Conclusions

Soil Biological Fertility Undergoes Fundamental Changes When Fast-growing Exotic Trees Are Planted on a Poor Savanna Soil

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The changing environment from savanna to artificial forests was investigated with a multidisciplinary approach including vegetation, soil and soil organisms, to understand the main relationships between plant diversity, management practices and the biological factors of fertility (Fig. 8.1).

Plantations Improve Biodiversity

An original vegetation, rich in pioneer species, developed under plantations. Although secondary forest patches occurred among the plantations and could act as a seed source, the floristic composition of the undergrowth was very different from that observed in a nearby forest: most species present in the forest were not found in the plantations, and most species in the plantation undergrowth were absent from the forest plot. The plantations studied were grown on savannas which are not colonised by forest species because annual fires destroy the forest tree seedlings, and where natural evolution from grassland to forest seems not to be possible, unlike the situation described in unburnt Congolese savannas (de Foresta 1990). Commercial tree plantations in a very poor savanna environment bring drastic changes in environmental conditions, due to the reduction of fire occurrence and to the change toward forest microclimate and forest soil. These changes allow plant diversity increase in understorey vegetation, as observed elsewhere in afforested degraded lands such as mined sites or abandoned pastures (Lugo 1997; Parrotta *et al.* 1997; Powers *et al.* 1997), although Parrotta and Knowles (1999) showed that changes were faster when native species were planted instead of exotic species. In unlogged eucalypt plantations, the general trends with plantation age were an increase of species number, forest species percentage, woody cover density, height and basal area. In managed commercial plantations, the species richness was higher, mainly due to the abundance of savanna and ruderal species, and height and basal area were lower. Further studies should examine the role of the natural forest and the conditions for seed dissemination, germination and seedling growth in plantations' undergrowth. Some results, especially the relationships between soil C, soil pH, and either the number of undergrowth species or the percentage of forest species, suggested that the changing soil environment through organic matter accumulation could promote the establishment of the undergrowth.

This biodiversity, unwanted by foresters, could improve soil functioning by increasing the diversity of organic sources for soil biota and by decreasing the negative effect of eucalypt litter

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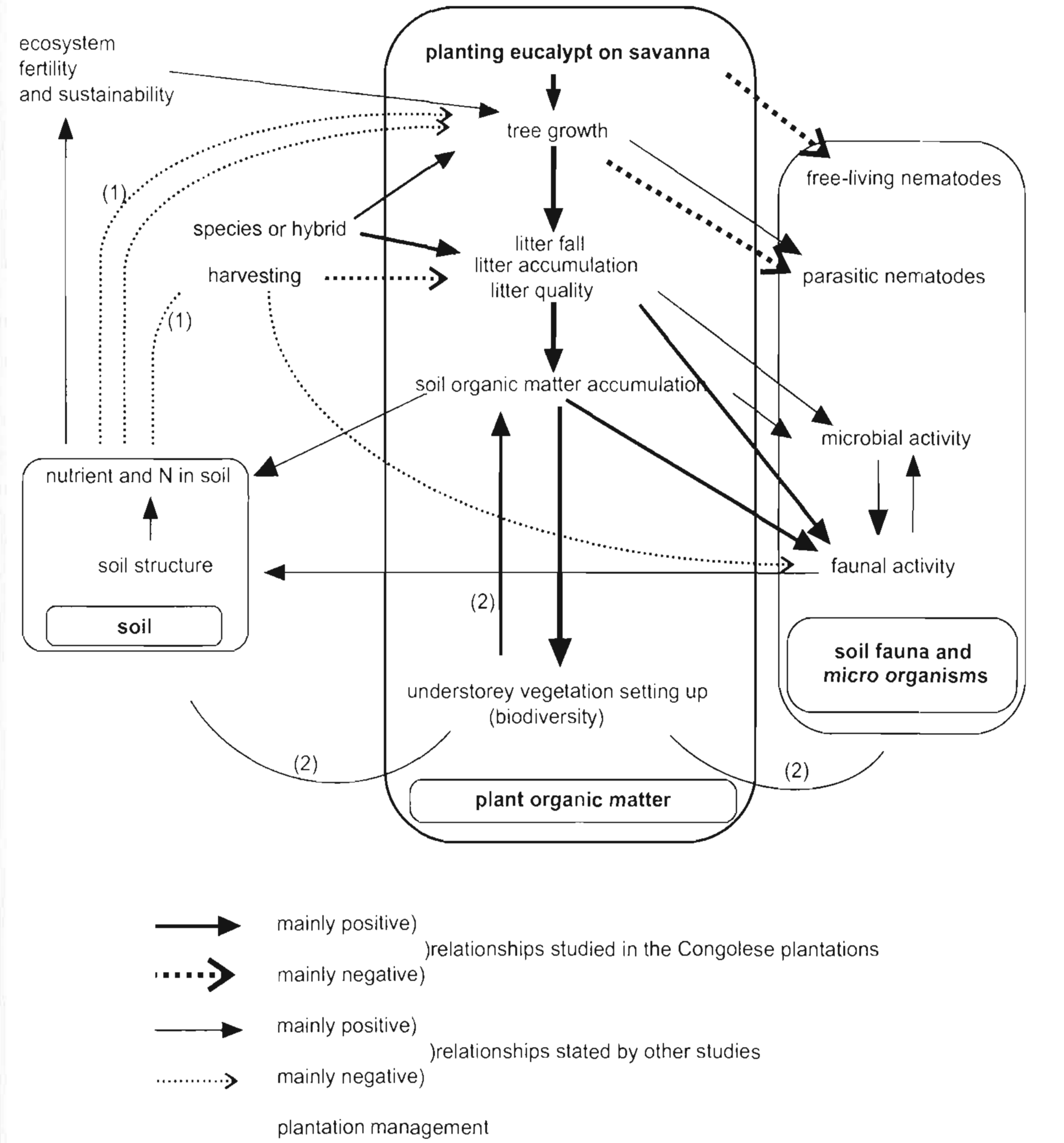
Figure 8.1 Relationships between the biological processes of fertility in eucalypt plantations in Congo



