Chapter 7.

Effect of Exotic Tree Plantations on Invertebrate Soil Macrofauna

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Introduction

The effect of plantations on plant biodiversity was discussed by Parrotta (1993) and for the studied plantations by Huttel and Loumeto (see chapter 1). Vegetation is known to influence the trophic chain and soil fauna in particular (Lavelle *et al.* 1994). Soil invertebrates carry out essential functions for soil functioning, specifically soil organic matter decomposition, soil aggregate formation, and soil mixing allowing the activation of micro organisms (Lavelle *et al.* 1997). Vegetation change is expected to affect macrofauna (Abbott *et al.* 1999; Vohland and Schroth 1999; Gonzales and Seastedt 2000) and degraded lands generally undergo a decrease in soil fauna density and diversity (Tian 1998). In order to assess the effect of growing exotic trees on savanna soils, soil macrofauna was studied among plots of various ages, species, hybrids and management practices.

Studied Plots and Methods

Soil macrofauna was studied in the Pointe-Noire age series plots of the first project (Sa, Ea, Eb, Ec, Ef, F Table 0.2), in Loudima plots (EL, AL, PL, SL, Table 0.2.) and in plots of the second project (Ep, Eq, Er, Es, Et, Eu, Ev, Ew, Sb, Table 0.3). Only *E.* urograndis was sampled in the two last multiclonal plots.

Soil macrofauna was sampled according to the Tropical Soil Biology and Fertility Programme method (Anderson and Ingram 1993). In each plot, 10 samples were taken 5 m apart along a randomly chosen transect. Each sample was a column of soil 30 cm deep and 25 x 25 cm square. Columns were separated into four layers: litter, 0-10 cm, 10-20 cm and 20-30 cm. Samples were hand-sorted in a large flat dish, and all visible invertebrates were placed in 85° alcohol and then in a 4% formol solution for conservation. They were counted and weighed. To take into account weight loss due to alcohol or formalin, corrections for fresh weight were applied (Anderson and Ingram 1993). Organisms were not identified to species and only the main taxa were considered. These taxa were gathered together in the following groups: earthworms, termites, ants, and litter inhabiting animals.

Results and Discussion

Changes with vegetation and soil

Densities of earthworms, termites and litter animals were significantly different between plots whereas ants were present everywhere and did not show significant differences (Fig. 7.1). However, because density data are highly variable, the relationships between vegetation and frequency

