RETOUR AU MENU

JEAN-MICHEL HARMAND
CIRAD-Forêt/IRAD Maroua
Cameroon

Nutrient cycling in tree improved fallows Effects on fertility recapitalization in the tropics

The Benoue area in northern Cameroon

THE AUTHOR, JEAN-MICHEL HARMAND, HERE DESCRIBES SOME OF THE FINDINGS FROM HIS DOCTORAL DISSERTATION SUBMITTED TO THE UNIVERSITY OF PARIS VI IN OCTOBER 1997.

In sub-Saharan savanna of Africa, the need to feed a growing population while at the same time protecting the environment – and the soil in particular – represents a major challenge. Many agronomic studies (PIERI, 1989) show that agriculture management practices are no longer sustainable in this region. It is necessary:

- in many instances to restore highly degraded soils in the wake of continuous crops with a low level of mineral and organic fertilization,
- in other cases to maintain a production potential by taking farmers' financial resources into account,
- lastly, to conserve or recreate timber production zones.

Agronomic research has shown that, in the long term, mineral fertilization alone does not help to maintain or increase crop yields, owing to a decrease in soil organic matter levels which alters the physical, chemical and biological properties of the soil. The introduction of agroforestry practices such as tree-improved fallows, helps both to maintain or restore fertility (by acting on the whole biogeochemical cycle) and to produce much needed economic returns e.g. timber or gum arabic.

The goal of this study, conducted in the Benoue area of northern Cameroon, was to compare the effects of different tree species on soil fertility and to understand the

processes at work through analysis of the biogeochemical functioning of each fallow stand. Comparisons were made between a natural grazed fallow, a protected grassy fallow, and fallows planted with *Acacia polyacantha*, *Cassia siamea* and *Eucalyptus camaldulensis*.

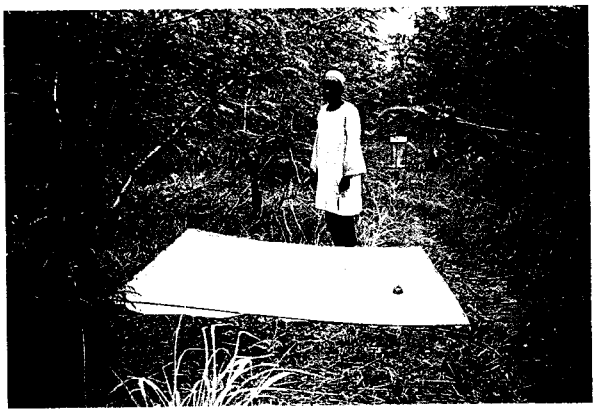
STUDY SITES

The study was conducted in two experimental units set up in the village of Ngong and Mayo Dadi, south of Garoua. The soil, of the ferruginous types, formed on the sandstone of the middle Cretaceous, is poor in organic matter, very sandy on the surface and increasing clay content with depth. In the 0-10 cm horizon, the level of clay + fine silt was less than 10 % but, at a depth of 1 m, it varied from 20 % to 40 % from site to site. This variation of mineral content with depth affects the development of the vegetation and litter production of the system, which in turn influences the organic and mineral balances of the fallow. During the study period, average annual rainfall at the sites was 1,050 mm.

Litter and water collectors placed under a six-year-old stand of *Acacia polyacantha* (local nitrogen-fixing species). The herbaceous stratum consists of *Pennisetum polystachyon*.

CONTENTS OF THE DISSERTATION

• The opening chapter of the dissertation (HARMAND, 1997) deals with the **soil sub-system** by comparing the organic and mineral levels. The pedological approach is complemented by examining the development of the macrofauna in the soil, and by an analysis of the **crop production**, using crops planted after two and five years of fallow.



R. PELTIER

Litter and water collectors under a *Cassia siamea* stand.

