# Chapter 4.

## Soil Fertility Changes with Eucalypt Hybrids and Plantation Age: Soil Organic Matter

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### Introduction

Soil organic matter in the plantations originates from eucalypt litter and from the previous savanna vegetation (Trouvé *et al.* 1994). The amount of organic input in savanna is low and originates mainly from dead roots due to annual burning. Soils planted with eucalypts have a low organic matter content together with low clay and nutrient contents. Increasing organic matter improves the nutrient status of soil, and is also assumed to improve biological activity and soil structure. Therefore any research and knowledge improvement in this area is of tremendous importance for nutrient conservation in the plantations, especially when grown on poor soils.

It was shown previously that soil organic matter content was the same in savanna soil and in a 7-year-old eucalypt plantation, and that it increased later, mainly due to light fraction increase (Bernhard-Reversat 1991). Observations carried out in other situations have either confirmed the above trend or shown different patterns of change. Trouvé *et al.* (1994) and Binkley and Resh (1999) showed that under eucalypt plantations, organic matter originating from the native savanna decreased whereas organic matter from eucalypt increased; therefore total C content did not change for several years. Parrotta (1999) also observed that no significant change in soil C occurred in 7.5-year-old eucalypt plantations established on a grassland soil in Puerto Rico. Jaiyeoba (1998) observed that soil organic matter decreased in eucalypt plantations grown on savanna soil during the first years and increased at a later age. Other observations showed organic matter decrease in eucalypt plantations grown on C-poor soils (Bernhard-Reversat 1988; Nandi *et al.* 1991; King and Campbell 1994). In the arboretum studied by Lugo *et al.* (1990) in a rain forest area where several planted species were compared, soil organic matter content either increased or decreased according to the species, and organic matter contents in eucalypt plots were among the highest. The aim of the present study was to investigate changes in soil fertility with a selected clone, and to assess the effect of plot age, exploitation and hybrids on soil organic matter, nitrogen and cation exchange capacity.

### Studied Plots and Methods

The study was carried out on seven planted plots either harvested or not (Ep, Eq, Er ,Es, Et, Eu, Ev) and on savanna (Sb) (Table 0.3). Six composite samples were made in two layers (0-10 cm and 10-20 cm) in each plot. Each composite sample comprised four cores were which were extracted, close to each other, with a 62 mm diameter tube

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sampler after removing the litter layer. Each composite sample was air dried for analysis. From the six replicates, three were made in February and three in April. A slight difference between dates was significant and was taken into account to assess the significance of plot differences.

Particle size fractionation was made in the 0-5 cm layer. For this purpose, three composite samples were made in each plot, from three cores extracted with a 62 mm diameter tube sampler together with the litter layer. Each composite sample was air dried and fractionated. The litter fraction was sorted by dry sieving at 4 mm and 2 mm and soil fractionation was performed by wet sieving according to Balesdent *et al.* (1991) to sort three light organic fractions (0.5-2 mm, 0.2-0.5 mm, 0.05-0.2 mm) and two organo-mineral fractions (0.02-0.05 mm, < 0.02 mm). Each fraction was analysed for C and N and the analysis of residual C in the mineral fraction was used to correct the organic fraction data. To assess the contribution of organic matter to cation exchange capacity (CEC), analysis of CEC was made on soil samples in which organic matter was removed by oxidation with hydrogen peroxide and on control samples. The above 0-10 cm soil samples were used.

Carbon was determined by the Walkey and Black method, nitrogen by the Kjeldahl method, and CEC by the ammonium acetate method.

