# The role of plant residues in soil management for food production in the humid tropics

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J.J. Neeteson and J. Henrot (editors)

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DLO-Instituut voor Agrobiologisch en Bodemvruchtbaarheidsonderzoek
Oosterweg 92, Postbus 129,
9750 AC HAREN

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# Summary

This report is the final report of the project "The Role of Plant Residues in Soil Management for Food Production in the Humid Tropics". The project has been carried out in Nigeria and Cameroon as a collaboration between the Research Institute for Agrobiology and Soil Fertility (AB-DLO, Haren, The Netherlands) and the International Institute for Tropical Agriculture (IITA, Ibadan, Nigeria). Funding was provided by the Dutch Directorate General for International Co-operation (DGIS) under contract NG/91/852.

The general objective of the project was to contribute to a better understanding of processes regulating plant residue decomposition, soil organic matter dynamics, and nutrient cycling in relation to the sustainability of agricultural systems in the humid tropics.

The focus of the project was on:
- Decomposition and nutrient release of plant residues.
- Role of soil fauna in plant residue decomposition and nutrient cycling.
- Role of leguminous cover crops in enhancing soil organic matter content and nitrogen availability to food crops.
- Increase of soil fertility and decrease of leaching in short fallow systems in the humid tropics.

The project started in March 1992 at the IITA High Rainfall Station in Onne in S.E. Nigeria. In 1993 experiments were conducted both at the IITA High Rainfall Station and at the IITA Humid Forest Station in Mbalmayo in Central Cameroon. From January 1994 to April 1995 the project was based at the IITA Humid Forest Station. In that period experiments were conducted on the IITA research farm in Mbalmayo and on farmers' fields in Central and Southern Cameroon.

The project included both research and training.

# Research

Several experiments took place in alley-cropping systems (crops planted in alleys between lines of trees) with hedgerow tree prunings as plant residue addition. To compare the effect of contrasting quality of plant residues on the processes under study, alley-cropping systems with *Flemingia congesta* as hedgerow trees were compared with alley-cropping systems with *Dactyladenia barteri* hedgerows. *Flemingia congesta* is a leguminous tree species with foliage with a high nitrogen content and which decomposes fast. *Dactyladenia barteri* has a foliage rich in fiber which decomposes very slowly.

## Decomposition and nutrient release of plant residues

In the humid tropics plant residues are applied to agricultural soils to limit soil erosion and water loss, to supply nutrients to crops, and to maintain or increase soil organic matter content. Generally, plant residues with high nitrogen contents are good suppliers of nutrients, but they decompose too fast to have a positive effect on soil quality.

The decomposition of plant residues was investigated by using litterbags or littertubes in field experiments. Mulches of tree prunings in an alley cropping system with *Flemingia congesta* or

*Dactyladenia barteri* as hedgerow species were stored in litterbags or littertubes and their decomposition was followed during six months. There appeared to be no effect of mulch quantity on the rate of decomposition.

*Dactyladenia* mulch decomposed slower than the *Flemingia* mulch, presumably due to its originally much higher lignin content. The decomposition of plant residues is also dependent on the prevailing microclimate, since *Flemingia* mulch decomposed slower in an alley cropping system with *Flemingia* as the hedgerow species than in a system with *Dactyladenia*.

It was investigated whether mixtures of plant residues with high (e.g. *Flemingia* and *Mucuna*) and low N contents (e.g. *Dactyladenia*) are able to improve both the nutrient supply to crops and soil quality.
The decomposition of a mixture of *Flemingia* and *Dactyladenia* foliage was about 20% slower than when the two mulches decomposed seperately. The decomposition of the faster decomposing mulch (*Flemingia*) was thus retarded by the presence of the slower decomposing mulch (*Dactyladenia*). Although a mixture of *Flemingia* and *Dactyladenia* had a positive effect on soil organic matter, the supply of nutrients to crops was inadequate. A better nutrient supply and simultaneously a positive effect on soil organic matter was obtained when *Dactyladenia* mulch was mixed with *Mucuna* mulch. Inclusion of a N-fixing cover crop to a *Dactyladenia* alley-cropping system during a period of fallow could thus be an amelioration of the system.