Nutrient cycling (1) and the effect of biodiversity (2) are currently studied in a third CIFOR project and UR2PI programs biochemicals such as polyphenols and terpenes, although undergrowth vegetation competes for water and nutrients with the tree crops (Dembi 1988). Microclimate, litter quantities and tree litter physical and chemical quality were assumed to control the abundance and nature of soil biota, and differed according to the planted species. The hypothesis of modified litter influence beneath undergrowth patches on soil biological processes will be studied during further investigations.

Plantations Improve Soil Organic Matter Status and Biological Activity

The present results suggest that litter accumulation and quality, and the resulting soil organic matter accumulation and quality, were among the main ecological changes when savanna was planted with trees, and determined the development of undergrowth and changes in soil characteristics (Wardle and Lavelle 1997). The fact that soil fauna was mostly correlated with percentage of forest or savanna species, rather than with the density of understorey plants, and the fact that changes in vegetation and fauna occurred after 7-10 years when soil organic matter content began to increase, suggested that both fauna and understorey vegetation were mainly affected by the type of habitat. Heal and Dighton (1985) observed that the increasing importance of fauna and the increasing dominance of macrofauna were related to the improvement of the quality of primary production residues. The great differences in litter quantity and quality occurring between eucalypt, acacia and pine resulted in major differences in soil microfauna and macrofauna density and biomass, and suggested that litter quality of the tree crop took precedence over plant biodiversity in controlling soil biota. In eucalypt plantations, the trend of fauna distribution to be associated with variations in eucalypt litter quality also supports this conclusion.

Lavelle (1996) suggests three mechanisms linking biodiversity and soil biological processes: the first implies plant diversity as the origin of soil fauna diversity (nested biodiversity), the second implies soil structure as mediator between biodiversity and functioning, and the third implies organic matter level and quality for changes in energy resources. In the plantations studied, organic matter resource could be of tremendous importance in changing savanna environment to forest environment, not only regarding energy resource availability but also nutrient resource and biochemical quality.

Improved soil processes were observed with the aging of eucalypt plantations due to changes in the soil-litter system: increased decomposition rates together with increased litterfall in aging plantations is assumed to enhance nutrient cycling. Increased soil organic matter with plot age enhanced cation exchange capacity and was therefore expected to improve the retention of nutrient imputs from rainfall, litter and fertilisers. An increase in soil organic matter is also assumed to be responsible for changes in macrofauna, and an improved soil functioning is expected from the increasing density of earthworm, termites and litter fauna (Lavelle 1994; Altieri 1999), related mainly to a faster organic matter turnover and improved soil structure.