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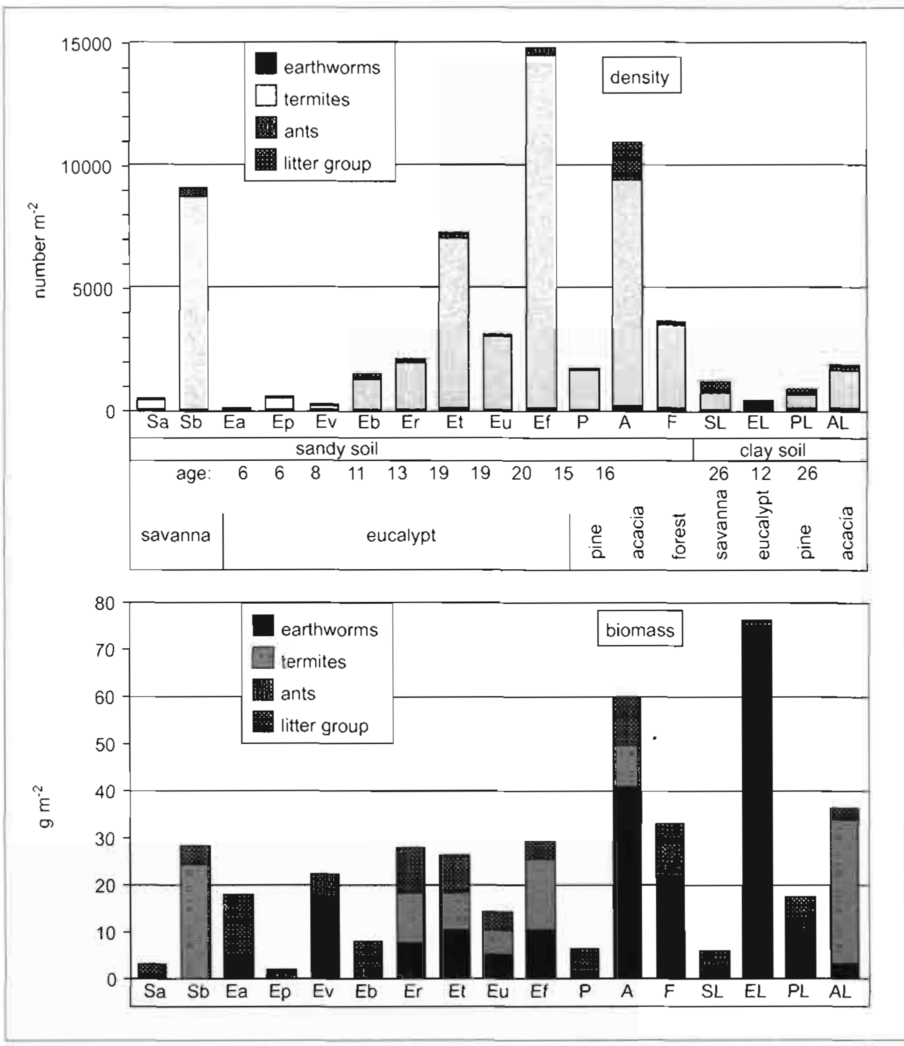
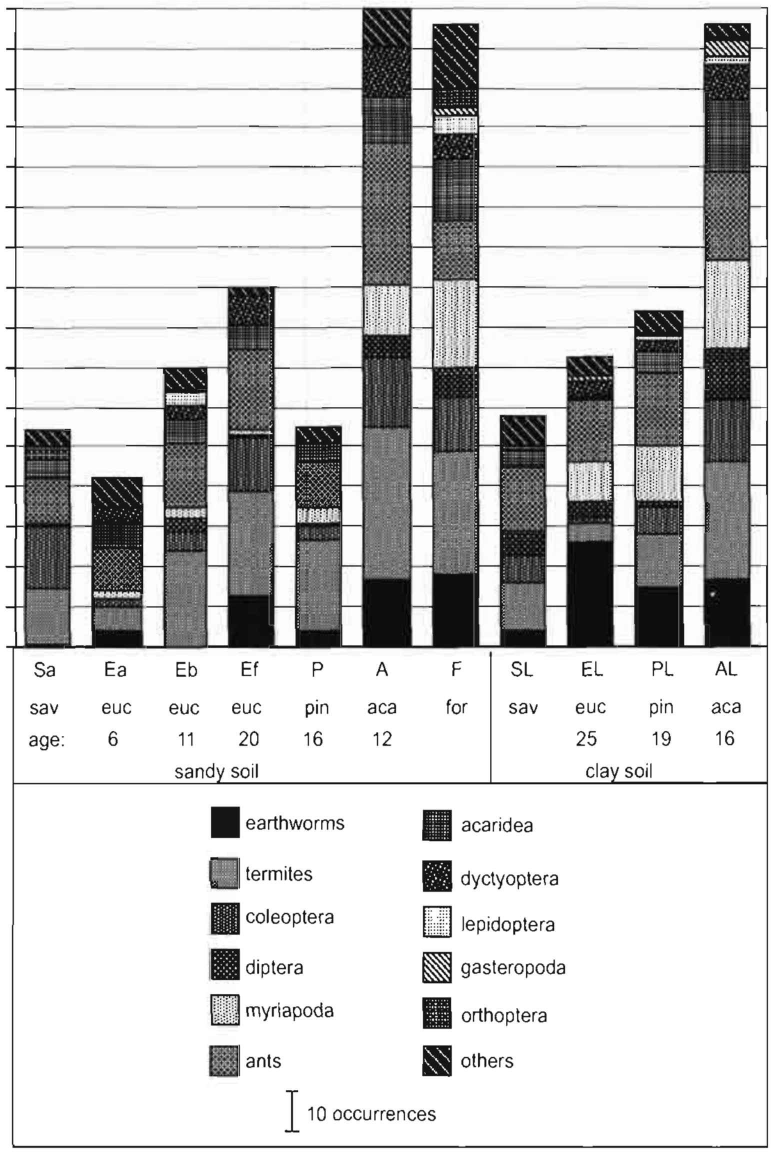
Figure 7.1 Density (number m^{-2}) and biomass (g m^{-2}) of the main groups of soil macrofauna in fast growing tree plantations and natural ecosystems