• Chapter two describes **storage of bioelements** in the ligneous and herbaceous vegetation of fallows by identifying many different compartments of aerial and root biomass, and litter accumulation. This chapter also examines **bioelement flows** through agroecosystems, with transfers involving solids (litterfall and decomposition) and flows of dissolved nutrients (throughfall, stemflow, atmospheric inputs from rain and losses due to surface run-off). The quality of drainage water is also presented.

• The last chapter summarizes **the organic matter dynamics** and the **nitrogen and other nutrient cycles** in the different types of fallow. Certain major factors of the nitrogen cycle, mineralization and symbiotic fixation, are also described.

SELECTED FINDINGS

With regards to the natural *Andropogon* herbaceous stratum, planting of trees associated with crops over a two-year-old establishment phase enhanced the production of dry matter in the fallow. This phenomenon already reported by OHTA (1990) and BERNHARD-REVERSAT (1996) was the result of the following processes observed in this study : (1) afforestation techniques and trees controlled the herbaceous stratum and the rate of nitrogen mineralization therefore increased, and ; (2) the increase in actual evapotranspiration (ET) shown by a lower soil water content under tree stands was linked with reducing deep drainage. This process has already been discussed by CHARREAU (1972) with regard to forest fallow as compared with herbaceous fallow in West African moist tropical regions. It suggested a reduction of leaching, and a better retention of atmospheric nutrient inputs in tree fallows.

❑ Tree development followed by slash-and-burn recycled nutrients rising into the upper layers of the soil

In this study, it was shown that trees were superior to herbaceous plants in the transfer of nutrients (particularly calcium), from soil layers deeper than 40 cm into the phytomass. With regards to grassy fallow, after logging and slash-and-burn, this transfer improved the mineral properties of the top soil of tree fallow, in spite of timber exports. Slash-and-burn had a significant effect above all in *E. camaldulensis* stands because of a large amount of nutrients stored in the litter accumulated on the soil. With the other species used in fallow, slash-and-burn had a lower effect on soil mineral properties. For that reason this practice was considered unnecessary.

It was noted also that the harvest of woody biomass with a diameter greater than 3 cm corresponded to removals of Ca and Mg lower than the amounts of the same nutrients rising up from deep soil.

❑ Young tree plantations often have a negative effect on the chemical properties of the soil...

As mentioned in various studies (OHTA, 1990, BERNHARD-REVERSAT, 1996), afforestation affects the environment and nutrient dynamics of the plant-soil system and leads to a significant decrease in the chemical values of the surface soil, during the early stages of tree growth. This phenomenon seems to be a pattern of many tree species in the tropics. In Nigeria, CHIJICKE (1980) noted a drop in the level of soil organic matter (SOM) under *Gmelina arborea* in comparison with the surrounding herbaceous stratum. In the Philippines, OHTA (1990) reported a decrease in pH values, C and N contents, CEC values and exchangeable Ca^{2+} of the surface soil, under five-year-old *Acacia auriculiformis*, and under eight-year-old *Pinus keysia*. In southern Côte-d'Ivoire, OLIVER, GANRY (1994) reported a lower level of N under five-year-old *A. auriculiformis* and *A. mangium* relative to herbaceous fallow. In Congo, BERNHARD-REVERSAT (1996) noted under the same seven-year-old Acacia species, lower levels in N content of the organo-mineral fraction, and in exchangeable bases of the soil (K, Ca, Mg) than in the surrounding herbaceous stratum. The negative effects of young plantations of Eucalyptus on the chemical properties of the soil have been already discussed by several authors : POCHON *et al.* (1959) in Morocco ; BERNARD-REVERSAT (1987, 1988) in Senegal ; JAMET (1975), BERNHARD-REVERSAT (1991, 1993, 1996) and LOUBELO (1990) in Congo ; TOKY and SINGH (1993) in India and KING and CAMPBELL (1994) in Zimbabwe.

Eucalyptus camaldulensis is the service wood producing species, presently the most planted in groves by the peasants of the Sudanese zone of Cameroon.