The decomposition rate and nutrient release patterns of the fallow species *Calliandra* (high N content), *Alchornea* (high Ca content), *Pennisetum* (high K content) and *Chromolaena* (high K content) were determined. *Chromolaena* was decomposed most rapidly: after 14 weeks only 36% of the original biomass was present, as compared to 41% for *Pennisetum*, 50% for *Calliandra* and 53% for *Alchornea*. There was a flush of nutrients, especially of K, during the decomposition of *Chromolaena* and *Pennisetum*, immobilization of N from *Calliandra*, and a very slow release of Ca from *Alchornea*. It is concluded that *Chromolaena* and *Pennisetum* mulches should be used in short fallow systems when there is a high K demand of the subsequent crop. For efficient nutrient management in short fallow systems it is recommended that in other cases these mulches should be mixed with more resistant mulches.

Little information exists on the contribution of roots to soil organic matter build-up and nutrient supply to crops in the humid tropics. Experiments were conducted to determine the decay rate of fine roots of the trees *Flemingia* and *Dactyladenia* in an alley-cropping system and of fine roots of the leguminous cover crop *Mucuna*. The root-decay rate was assessed with the "clay-pot technique".
*Flemingia* fine roots, which had an about three times higher N content than *Dactyladenia* fine roots, decomposed three times faster than *Dactyladenia* roots. Decomposition constant rates were found to be 0.069 and 0.024 $week^{-1}$, respectively. It is therefore expected that fine roots of *Dactyladenia* rather than of *Flemingia* contribute to soil organic matter build-up.
*Mucuna* fine roots decomposed and lost their N at an extremely fast rate. The decomposition constant rate was 0.910 $week^{-1}$ . Within 20 days after placement in the field, the roots had lost 80% of their N and dry matter. This suggests that the N contribution of *Mucuna* fine roots to a following maize crop is insignificant.

## Role of soil fauna in plant residue decomposition and nutrient cycling

The density of earthworms, their surface cast production and the composition of surface casts were studied in a field experiment on an acid ultisol where maize and cassava were grown as food crops, continuously or every other year in a maize/fallow rotation, and in alley-cropping systems with *Flemingia* or *Dactyladenia* as hedgerow trees. Notwithstanding the low pH of the soil, more than 60 earthworms were recorded per $m^2$. Their biomass, however, was low

(approximately 2 g $m^{-2}$). Surface casts consisted of tubular, up to 3 cm high casts of *Pontoscolex corethrurus* and some other large earthworm species and small granular casts of *Eudrilidae earthworms*. The standing mass of casts after 5 months of activity (May - September) ranged from 260 to 570 kg $ha^{-1}$. Tubular cast production between September and December dropped from 97 to 18 g $m^{-2}d^{-1}$. The estimated amounts of C and nutrients returned to the soil surface in casts were considerable: 750 kg C, 51 kg N, 16 kg Ca, 2.5 kg Mg and 2 kg K $ha^{-1}$ $yr^{-1}$ on average. It is concluded that introduction and manipulation of earthworms, in particular during fallow periods, could have a beneficial impact on nutrient recycling in acid ultisols.

Gut content analysis was carried out on nine species of higher termites. A hierachical classification of the species, based on gut contents, was prepared using a two way indicator species analysis, and suggested the following rank order of species along a hypothetical humification gradient (soil to sound wood): *Thoracotermes macrothorax; Astalotermes quietus* (both soil-feeders); *Termes hospes; Amalotermes phaecocephalus; Pseudacanthotermes militaris; Microtermes congoensis; Nasutitermes lujae; Microcerotermes parvus; Schedorhinotermes putorius* (all notional wood-feeders). Arthropod parts, silica and humus were identified as indicator factors.
It is proposed that wood-feeding forms can be subdivided into a group consuming some silica and humus (5 species: humified wood-feeders) and a second group of sound wood-feeders (2 species).
Pianka's equations for diet breadth and diet overlap were also applied to the data. These identified *Microtermes congoensis, Schedorhinotermes putorius,* and *Pseudacanthotermes militaris* as the most specialized feeders, i.e. that they can extract their nutrients from the least heterogeneous substrates.