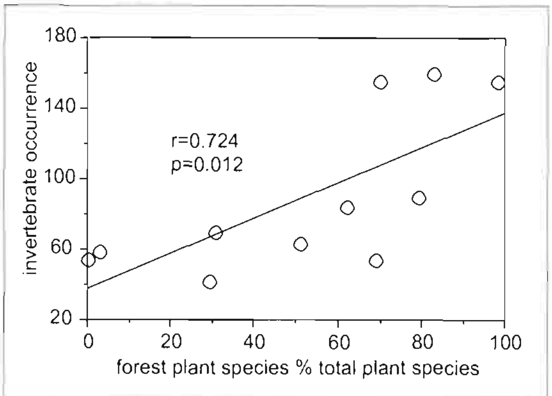
See Tables 0.2 and 0.3 for plot codes. The plot age is given in years. Sandy soils are near Pointe-Noire, clay soils are near Loudima.

Figure 7.2 Frequency of the groups of soil macrofauna taxa in fast growing tree plantations, savanna and forest plots



Plot age in years. sav = savanna, euc = *Eucalyptus* PF1, pin = *Pinus caribaea*, aca = *Acacia auriculiformis*, for = natural forest. See Tables 0.2 and 0.3 for plot codes.

Figure 7.3 Frequency (occurrence of invertebrates in samples) related to the percentage of forest plant species in the understorey vegetation of experimental plantations



were studied in experimental plantations for the first set of data. The frequency was the number of samples where individuals were found in each 40 samples in one plot (4 layers x 10 replicates) (Mboukou-Kimbatsa *et al.* 1998). The frequency gives weighted data for the different taxa (Fig. 7.2). Total frequency, as well as the frequency of earthworms, termites, myriapods and cockroaches in eucalypt plantations, was significantly correlated with the vegetation type ($p = 0.01$), expressed as the percentage of forest plant species in the understorey vegetation (Fig. 7.3). The closer the specific plant composition is to that of a forest, the more the plot is colonised by macrofauna. Several taxa were lacking in savanna, whereas all the counted taxa were well represented in forest. The lack of earthworms in the 11-year-old eucalypt plot might be due to the herbicide treatment that was made one year prior to sampling in this plot. However, the observed frequency in the oldest eucalypt plot (20 years) was far from that of forest. Because frequency is linked not only with the number of individuals, but also with the evenness of their distribution, it seemed to change slower than total biomass, which reached a level close to that of the forest in the 20-year-old plot (Fig. 7.2).

Pine and acacia showed very different results (Fig. 7.2 and 7.3). Pine plantations, like most eucalypt plantations, had poor invertebrate populations, and some taxa were lacking, whereas taxa frequency pattern under acacia resembled that of natural forest. In sandy soils at Pointe-Noire, total biomass was 6.3 g m^{-2} under pine and 59.7 g m^{-2} under acacia, this last value being higher than that of the forest (33.1 g m^{-2}). In clay soil in Loudima, biomass was 17.6 under pine and 36.3 g m^{-2} under acacia. This variation between planted species could be due to the quality of litter and soil organic matter and similar trends were observed for microarthropods (Bernhard-Reversat 1993). It was previously shown that pine litter was very poor in nutrients, particularly nitrogen, and that eucalypt litter was rich in tannins, whereas acacia litter was poor in tannins and rich in nitrogen (Bernhard-Reversat 1996, 1999).