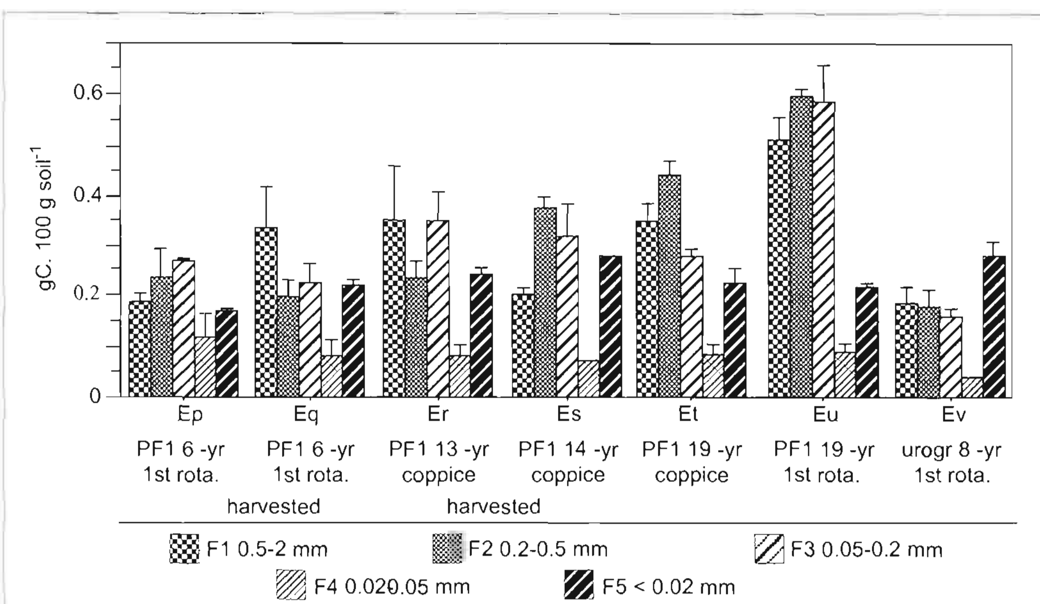
## Results and Discussion

### Organic matter particle size fractions

Particle size fractions were studied in the 0-5 cm layer of soil. The amount of organic matter in each fraction, expressed as mg C per g of soil, was different between plots (p ranging from 0.007 to 0.0001 with ANOVA) for all fractions except for F4-C (coarse loam) (Fig. 4.1).

The amount of organic matter in light fractions (> 0.05 mm, F1, F2, F3) was greater in the first rotation crop soil than in the coppice soil when the 19-year-old plots were compared (p=0.05, test of Mann-Whitney). Litterfall and litter accumulation on the soil were also greater in the first rotation crop than in the coppice, increasing organic matter input to the soil. Although assessed only on five plots, a significant relationship (p=0.01) between coarse light fraction C and litter disappearance in litterbags during the rainy season, either March or October, was observed (Fig. 4.2 and see chapter 3). Organo-mineral fractions were

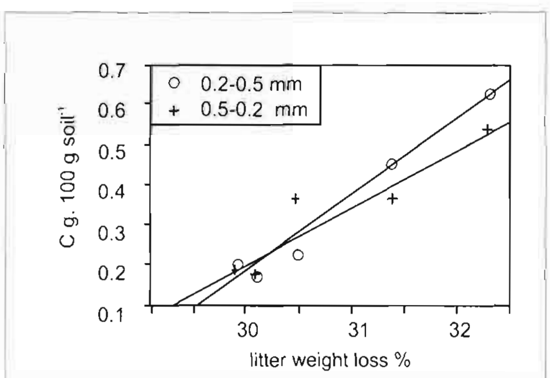
**Figure 4.1** Carbon in light organic fractions and organo-mineral fractions in the 0-5 cm layer of soil in eucalypt plots



not affected. Tree logging every 6-7 years did not prevent organic matter accumulation but it decreased the accumulation rate. The comparisons of hybrids in the young first rotation plots did not show any significant differences for F1 and F2 fractions, perhaps because of a too high variability. The F3 fraction was significantly lower in *E.* urograndis than in *E.* PF1 ($p=0.05$ test of Mann-Whitney).