## Role of leguminous cover crops in enhancing soil organic matter content and nitrogen availability to food crops

The need to grow more food in the humid tropics to be able feed the ever-growing population has resulted in a drastic shortening of the fallow period necessary to maintain soil fertility. This urges the need to develop improved fallow systems, e.g. by using herbaceous legumes as relay cover crops. Herbaceous legumes improve the yield of food crop through weed suppression, $N_2$ fixation, and production of fast decomposing residues that release nutrients to the subsequent crop.

The cover crop species *Canavalia gladiata, Canavalia ensiformis, Centrosema* and *Mucuna* were screened for growth and nodulation on an acid ultisol under humid tropical conditions. The species were grown for three months in PVC buckets. Above-ground dry matter yields were in the order: *Centrosema* > *Canavalia gladiata* = *Canavalia ensiformis* > *Mucuna*. Below-ground biomass of *Centrosema* and *Canavalia gladiata* constituted only 16 and 28% of total (above- + below-ground) biomass, respectively, as compared to 33 and 36% for *Canavalia ensiformis* and *Mucuna*,respectively. Nodules constituted 8% of the total dry matter produced by *M. pruriens*, 4 to 5% for the *Canavalia* spp. and only 3% in the case of *Centrosema*. In all cases more than 45% of the nodules actively fixed $N_2$.

Experiments were conducted to evaluate the potential benefits of the leguminous cover crops *Mucuna* and *Pueraria* and *Dactyladenia* mulch on highly degraded ultisol.
*Mucuna* established itself quickly, suppressed weeds, improved soil mineral N status and decomposed slowly during the dry season, and therefore constituted an input of plant residues in the next cropping season. Because of its slow decomposition, *Dactyladenia* leaves provided a long-lasting mulch, which not only suppressed weeds, but also shifted weed composition from grasses to broadleaved species. *Dactyladenia* mulch also improved soil exchangeable cations. *Mucuna* reduced the density of weeds by 21.2%, but a combination of *Mucuna* with *Dactyladenia* mulch reduced weed density by 31.3%. The *Mucuna* relay cover crop succeeded in sub-

stituting low N containing residues (weeds) with plant material (*Mucuna*) which is a better source of N for the subsequent crop. The residual effect of *Mucuna* and *Dactyladenia* was an increase of maize grain yield by 75.3 and 85.1%, respectively, while, in combination, they doubled the grain yield. These results suggest that a combination of *Dactyladenia* mulch and *Mucuna* is a more efficient form of fallow than the natural regrowth. Therefore, the inclusion of a fast-growing herbaceous legume into *Dactyladenia* mulched systems, could be a promising low input management practice for a more sustainable agriculture on the highly degraded ultisols.

In another field trial the residual effects of the herbaceous legume *Mucuna* used as a fallow crop on the performance of a subsequent maize crop were studied.
Maize grain yields obtained from *Mucuna* plots were about twice as high as those on the control plots, they were about 320 and 180 kg $ha^{-1}$, respectively. It should be noted that much higher yields could be obtained after the application of 40 kg N $ha^{-1}$ as urea. Grain yield then amounted to about 700 kg $ha^{-1}$. The low maize yields obtained were probably due to the low inherent soil fertility.

## Increase of soil fertility and decrease of leaching in short fallow systems in the humid tropics

The potential to enhance the fertility of acid ultisols by using *Alchornea*, *Calliandra*, *Pennisetum* and *Chromolaena* was investigated in a two-years fallow. The species were evaluated for quality and quantity of biomass production, root distribution, interaction with mycorrhizae and earthworm activity.
*Pennisetum* and *Alchornea* produced more biomass (66.6 and 54.2 Mg $ha^{-1}$, respectively) than *Calliandra* (15.4) and *Chromolaena* (15.4 and 9.9 Mg $ha^{-1}$, respectively). *Pennisetum* produced the highest amount of root mass. All species yielded sufficient biomass to maintain soil organic matter. A high proportion of *Pennisetum* roots (92%) was found in the 20 cm top soil, as compared to *Chromolaena* (76%), *Alchornea* (74%) and *Calliandra* (57%). *Calliandra* is thus a good option for intercropping. *Alchornea* and *Calliandra* had deeper roots and are therefore able to recover leached nutrients. *Alchornea* residue was rich in N and Ca, and *Pennisetum* in N and K; most of the nutrients in *Calliandra* and *Alchornea* were recovered in the wood. Earthworm casting activity was slightly higher under *Pennisetum* fallow, and mycorrhizae infested mostly *Alchornea* roots. Also *Pennisetum* enriched the top soil in P and K, and *Alchornea* in P. *Pennisetum* and *Alchornea* were therefore the most promising fallow species to enhance soil fertility.

