10 quadrats of 0.25 m^2, and sampling was made every week during the rainy season and every other week during the dry season. The quadrats were covered with 1-2 mm mesh plastic screen. Samples were oven-dried (65-75°C) and weighed. Three fractions were sorted: leaves, twigs and bark, fruits and flowers. Samples from each four-week period were combined for nutrient analysis at the IRD Analysis Laboratory of Pointe-Noire. Unfortunately, except in 6-year-old plot Ep, this pattern was disturbed because the time lag between sampling, was occasionally longer and some quadrats' screens were sometimes stolen; consequently it was not possible to calculate the annual litterfall per quadrat for statistical purposes. Statistical analysis was made on the basis of

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litterfall per week, and comparisons took into account the overall results for a sampling time. Annual litterfall was calculated by multiplying the mean weekly litterfall for each plot by 52.

Standing litter was sampled with a 6 cm diameter cylinder, and three cores were taken for each sample. Three replications were made in each plot. This rapid method gave good reproducibility and therefore allowed reliable comparisons between stands, but over-estimated by approximately 25% the results when compared with the usual single sampling of larger areas.

Characterisation of leaf litter

For the organic characterisation of litter, freshly fallen leaves, recognised by their colour, were picked up from the soil, and air-dried. Sampling was made in February 1998 and 1999. The thickness of the leaf blade was measured. It was measured between the main veins with a thickness gauge (by 0.01 mm), after re-humidification of litter leaves in boiling water. Two measurements were made on each of ten leaves for each clone.

Air-dried and milled litter were chemically analysed and chemical contents were expressed as oven-dried weight (75°C). Fibres were analysed by the method of Van Soest (1963) by determination of neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) at the CIRAD-AMIS Laboratory. With this proximate method, a variety of compounds are included in the so-called "hemicellulose", "cellulose" and "lignin" fractions but it is generally used for comparisons in plant material. Some samples were analysed for nitrogen on 100 mg samples using a LECO FP 428 CHN apparatus in the same laboratory, and in other samples nitrogen was determined as NH_4 by the Nessler method after mineralisation in concentrated sulphuric acid with H_2O_2. Soluble C and soluble phenolics were extracted by mixing 1 or 2 g of litter in 60 ml of cold water during two hours. Total extractable phenolic compounds were extracted according to the Tropical Soil Biology and Fertility Programme method (Anderson and Ingram 1993) by heating 0.5 g of litter in 50% (v:v) methanol in water at 80°C for one hour. The difference between methanol extracted phenolics and water extracted phenolics was referred to as "insoluble phenolics", and the phenolic compounds which were not extracted by methanol were not taken into account in this study. Soluble carbon was determined in water extracts by the chemical oxygen demand (COD) with the rapid HACH method (Anonymous 1994) and for conversion of COD to carbon, the assumption was checked previously that soluble carbon consisted mainly of glucids (Reversat 1981). Phenolic compounds were determined in water extracts and in methanol extracts by the tyrosine reagent (HACH method, Anonymous 1994) which takes into account all hydroxyled aromatic compounds.

Iron mobilisation ability

Litter solutions were made with 2 g in 60 ml distilled water and 2 hours shaking. To perform iron extraction, 30 ml of litter extracts were shaken for one hour with 5 g of a standard eucalypt soil (0-5 cm depth) and centrifuged. Iron was determined colorimetrically in the solution by the phenanthroline reactant after organic matter was mineralised with H_2O_2. Control extractions were made with distilled water.

In vitro and *in situ* decomposition rates

In vitro litter decomposition was studied by carbon mineralisation measurements of air-dried and milled fresh litter. Micro-litterbags (50 x 50 mm) were made with 60 mm pore size nylon mesh. They were filled with 1 g of litter, which was humidified, with 2 ml of soil solution (20 g of savanna soil mixed with 50 ml of water for 30 minutes and decanted). Each bag was put in a jar with a beaker containing 50 ml of 0.1 N NaOH, which trapped the CO_2. NaOH determinations were made at intervals with 0.5 N HCl.

In situ decomposition rates were measured in 20 cm x 20 cm litter bags, 1.5-2 mm mesh size each, with 10 g of air dried leaf litter, the oven dried weight being measured in another part of the sample. Litter bags were put on the soil surface in the same plot from which the litter came, in March, July and October, and were sampled after 4 and 12 weeks in the field with 12 replications at each date (in some cases, a few replications were lost). The decomposed litter was dried at 75°C and weighed.