Assessment of the Adverse Effect of Plantations

Among fast-growing trees, eucalypt is the only one grown commercially on large areas in the Congo and consequently their adverse effects on the environment must be managed.

Strong evidence for disturbance of microbial processes in eucalypt plantations is indicated by the absence of N fixation (chapter 4), nitrification (Bernhard-Reversat 1996), and white rot fungi (Bernhard-Reversat and Schwartz 1997). Although the lack of nitrification reduces nitrogen leaching, the decreasing nitrogen content of soil organic matter with plot age leads to mineral nitrogen deficiencies for tree growth, requiring fertiliser use by the second rotation, and this is one of the main problems foresters have to address. The introduction of a nitrogen-fixing understorey crop could greatly improve litter quality and soil organic matter content, but could also increase the level of tree infestation by plant parasitic nematodes.

Eucalypts are often regarded as damaging for the environment (Poore and Fries 1985) because of their allelopathic effects, which was shown in experimental conditions for the Congolese plantations (Bernhard-Reversat 1999) and numerous authors in other countries (e.g. Lisanework and Michelsen 1993; Souto *et al.* 1995; Reigosa *et al.* 1999). Concerning undergrowth biodiversity, eucalypts depressed forest species more than pine or acacia plantations, and the question arises if it is due either to allelopathy or to environmental conditions. Light intensity is often put forward as an alternative cause, but observations showed a lower canopy density under eucalypt than under the other planted species (Loumeto, unpublished results), which should result in a higher light intensity in eucalypt stands and favour pioneer species. The decrease in soil humidity due to eucalypt is also pointed out, but although comparison with savanna showed a depletion of soil humidity under eucalypt below 1 m, no data are available for comparison with other tree species (Nizinski *et al.*, in press). Dembi (1988) showed that in a young eucalypt plantation the adventitious vegetation competed efficiently for water, but in older plantations it might be stressed by water shortage. Nevertheless the need for weeding and the abundance of undergrowth in the field after 10-years of eucalypt cropping demonstrated that some plant species were able to avoid the adverse effect of eucalypts on plant growth.

The increasing density of the eucalypt parasitic nematodes *Xiphinema parasetariae* with the aging of plantations suggested that continuous eucalypt cultivation should result in an entirely infested area, and the effect of some practices, such as tree spacing or stump killing, on population decrease should be assessed. The effect of nematodes on tree growth is still unknown and should be studied together with the evaluation of the susceptibility of hybrids and its relationship with easily measurable parameters. Eucalypt plantations seem to be safe for eventual further cropping: *Xiphinema parasetariae* does not affect most local crops (cassava, groundnut, vegetable crops) which could replace the plantations, and the nematodes which are highly noxious for many food crops (mainly *Meloidogyne* spp.), do not develop on eucalypt roots.

The present practices of exploitation of eucalypt did not affect biological soil fertility factors, although the floristic composition of undergrowth and its abundance were changed. These practices kept the existing litter and residues on the ground, and even though the temporary increase of litter after exploitation does not last more than one year (Nzila, personal communication), it balances the low litterfall in the young regrowth. Consequently, although the litter system was affected by exploitation, soil organic matter was not obviously affected, and the biological activity in litter and soil was preserved. Silvicultural practices which improve the conservation of plant residue on the ground, besides being recommended to prevent nutrient export (O'Connell and Sankaran 1997), will enhance soil fauna density and consequently soil fertility (Altieri 1999).

Conclusions

The debate on growing block plantations of exotic trees is not closed and more factors must be taken into account than those studied here. The replacement by plantations of biological diverse ecosystems like rain forests are rightly questioned. In the case of harsh environment like the Congolese savanna, silviculture is a land use that has numerous positive effects although there are many problems still to be addressed.

The increase in soil organic matter which accounts for many positive changes is however a fragile process. All management practices likely to decrease inputs, such as the burning of harvest residues, the harvest of twigs and leaves for fuel, and the harvest of logs with the bark, are expected to counteract environmental improvement resulting from eucalypt growth (Brown *et al.* 1997). The choice of species and hybrids, beside their growth and wood qualities, should take into account litter quality and decomposition rate. Further research is needed on the cummulative effect of silvicultural practices involved in short-rotation forestry and its relation with soil organic matter.

This interdisciplinary work emphasised positive trends in eucalypt and other fast-growing plantations in relation to plant diversity and biological soil fertility. The knowledge generated by this study suggests changes in cultural practices which could have potential for more sustainable production in the long-term.