Since acid soils in the humid tropics usually have a low CEC and they experience a high rainfall, there is a risk of leaching of base cations. There is no natural mechanism that can balance the losses of base cations. External inputs of base cations are therefore required for sustainable crop production on these soils.
Two hypotheses were tested in a lysimeter study: (i) Base cations applied to the soil in combination with mulch as nitrogen input are less rapidly subjected to leaching than when they are applied with inorganic N fertilizer, and (ii) Mulches of contrasting qualities (N and lignin content) have different effects on base cation leaching. The type of green manure applied on the soil (and probably even its presence) affected little the base cation and N output of the soil column at 1.3 m depth. Application of inorganic N fertilizer, in contrast, resulted in substantial losses of K, Ca, and Mg. Losses in base cation increase soil acidity. It is concluded that base cation conservation is better achieved with mulch than with mineral N fertilizer. Because leaching of Ca + Mg is proportional to that of nitrate, the management of base cations in the soil is intimately tied to the management of nitrogen.

# Training

Two students of the Rivers State University of Science and Technology (Port Harcourt, Nigeria) carried out the research for their Master of Soil Science degree within the framework of the project.
A student of the Wageningen Agricultural University (The Netherlands) and a student of the Georg-August University in Göttingen (Germany) also performed research for their Master of Science degree within the framework of the project.
A student of the Rivers State University of Science and Technology in Port Harcourt (Nigeria) and a student the University of London (UK) conducted their Bachelor of Science research with the project.
Numerous trainees from Nigerian universities joined the project for durations varying between three months and one year. The universities include the Federal University of Technology (Owerri), the Rivers State University of Science and Technology (Port Harcourt), the Federal University of Technology (Yola), the Michael Okpara College of Agriculture (Umuagwo), the Rivers State College of Education (Port Harcourt), and the University of Jos.

# 1. Introduction

The project "The Role of Plant Residues in Soil Management for Food Production in the Humid Tropics" has been carried out as a collaboration between the Research Institute for Agrobiology and Soil Fertility (AB-DLO, Haren) in the Netherlands and the International Institute for Tropical Agriculture (IITA) in Nigeria and Cameroon. Funding was provided by the Dutch Directorate General for International Cooperation (DGIS) under contract NG/91/852.

Dr. Jacqueline Henrot was stationed at IITA by AB-DLO Haren from January 1992 to April 1995 to execute the project. Dr. Lijbert Brussaard (currently at the Wageningen Agricultural University) and Dr. Jacques Neeteson provided the backstopping from AB-DLO.

## Objectives

The general objective of the project was to contribute to a better understanding of processes regulating plant residue decomposition, soil organic matter dynamics and nutrient cycling in relation to the sustainability of agricultural systems in the humid tropics.

The project focused specifically on:

- Decomposition and nutrient release of plant residues.
- Role of soil fauna in plant residue decomposition and nutrient cycling.
- Role of leguminous cover crops in enhancing soil organic matter content and nitrogen availability to food crops.
- Increase of soil fertility and decrease of leaching in short fallow systems in the humid tropics.

## Research sites

The project started in March 1992 at the IITA High Rainfall Station in Onne, near Port Harcourt in S.E. Nigeria. In 1993 experiments were conducted both at the IITA High Rainfall Station and at the IITA Humid Forest Station in Mbalmayo, near Yaoundé in Central Cameroon. From January 1994 to April 1995 the project was based at the IITA Humid Forest Station. In that period experiments were conducted on the IITA research farm in Mbalmayo and on farmers' fields in Central and Southern Cameroon.