Results and Discussion

Litterfall

Annual litterfall ranged from 6.9 t ha^{-1} in the younger plot to 12.8 t ha^{-1} in the old first rotation plot (Table 3.1). Total litterfall and leaf litterfall were significantly different among plots, unlike wood litterfall. Fruits fell only in the 19-year-old first rotation plot. In the young 6-year-old first rotation plot the result was close to the 6.5 t ha^{-1} which was found previously in another PF1 plot (clone 1-45) (Bernhard-Reversat 1993). It was higher than in dry tropical or Mediterranean eucalypt plantations where litterfall was 2-3 t ha^{-1} yr^{-1} (Knokaert 1981 in Morocco; Bernhard-Reversat 1987 in Senegal; Abelho and Graça 1996 in Portugal). In temperate natural eucalypt forests litterfall was of the same order of magnitude as found in Congo at the same age (Polglase and Attiwill 1992). In Puerto Rico, Parrotta (1999) found an annual average of 5.4 t ha^{-1} in younger tropical plantations. When compared to nitrogen fixing plantations, eucalypt had generally a lower litterfall (Parrotta 1999; Bernhard-Reversat and Loumeto, in press).

Litterfall increased with aging of plantations, and was also influenced by harvest operations and between hybrids. Although the trees were approximately of the same age, leaf litter production was significantly lower in the young 6-year-old first rotation plot than in the older 13-year-old coppice plot (about 6 years of coppice growth). Previous observations (Bernhard-Reversat 1993) reported that the litterfall of 2-year-old *E.* PF1 coppice plot was the same as that of the former 7-year-old first rotation crop in the same plot. This suggested a rapid growth of the canopy in the coppice, allowed by the expanded rooting system. The lower litter production in the 19-year-old coppice compared to the 13-year-old coppice, and to the 19-year-old unlogged first rotation crop, might suggest the physiological aging of the stock, the depletion of soil nutrient by export (Steward *et al.* 1988, Miranda *et al.* 1998) or the alteration of the roots by parasitic nematodes (Loubana and Reversat, chapter 6), together with the possible decrease of nutrient availability.

Eucalyptus urograndis had a significantly higher leaf litterfall (6.8 t ha^{-1} yr^{-1}) than the young first rotation plot of *E.* PF1 (4.3 t ha^{-1} yr^{-1}). The age of the trees differed by two years and might explain the difference in litterfall, although a linear regression with the 6-year-old and the 19-year-old first rotation plot litterfall gave 5.2 t ha^{-1} for a 8-year-old *E.* PF1 plot. It was shown previously that the leaf biomass of four *E.* urograndis clones was about 30% higher than the leaf biomass of *E.* PF1, clone 1-41 (Safou-Matondo *et al.* 1999). During the study of an age series of *E.* PF1 (clone 1-41) by Laclau (unpublished data), a very low amount of litterfall was collected during the first year after planting (0.4 t ha^{-1} yr^{-1}) and was only leaves. Between the second year and the logging age, leaf litterfall remained stable (about 4 t ha^{-1} yr^{-1}) while the amount of wood and bark litterfall increased up to the fourth year after planting. Parrotta (1999) also observed a relatively steady litterfall from the second to the fourth year of plantation.

Nutrients in litterfall

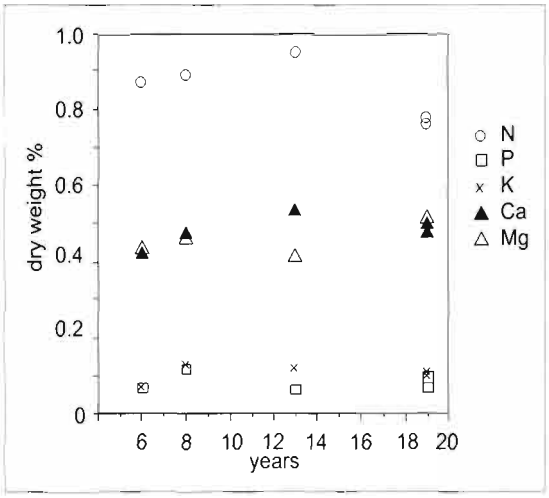
Similar values of leaf litter nutrient concentration were observed for the different plots and neither plot age nor previous exploitation appeared to have an effect on nutrient contents (Fig. 3.1). *Eucalyptus* urograndis leaf litter was not different from *E.* PF1 except for a higher P concentration. Laclau *et al.*

Table 3.1 Annual litterfall in eucalypt plots (g m^{-2} yr^{-1} with standard error in brackets)