The amount of soil organic matter in the various organic fractions increased with plot age whereas the amount of soil organic matter in the organo-mineral fractions did not (Fig. 4.3), as found previously (Bernhard-Reversat 1991). Feller *et al.* (1991) pointed out the importance of light fractions for organic matter accumulation in sandy soils. Harmand (1998) in Cameroon observed in a more clayey soil that C in organo-mineral fraction increased under *Acacia polyacantha* and not under *Eucalyptus camaldulensis*, and it could be possible that some humification processes are lacking or slow in eucalypt litter (Bernhard-Reversat and Schwartz 1997)

**Figure 4.2** Relationship between C in coarse particle-size fractions of (total soil) and eucalypt litter decomposition in litter bags expressed in percent of initial weight (March-May)




## Carbon and nitrogen

An ANOVA (Fig. 4.4) showed significant differences in C content between plots ($p = 0.0002$), plot average ranging from 6.7 to 11.1% in the 0-10 cm layer and from 5.0 to 5.7% in the 10-20 cm layer. Carbon content increased significantly with plot age ($r=0.548$, $p<0.001$) in the 0-10 cm layer, but not in the 10-20 cm layer (Fig. 4.5). The highly productive hybrids grown

**Figure 4.3** Amounts of C in soil particle size fractions versus plot age in eucalypt plantations

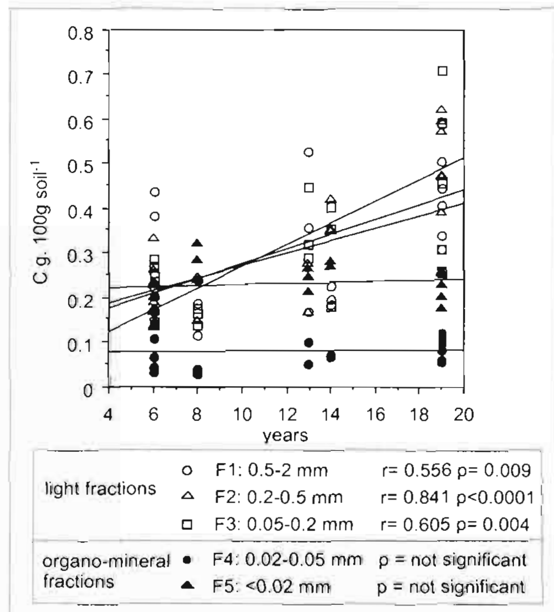
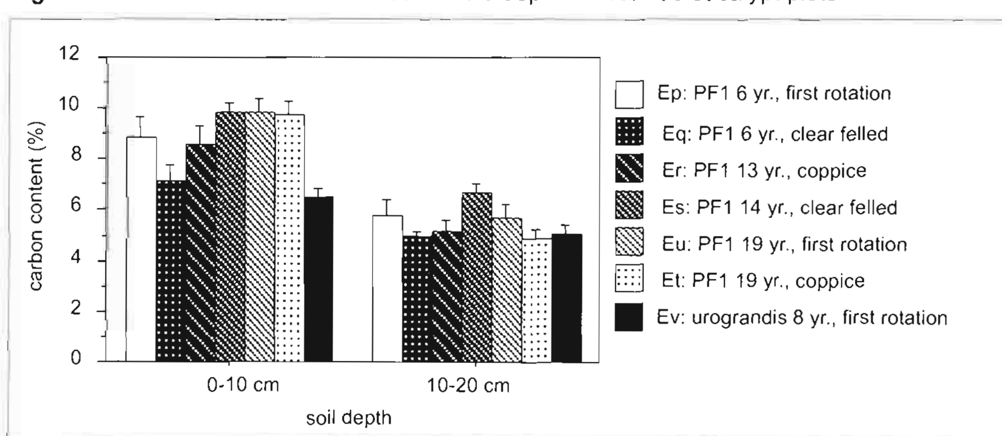



**Figure 4.4** Mean carbon content of soil at two depths in various eucalypt plots



in Congo might have a higher litterfall which could explain soil C increase with age.

The relationship between plot age and C content in the 0-10 cm layer of soil did not seem to depend on management practices (Fig. 4.5): there was no significant difference either between first rotation crop and coppice when plots were 19-20 years old, or between harvested and forested plots. Hybrids alone had a significant effect, and C content was significantly lower in the *E.* urograndis plot than in the *E.* PF1 plot of similar age ($p = 0.02$).