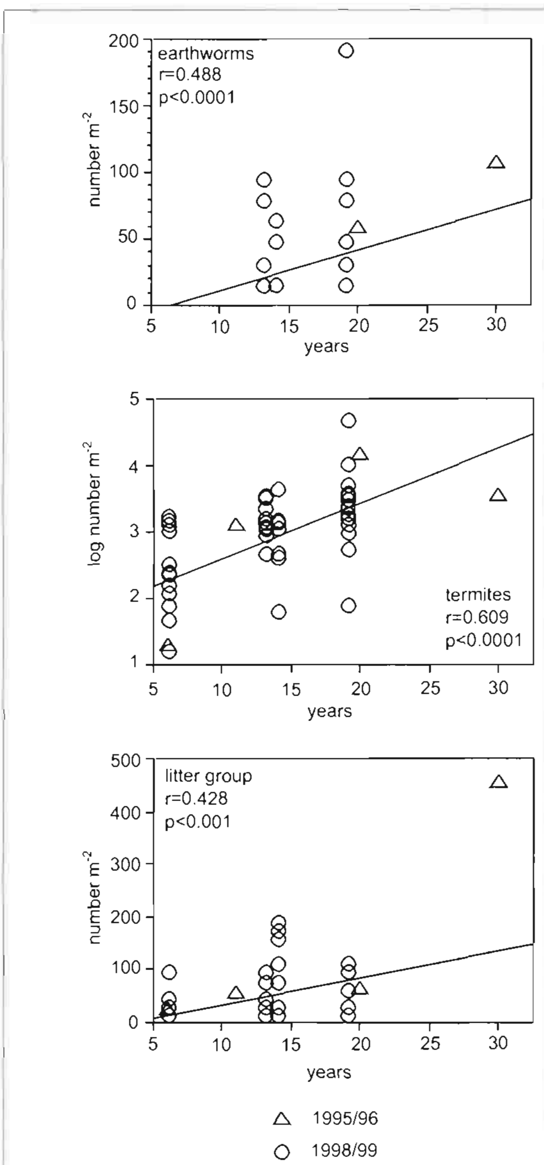
Ants, litter animals and especially termites had higher densities in the savanna plot of the second project than that of the first. For the litter group this difference was mainly due to Coleopterae, and the other litter taxa were absent or scarce in the savanna. The savanna plot in the second study was more fertile and had a greater plant biomass than the previous one, which was very poor. In the two studies, there were no earthworms in savanna. In wet savannas Lavelle *et al.* (1994) found an average macrofauna biomass of 32 g m^{-2}, whereas the biomass was lower in the studied Congolese savanna plots, especially two of them, which had biomass similar to that of drier savanna (Dangerfield 1990). The value for the forest was comparable to the forest average of 21 g m^{-2} given by these authors who pointed out that tree plantations may have higher macrofauna biomass (average 38 g m^{-2}) than the forest, due to new niches added to the forest population. In a drier environment, a mature *Eucalyptus grandis* stand showed the same macrofauna biomass (near 10 g m^{-2}) and diversity as the native woodland (Dangerfield 1990). However it was shown that plantations had highly variable results.

Soil type and vegetation are assumed to play a decisive role in the composition of soil population. Regarding the soil/site factor (Fig. 7.2), frequency patterns under acacia and under savanna were surprisingly not very different in the two sites. On the contrary, soil clay content appeared to be related to macrofauna frequency under eucalypt plots, and many earthworms were found in Loudima, resulting in high biomass (74 g m^{-2}) and low frequency and number of termites and of most other taxa. Pine plots were too different in age to be compared on a site basis.