Plot	Stand type	Eucalypt hybrid	Plot age (yr)	Leaves	Twigs and bark	Fruits	Total
				(g m^{-2} yr^{-1})			
Ep	Seedling	PF 1	6	431 (75)	256 (80)	0	688 (107)
Er	Coppice	PF 1	13	831 (27)	256 (48)	0	1087 (54)
Et	Coppice	PF 1	19	664 (28)	271 (37)	0	938 (46)
Eu	Coppice	PF 1	19	888 (44)	378 (57)	25 (3)	1290 (76)
Ev	Seedling	urograndis	8	684 (27)	320 (72)	0	1004 (77)

(2000a) reported an increase of leaf N content with age and a decrease of P, K, Ca, and Mg in young plantations from 1- to 7-year-old, but no information was available for older plantations. Polglase and Attiwill (1992) observed little variation in leaf N content in 5- to 80-year-old eucalypt stands in Australia. A trend for the concentration in N, P and K in leaves and in leaf litter from 1- to 8-year-old eucalypt plantations to decrease was shown by Bargali *et al.* (1992, 1993). The decrease in leaf litter nutrient concentration during the first years of plantation might decrease and disappear when the accumulation of litter on the soil allows nutrients to be partly involved in direct litter-root cycling.

Figure 3.1 Nutrient content of leaf litter of eucalypt plots at different plot ages. The 8-year-old is *E.* urograndis, the others are *E.*PF1



As a consequence of the low variations in nutrient concentration, nutrient input to the soil through litter varied mainly according to the amount of litterfall (Fig. 3.2) and decreased in the coppice that was twice logged, reinforcing the hypothesis of nutrient shortage due to exploitation.

Leaf litter blade thickness

The differences in leaf litter blade thickness among eucalypt clones, calculated with individual leaf measurements, were highly significant (ANOVA, $p<0.0001$). Leaf litter thickness was significantly different among hybrids ($p<0.001$), years of sampling ($p=0.01$), and production levels ($p<0.01$). The year effect might be due to rainfall amount or distribution. For each hybrid, leaves from high production clones are thicker than leaves from low production clones and it needs to be determined if this corresponds to thicker photosynthetic parenchyma. Blade thickness was correlated to the (Van Soest 1963) hemicellulose content and to leaf litter N content ($p<0.05$), and this last relationship could contribute to the relationship with production (Fig. 3.3).

Leaf litter organic compounds

Water soluble carbohydrates

The average soluble carbon content was 105 mg g^{-1} of litter, which is equivalent to 26% of dry weight if expressed as soluble organic matter, and it ranged from 15 to 35% of dry weight. However,

Figure 3.2 Annual nutrient input to the soil by litterfall in eucalpt plots

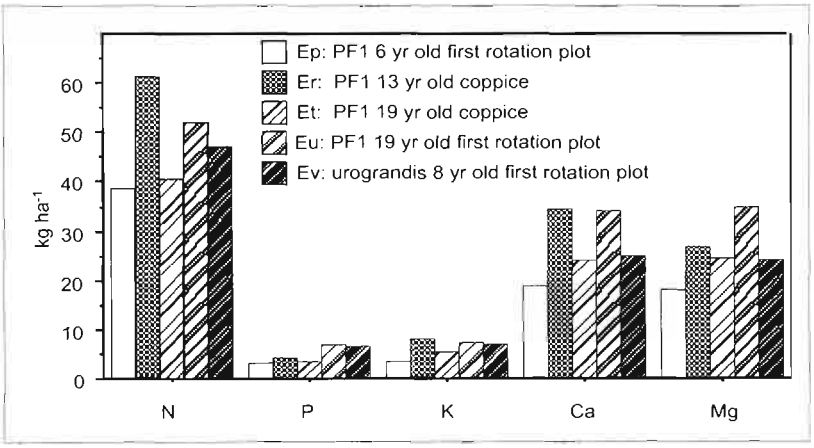


Figure 3.3 Eucalypt leaf blade thickness, hemicellulose (Van Soest) and total N contents