A small but significant decrease in N content was observed in the 0-10 cm soil layer of a 7-year-old eucalypt plantation (another hybrid, HS2) compared to savanna (Bernhard-Reversat 1996). In the PF1 hybrid studied here the decrease in N content of soil organic matter (N/C ratio) was more strongly marked and went on as plantations aged and it could be related to changes in litter quality resulting in an increase of N mineralisation rate compared to savanna. The N content in organic matter of the 0-10 cm layer of soil (N/C ratio) was slightly significantly lower ($p=0.05$) in *E.* urograndis than in *E.* PF1 plots. This observation deserves to be confirmed using more samples, because it could be related to N mineralisation reduction by the higher soluble phenolic content of *E.* urograndis litter, as observed in litter (Fox *et al.* 1990; Constantinides and Fownes 1994) although such effect was not found in soil by Aggangan *et al.* (1999). An increase in soil C/N

**Figure 4.5** Effect plot age and management practices on the soil carbon content of the 0-10 cm and 10-20 layers of soil in eucalypt plantations

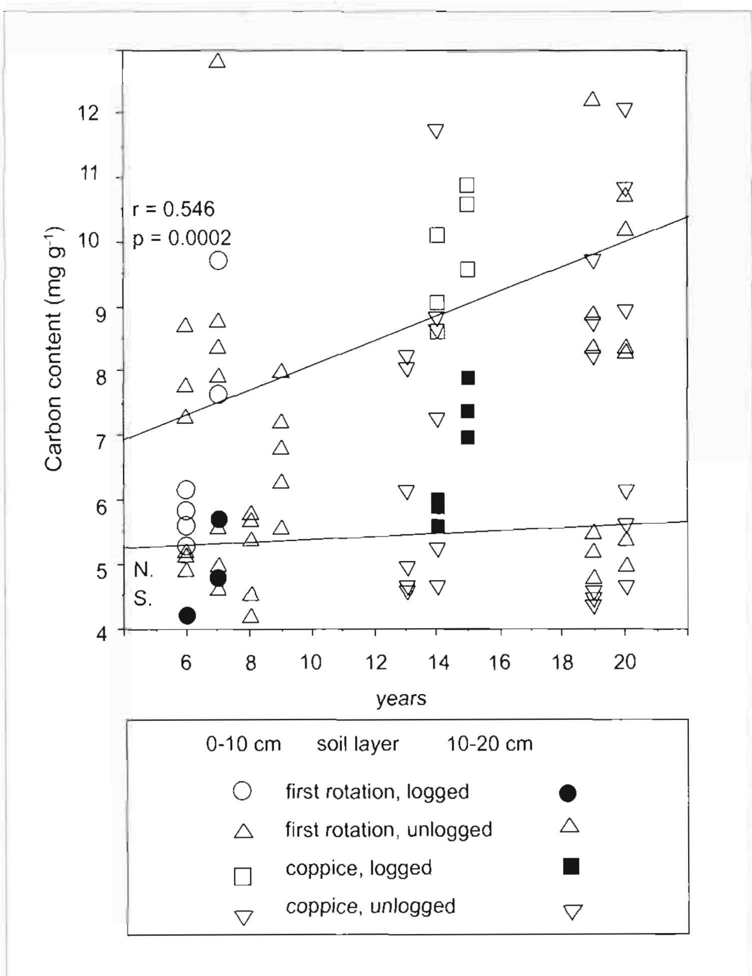
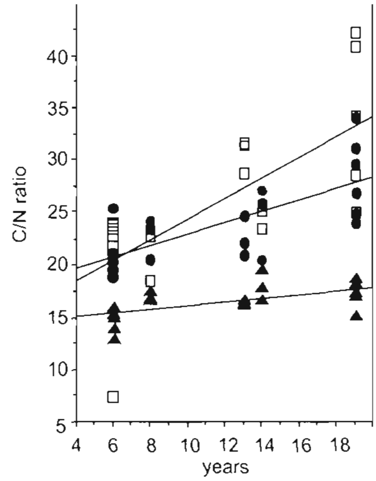
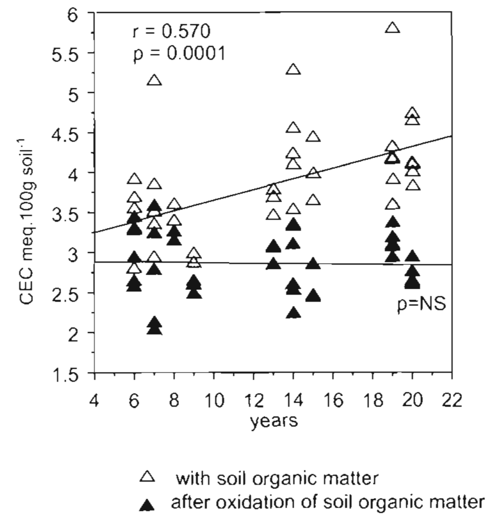