Changes with plantation age

The changes occurring with age were studied for *Eucalyptus* PF1 hybrid only. When the results of the two projects were put together the relationships with age were very similar (Fig. 7.4). The high variability of biomass did not result in any clear patterns between biomass and plot age, whereas significant positive regressions with plot age (since it was first planted) were observed for total density ($p = 0.0001$), earthworm density ($p = 0.0001$) and termite density ($p = 0.0001$). The litter group density showed a weaker relationship with age ($p<0.05$), mainly due to the density of the main component, Coleopterae ($p<0.01$); Pseudoscorpionidae and Orthopterae increased also. The other litter inhabiting taxa were not abundant enough to show any significant relationships. Vohland and Schroth (1999) found a strong relationship between the amount of litter on ground and the density of soil macrofauna, and the relationship was even stronger with macrofauna biomass. The above observations on increasing earthworm density with age did not accord with the assessment of the disappearance of earthworms under eucalypt plantations by other authors (e.g. Paoletti 1999). However similar observations were made by Zou and Bashkin (1998) who reported a steady increase in earthworm density in eucalypt plantations of increasing age, up to 10 years old, grown on abandoned sugar cane fields free from earthworms; the earlier occurrence of earthworm populations compared to the Congolese plantations could be due to a faster accretion of soil organic matter. In a rubber plantation in Côte d'Ivoire, Gilot *et al.* (1995) observed an increase in earthworm biomass from 5-year-old plots to 20-year-old plots, followed by a decrease in 30-year-old plots which was attributed to the decrease of mineralisable organic matter. These observations confirm that soil macrofauna is strongly dependent on soil organic matter and litter accumulation.

Figure 7.4 Change of soil macrofauna densities (number of individuals m^{-2}) with eucalypt plot age for the two projects

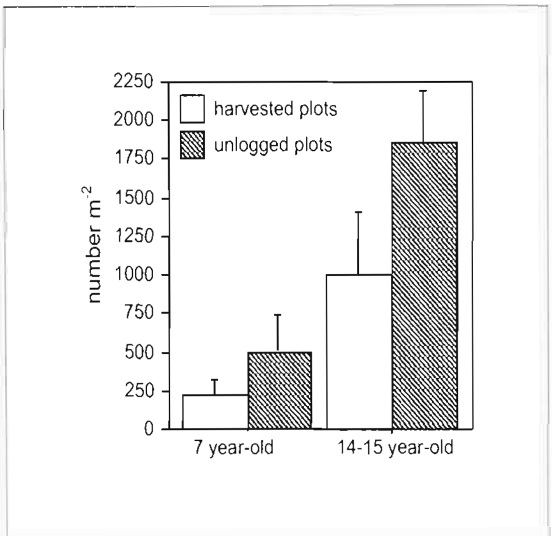


Changes with management practices

Clear felled plots were compared with forested plots at 7 years and at 14-15 years (Fig. 7.5). The density of termites was higher in unlogged plots than in harvested plots, although there were great amounts of plant residues on the soil surface in the harvested areas; humivorous termites as well as other termites were affected. Microclimate change and human impact such as harvesting vehicle traffic could have disturbed termite populations. Harvesting decreased termite density but did not seem to affect the other groups.

Coppice was compared to first rotation plantation in the 20-year-old plots and neither density nor biomass was significantly different for any macrofauna groups. Although termite density was decreased by logging this effect might be short-lived, and old coppice stands were not