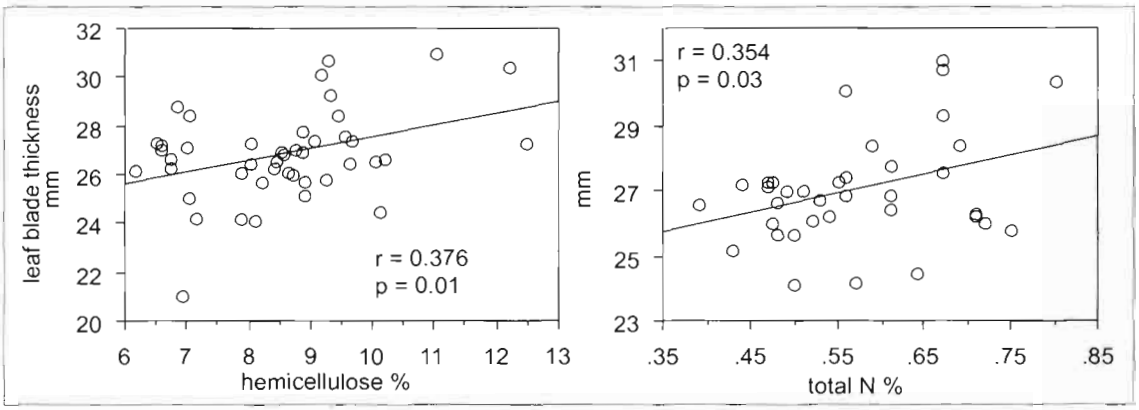


Table 3.2 Fibre content of leaf litter of two eucalypt hybrids (% of dry weight with standard error in brackets), estimated by the Van Soest method

Fibre	*E.* PF 1 % of dry weight	*E.* urograndis p*	Significance
Hemicellulose	8.5 (1.4)	8.6 (1.5)	Not significant
Cellulose	15.9 (0.9)	14.3 (1.7)	0.0004
Lignin	16.4 (1.5)	15.5 (1.7)	0.06

*p = probability for significant differences between eucalypt hybrids.

this large range of variation was related neither to hybrids nor to production level nor to plot age, and neither did non-phenolic soluble organic matter when soluble phenolics were considered separately.

The average water-soluble phenolic compounds were 9.5% of dry weight, and 36% of soluble organic matter. Soluble phenolic content was correlated with non-phenolic soluble carbon content ($p<0.01$). ANOVA analysis showed a significantly higher phenolics content in *E.* urograndis than in *E.* PF1 ($p<0.01$). When coppice and first rotation crops were compared in the 19-year-old plots, soluble phenolic content was the only litter characteristic that was different, and coppice litter had a lower soluble phenolic content. Water soluble phenolic content of eucalypt was high compared to most other tropical tree species which we analysed previously (Bernhard-Reversat 1998). Most other data record methanol soluble phenolic contents (Palm and Rowland 1997) rather than water soluble contents. However, in our case we found the water soluble fraction to be more relevant for decomposition (Bernhard-Reversat 1998) and faunal activity studies (chapter 7).

Fibres and methanol extractable phenolic compounds

The average concentration of "insoluble" phenolic compounds (methanol extractable minus water extractable) was 70 mg g^{-1}, and the range was 26-93 mg g^{-1}. Variations were not related to hybrids or clones.

The lignin concentration of eucalypt litter was found to be low compared to tropical species and to Congolese natural forest litter (Anderson and Swift 1983; Bernhard-Reversat and Schwartz 1997), although in the range of concentration given by Constantinides and Fownes (1994) for a number of tropical trees. Cellulose and lignin contents are significantly different between hybrids (Table 3.2). Most *E.* PF1 clones had a higher fibre content than *E.* urograndis clones. When considering *E.* PF1 alone, lignin concentration decreased significantly with plot age ($p<0.0001$). Although the relationships between litter organic composition and plantation age were scarcely studied, lignin was not related to plot age in the agroforestry species studied by Nyathi *et al.* (1991).

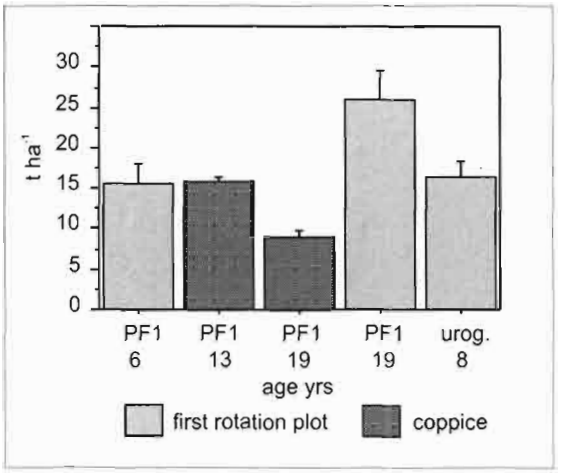
Nitrogen

Nitrogen concentrations exhibited a wide range of variation from 0.39 to 0.80%, with an average of 0.57%. The two different chemical analysis methods were taken into account for ANOVA analysis, and the two hybrids have significantly different N content; the averages were 0.61% for *E.* PF1 and 0.54% for *E.* urograndis.