... but the properties of the surface soil improve over time

The deterioration of the chemical properties of the top soil under young tree plantations is due to a rise in the mineralization rate of the initial SOM and to the uptake of nutrients by trees. These losses are slowly made up for by leaf litter decomposition. Over time, however, authors generally observe an improvement in the soil characteristics. It thus seems that there is a lag time, varying from species to species, between planting and the increase in soil carbon and nitrogen contents. In the case of plantations of *A. auriculiformis* and *A. mangium*, in Congo, this period is shorter than in Eucalyptus plantations, and the rise in C an N levels takes effect after seven years (BERNHARD-REVERSAT, 1996). This difference in soil regeneration dynamics between species is assumed to be linked with the accumulation level and quality of the litter, and with the type of microclimate created by the trees.

As VAN BREEMEN (1995) has mentioned for other plant species, the tree species we have examined influence the nutrient cycle – each in a different way – and thus have favourable or adverse effects on soil fertility.

❑ *A. polyacantha* increased C and N contents of the soil by symbiotic nitrogen fixation and recycling of nitrogen

Unlike the species mentioned above *Acacia polyacantha* did not show any depressive effects on chemical properties of the soil. On the other hand, at the age of five years, an improvement in C and N contents of the soil was observed, with an increase in the levels of coarse plant debris and of C and N contents of the organo-mineral fraction. Here we thus have a humification of the plant debris. This process was already shown by BERNHARD-REVERSAT (1987) for 14-year-old *Acacia seyal* in Senegal. As a result, *A. polyacantha* is shown to be

more suitable than Acacia of Australia origin, previously mentioned, for a rapid replenishment of the SOM.

In this species, the increased storage of nitrogen in the different compartments of the agrosystem was the combined effect of (1) symbiotic nitrogen fixation and (2) external recycling of nitrogen through the rapid decomposition of leaf litter.

Compared to the other systems studied, *Acacia polyacantha* fallow contained a larger amount of readily mineralizable nitrogen, both in the SOM and the root phytomass that was highly developed on the surface; this resulted in a greater effect on the production of subsequent crops after two and five years of fallow.

❑ Eucalyptus species removed nutrients from the soil and put little back...

With six-year-old *Eucalyptus camaldulensis*, the marked accumulation of nutrients in the biomass and the litter accumulated on the soil resulted in a depressive effect on the mineral properties of the soil, which corresponded to a desaturation of the absorbant complex and to a decrease in the CEC. The limited development of the surface root system was linked with a low external recycling of nutrients.

With *Cassia siamea*, at the age of four years, the soil nitrogen mineralization rate decreased markedly, resulting in a sudden slowing down of the tree growth and litter production. This corresponded with an early maturity of the tree, the effects of which on the soil characteristics seemed to be more or less comparable to those of herbaceous fallow.

❑ The storage of bioelements in the soil and the root phytomass are of special significance

With increasing land pressure in the tropics, the aboveground biomass of fallows is exported for use as fuelwood and fodder. In such conditions, nutrients and organic matter accumulation in the under ground compartments (SOM and root phytomass) is a process of the highest importance for fallow efficiency. Based on these criteria, *A. polyacantha* offers far and away the best advantages, while *C. siamea* can be compared at least with herbaceous fallow advantages. *E. camaldulensis*, on the other hand, does not show the qualities required for good fallow.

❑ Once improved, soil fertility must be conserved

Planted fallows are potential means of regenerating soil fertility in the tropics. This system may be followed by a fertility-conserving crop system, such as parkland farming or conservation tillage practices. Parkland may be partly made up of fallow trees; the mulch would initially be the litter from the fallow. Different following scenarios are proposed on the basis of the species used. In the case of *Acacia polyacantha*, a number of trees can be conserved in the crop phase so as to supply easily mineralizable nitrogen to cultivated plants. Partial pruning of these trees will help to scale down the adverse effects that shade and root competition might have on the crops especially where water is concerned ; thus pruned, these trees will provide usable timber. In the case of *Cassia siamea*, the absence of slash-and-burn at the moment of harvesting the fallow will help to keep the nitrogen in the agrosystem and maintain live stumps in association with the crops. When treated as coppice selection stands, these stumps will act as a basis for a new fallow phase.