**Figure 4.6** Relationships between plot age and the C/N ratio of particle size fractions in eucalypt plots




| fraction | slope | r | p |
|---|---|---|---|
| □ F3 0.05-0.2 mm | 0.984 | 0.708 | 0.0003 |
| ● F4 0.02-0.05 mm | 0.557 | 0.722 | 0.0002 |
| ▲ F5 <0.02 mm | 0.176 | 0.600 | 0.0041 |

**Figure 4.7** Change of CEC with the age of eucalypt plots in the 0-10 cm layer of soil, before and after organic matter destruction




ratio (decrease in organic matter N content) under eucalypt plantations was observed by King and Campbell (1994) who ascribe it to poor litter quality.

The C/N ratio did not change with age in the coarse light fractions, whereas it did in the fine light fraction and in the organo-mineral fractions (Fig. 4.6), showing that the decrease in N content of soil organic matter, described above, resulted from a lower N content of the fine organic matter. Nitrogen decrease was also observed by Binkley and Resh (1999) and this could confirm the observation on the changing organic matter origin from savanna material to eucalypt material underlined by these authors and Trouvé *et al.* (1994) with $^{13}C$ analysis, even when organic matter amounts did not change. Madeira *et al.* (1989) also observed an increase in the C/N ratio of soil organic matter fractions in eucalypt plantation compared to the previous *Quercus* forest.

### Organic matter contribution to CEC

Cation exchange capacity (CEC) was significantly different among plots. Plot management practices (logged compared to unlogged and first rotation crop compared to coppice) had no influence on CEC. Cation exchange capacity increased with age. When organic matter was destroyed by oxidation, the remaining CEC, mainly due to clay, was not related with age (Fig. 4.7), whereas the difference with total soil CEC, assumed to be due to organic matter exchange sites, was highly correlated with age ($r=0.62$, $p<0.0001$). Although this process occurred only in the top layer of soil (0-10 cm), it may be of significance for tree nutrition because a great part of eucalypt fine roots is in this layer.

## Conclusions

Soil organic matter changes are strongly related to plot age, although organic matter accumulation did not begin before 6-7 years after planting. The increase in soil organic matter was related to the highly productive hybrids that are grown in Congo However, the nitrogen content of the soil organic matter decreased with plantation age due to efficient nitrogen mineralisation and tree growth needs. This might result in a severe lack of nitrogen in aging coppice stands in the absence of nitrogen fertilisation.

The soil organic matter component was apparently less affected by harvest practices than the litter system, and previous exploitation did not show any important effect. An approximate estimate according to Laclau *et al.* (2000a) gave 22 t ha$^{-1}$ for the part of biomass assumed to stay on the ground after clear felling in a 7-year-old plot. If each harvest brings to the soil approximately this amount of residue, accounting for the equivalent of 3 t $yr^{-1}$, it could make up for the annual difference of litterfall input between the 19-year-old coppice and the first rotation crop. The branch wood which is left on the soil may be easily humified because its lignin is less polymerised than that of the stem wood, and it has a higher nutrient content (Lemieux 1996). Although eucalypts are among the less efficient species for improving soil nutrient status (O'Connell and Sakaran 1997) when grown on the poor savanna soils of Congo, their litter contributes to soil fertility increase after 6 to 7 years of plantations.