Iron mobilisation

Ellis (1971) in Australia observed iron mobilisation by eucalypt litter extracts, and percolates of *E.* PF1 were shown previously to mobilise iron (Bernhard-Reversat 1999). Ellis (1971) and Enright (1978) related this effect to podzolisation. Iron mobilisation ability of *E.* PF1 and *E.* urograndis litter extract was high. The observed range in iron mobilisation in the studied samples (ranging from 1.1 to 1.6 mg ml^{-1}) was narrow, and it was not significantly different between either hybrids or clones. Although phenolic compounds, with organic acids, are known to be responsible for soil iron mobilisation (Pohlman and McColl 1988), the relationship found here was negative, and the ratio extracted Fe/soluble phenolics was higher in *E.* PF1 than in *E.* urograndis. The suggested hypothesis that phenolics compounds differed in quantity or quality in the two hybrids will be investigated in further studies.

Figure 3.4 Estimated standing litter accumulated on the soil of eucalypt plots (over-estimated due to the sampling method)



Leaf litter accumulation and decomposition

Stand harvests appeared to decrease sharply the amount of standing litter, which otherwise increased with plot age and reached high values (Fig. 3.4). The decomposition coefficient was previously calculated in a 7- to 8-year-old *E.* PF1 plantation and was shown to be low (Bernhard-Reversat 1993). In the present litterbag experiment, 25 to 30% of dry weight was lost in three months. The ANOVA showed a highly significant effect of plot and season ($p<0.0001$,

Figure 3.5 Leaf litter decomposition rate after 4 and 12 weeks in three experiments in different seasons

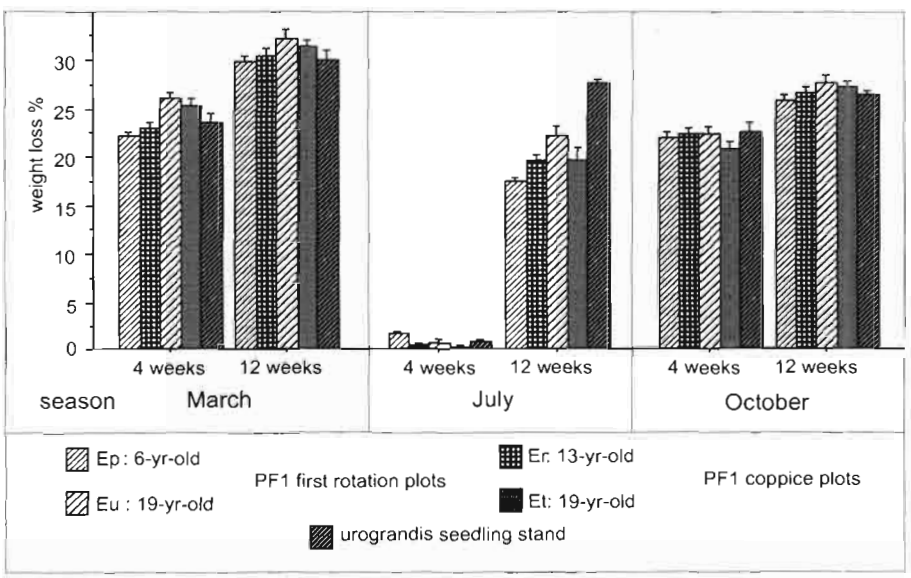


Fig. 3.5). The plot effect was due to a slight increase of decomposition rate with plot age and a higher ($p<0.05$) one in the first rotation plot than in coppice when compared in the 19-year-old plots, suggesting an effect of litter quality. The slow decomposition in tropical plantations compared to natural forest, especially in eucalypt and pine plantations, has been observed by numerous authors and stressed in some reviews (O'Connell and Sankaran 1997; Bernhard-Reversat and Loumeto 2001). The decrease in lignin content with age could account for increasing decomposition rate. Such an increase in decomposition rate with plot age was observed for subtropical tree fine roots by Arunachalam *et al.* (1996) together with lignin content decrease.

The difference between hybrids changed according to seasons; during the rainy season (experiments beginning in March, October or January), decomposition rates were only slightly higher in *E.* urograndis compared to *E.* PF1 (8- and 6-year-old respectively); during the dry season the litter of *E.* urograndis decomposed significantly faster than the litter of PF1. Differences in litter fauna activity might explain this observation but fauna observations (Mboukou-Kimbatsa *et al.* 1998) were not made during the dry season.

Conclusions

The litter system is highly dependent on the management factors: the results suggest that plot age, exploitation, and hybrid have an effect on litter quality and decomposition rate. Although these effects are small as measured values, they are significant and might influence nutrient cycling and soil organic matter accumulation and could also control microbiological and faunal activity. The aging of plots appeared to improve the functioning of the litter system. Logging operations create major disturbance of litter decomposition dynamics.