Three-year-old herbaceous fallow protected against fire and pasturing and colonized entirely by *Andropogon guyanus*.

Further studies on different nutrient pools in the soil and their changes during the cropping season are necessary to understand more thoroughly the effects of these various fallows on subsequent crops. However, this study has demonstrated that measurements of organic matter and soil biological processes provide a better measure of the effects of young tree fallows than mineral soil tests carried out at the beginning of the crop cycle ; accordingly, the selection of efficient tree species for fallow may more efficiently be based on criteria such as litter quality and quantity, root features (biomass and renewal) and biological soil processes, which directly influence the carbon and nitrogen cycles. ❐

▶ Jean-Michel HARMAND
ORSTOM
Projet Jachère
B.P. 1386
DAKAR
Senegal

REFERENCES

BERNHARD-REVERSAT F., 1987.
Litter incorporation to soil organic matter in natural and planted tree stands in Senegal. Pedobiologia 30 : 401-417.

BERNHARD-REVERSAT F., 1988.
Soil nitrogen mineralization under a *Eucalyptus* plantation and a natural *Acacia* forest in Senegal. Forest Ecology and Management 23 : 233-244.

BERNHARD-REVERSAT F., 1991.
Evolution of the soil litter interface under *Eucalyptus* plantation on sandy soil in Congo. Acta Oecologica 12 (6) : 825-828.

BERNHARD-REVERSAT F., 1993.
Dynamics of litter and organic matter at the soil-litter interface in fast-growing tree plantations on sandy ferallitic soils (Congo). Acta Oecologica 14 (2) : 179-195.

BERNHARD-REVERSAT F., 1996.
Nitrogen cycling in tree plantations grown on a poor sandy savanna soil in Congo. Applied Soil Ecology 4 : 161-172.

CHARREAU C., 1972.
La jachère peut-elle être supprimée en région tropicale sèche ?. Techniques et Développement 4 : 48-52.

CHIJICKE E. O., 1980.
Impact on soils of fast-growing species in lowland humid tropics. F.A.O. For. Pap., n° 21, 30 p.

JAMET R., 1975.
Evolution des principales caractéristiques des sols des reboisements de Pointe-Noire (Congo). Brazzaville, Congo, ORSTOM, 36 p.

KING J. A., CAMPBELL B. M., 1994.
Soil organic matter relations in five land cover types in the miombo region (Zimbabwe). Forest Ecology and Management 67 (1-3) : 225-239.

OHTA S., 1990.
Initial soil changes associated with afforestation with *Acacia auriculiformis* and *Pinus kesiya* on denuded grasslands of the Pantabagan area, Central Luzon, the Philippines. Soil Sci. Plant. Nutr. 36 (4) : 633-643.

OLIVER R., GANRY F., 1994.
Etude des modifications de fertilité induites par une jachère arborée. Cas de la zone forestière de Centre Côte-d'Ivoire. Montpellier, France CIRAD-CA, 27 p.

PIERI C., 1989.
Fertilité des terres de savanes. Bilan de trente ans de recherche et de développement agricoles au sud du Sahara. Paris, Ministère de la Coopération et du Développement, CIRAD-IRAT, 444 p.

POCHON J., DE BARJAC H., FAIVRE-AMIOT, 1959.
L'influence de plantations d'eucalyptus au Maroc sur la microflore et l'humus du sol. Annales de l'Institut Pasteur 97 (3) : 403-406.

TOKY O. P., SINGH V., 1993.
Litter dynamics in short-rotation high density tree plantations in an arid region of India. Agriculture, Ecosystems and Environnent 45 : 129-145.

VAN BREEMEN, 1995.
Nutrient cycling strategies, Plant and Soil 168-169 : 321-326.