The change in location was motivated by several factors: the political circumstances prevailing at that time in Nigeria (e.g. military coup, strikes, shortage of fuel), the presence of a team of scientists working together on cropping systems in Cameroon (whereas research at the HRS in Nigeria was focused on the genetic improvement of banana and plantain), the presence of an analytical chemistry laboratory at the IITA Humid Forest Station (as well as communication facilities such as telephone, fax and electronic mail), and the opportunity to compare similar alley-cropping systems on contrasting sites (Table 1-1 and Figure 1-1).

Table 1-1. Characteristics of the High Rainfall Station (HRS) in Onne (Nigeria) and the Humid Forest Station (HFS) in Mbalmayo (Cameroon).

| | HRS | HFS |
|---|---|---|
| Coordinates | 7° 01' E, 4° 51' N | 11° 28' E, 3° 25' N |
| Altitude | 30 m | 640 m |
| Mean annual rainfall | 2.42 m, monomodal | 1.53 m, bimodal |
| Soil | Typic Paleudult | Typic Kandiudult |
| pH | 4.3 - 4.4 | 5.5 - 6.3 |
| C in the soil layer 0-5 cm (%) | 1.6 | 2.3 |
| C in the soil layer 5-10 cm (%) | 1.2 | 1.1 |
| N in the soil layer 0-5 cm (%) | 0.12 | 0.20 |
| N in the soil layer 0-5 cm (%) | 0.09 | 0.14 |
| P (µg P/g soil) | 4.0 - 4.5 | 3.2 |
| % sand (top 20 cm) | 76 | 62 |
| % clay (top 20 cm) | 14 | 22 |

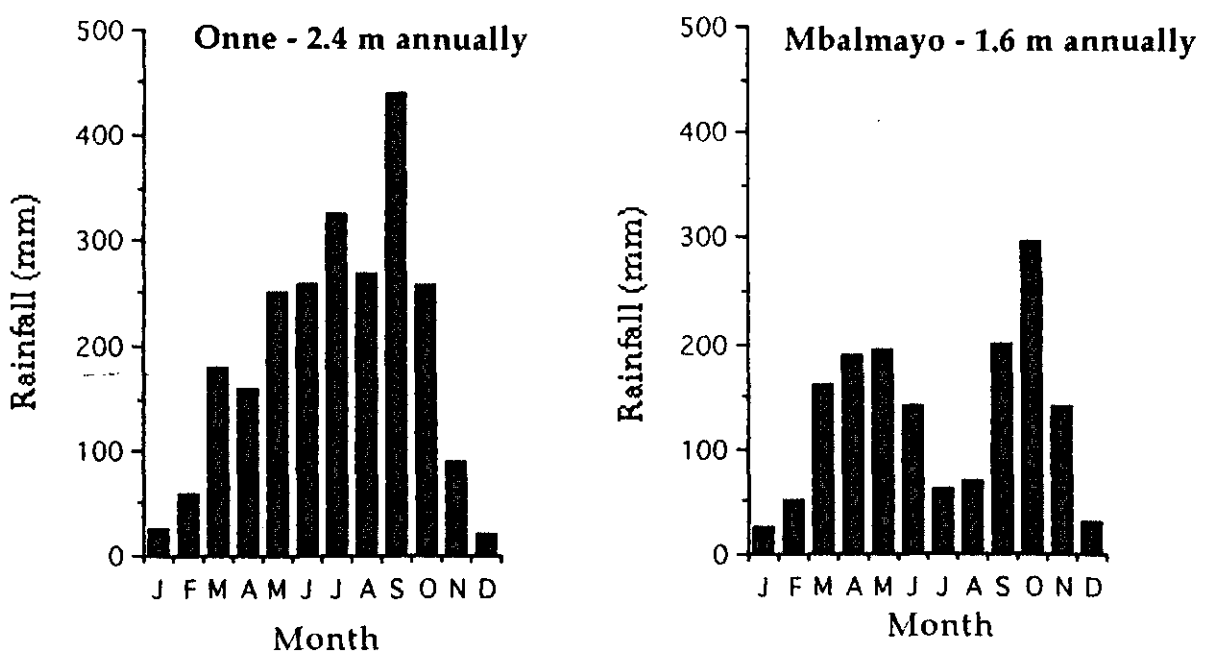


Figure 1-1. Rainfall pattern at the IITA High Rainfall Station (Onne, Nigeria) and at the IITA Humid Forest Station (Mbalmayo,Cameroon).