Figure 7.5 Effect of eucalypt harvest on termite density

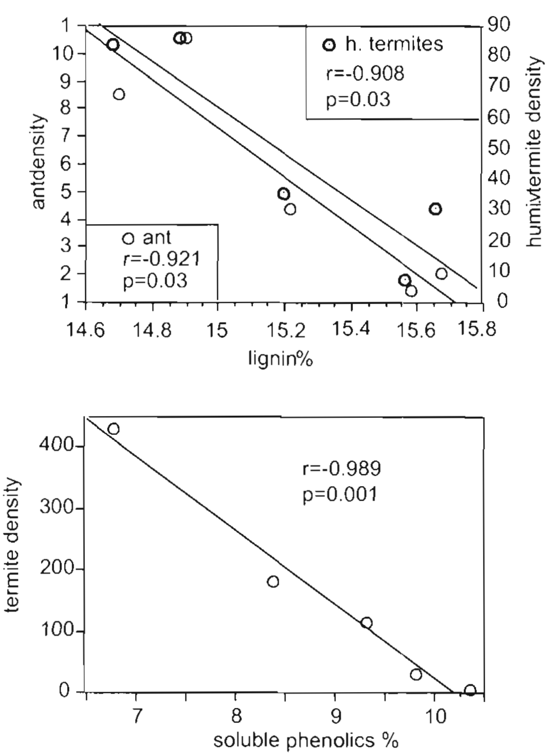


affected. The way wood harvesting is currently undertaken does not prevent the increase of macrofauna populations and consequently the improvement of ecosystem functioning which is expected from it.

Relationships with litter quality

The amount of more recent litter (> 4 mm) on the soil had rather a negative effect on soil macrofauna density and this relationship was significant for humivorous termites and ants. This relation might be related to litter quality, although our results were based on only five plots and must be confirmed by further studies. The lignin content of fresh litter was negatively correlated with the density of humivorous termites ($p<0.05$) and ants ($p<0.05$), and soluble phenolic compounds also exhibited a strong negative correlation with termite density ($p = 0.001$) (Fig. 7.6). Termites did not consume fresh litter, but during the rainy season, rain brought soluble phenolic compounds from the fresh litter to the fragmented litter layer below and might therefore decrease food quality for termites, thus controlling termite activity or reproduction. Zou (1993) attributed lower earthworm density in eucalypt plantations compared to albizzia plantations to the lower litter quality in eucalypts. Maity and Joy (1999), observed that mesofauna were not found in eucalypt litter before two months decomposition, unlike in litter of some other species. According to Heal and Dighton (1985), the combined effect of resource quality and physical environment selects microflora, which in turn selects the characteristics of the associated fauna. The effect of phenolic compounds on the feeding behaviour of herbivores is well known (Waterman and Mole 1994; Harborne 1997).

Figure 7.6 Relationships between macrofauna density (number m^{-2}) and eucalypt fresh litter quality: lignin and soluble phenolic compounds (percent litter dry weight)



Conclusions

According to Heal and Dighton (1985), the combined effect of resource quality and physical environment selects microflora and the associated fauna. Consequently, the quality of primary producers could have more importance than their biodiversity, regarding the improvement of soil organic and biological status. Thus acacia plantations, with their low level of plant species richness, had the highest soil organic matter content and litter input (Bernhard-Reversat 1993), and the higher biomass of macrofauna. Vohland and Schroth (1999) studying an agroforestry system in Brazil, observed a greater density of macrofauna in a tree monoculture of peach palm than in a tree polyculture including peach palm, because this tree had a better litter quality. In the Congolese plantations which are grown on a very poor sandy soil, the increase of organic matter resource could be of tremendous importance in changing savanna habitat to forest habitat, not only regarding energy but also nutrient resource and biochemical quality (Mboukou-Kimbatsa *et al.* 1998). Although eucalypt plantations exhibit lower density and biodiversity than other tree species, they are able to improve degraded soil fertility by enhancing macrofauna populations as they do for mesofauna (Day *et al.* 1999).

Some trends were assessed through the 1996 and 1999 studies gathering 11 eucalypt plots in the Pointe-Noire plantations. Soil macrofauna spread out in plantations, together with aging and soil change, at different rates according to the planted tree species. Forest exploitation had little impact on these changes.