# Research

Results of the research conducted within the framework of the project "The Role of Plant Residues in Soil Management for Food Production in the Humid Tropics" are presented in

Chapters 2-12. Chapters 2-5 deal with the decomposition and the nutrient release of residues and roots of various plant species. The role of the soil fauna in plant residue decomposition and nutrient cycling is described in Chapters 6-7. Results on the role of leguminous cover crops in enhancing soil organic matter content and nitrogen availability to food crops are presented in Chapters 8-10. Finally, Chapters 11 and 12 deal with possibilities to increase soil fertility and decrease leaching in short fallow systems in the humid tropics.

# Training

Two African students carried out the research for their Masters in Soil Science degree within the framework of the project: Mohammed Kuruma Hamadina from Nigeria, and Jacques Kanmegne from Cameroon. Both graduated in September 1995 from the Rivers State University of Science and Technology in Port Harcourt, Nigeria. Mohammed Hamadina's thesis was entitled "Effect of selected cover crops and *Dactyladenia barteri* mulch on Ultisol in the humid tropics". Jacques Kanmegne's thesis was entitled "Evaluation of selected fallow plant species for enhancing soil fertility in the humid forest zone". Results of their work are included in Chapters 3-5 and 8-11.

Within the framework of the project two students from European universities executed the research for their Master of Science degree: Ellen de Groot from the Wageningen Agricultural University (The Netherlands) and Nakato Kidza from the Georg-August University in Göttingen (Germany). Both their work related to the effect of earthworms on plant growth and soil properties. Ellen de Groot did her research in Nigeria while Nakato Kidza did hers in Cameroon.

Fiona Sleaford from the University of London (UK) and Elsie Ile from the Rivers State University of Science and Technology (Nigeria) conducted their Bachelor of Science research with the project. Fiona Sleaford worked on the classification of taxonomically-known termites in functional groups by examination of their mandibles and gut content. Results of her work are included in Chapter 7. Elsie Ile studied the effect of a *Mucuna pruriens* crop on the performance of a subsequent maize crop. Her work is reported in Chapter 9.

Numerous trainees from Nigerian universities joined the project for durations varying between three months and one year: Ikejimba Stellamaris and Kate Agwu (Federal University of Technology, Owerri), Monika Barida Normakoh (University of Port Harcourt), Comfort Philemon, (Federal University of Technology, Yola), Chinwendu Akalonu (Michael Okpara College of Agriculture, Umuagwo), Elsie Ile (Rivers State University of Science and Technology, Port Harcourt), Gloria Chuku (Rivers State College of Education, Port Harcourt), and Carol Chioma Umesi (University of Jos).

# Collaboration with other research projects

There was ample exchange of ideas, material, and expertise between this project and those listed below.

- "Dynamics of soil organic matter and soil fertility under different fallow and cropping systems" and the second phase "Process-based studies of soil organic matter dynamics in relation to the sustainability of agricultural systems in the tropics", funded by the Belgian General Administration of Cooperation for Development.
Bernard Vanlauwe (IITA, Resource and Crop Management Division, Ibadan, Nigeria) and Roel Merckx (Katholieke Universiteit te Leuven, Laboratorium voor Bodemvruchtbaarheid, Leuven, Belgium).
- "Terrestrial Initiative in Global Environmental Research Programme" (TIGER), funded by the Natural Environment Research Council (UK)

rate of mulch decomposition in the field is often difficult to forecast because of other factors, such as soil macrofauna (Edwards and Heath, 1963) and changes in climate (drying-rewetting, Vanlauwe *et al.*, 1995).

This study was designed to evaluate the importance of three factors on the decomposition of contrasting tree foliage (hedgerow pruning) applied on the soil surface in alley-cropping systems: the access of soil macrofauna to the decomposing material, the micro-environment provided in the alley-cropping system (soil moisture and temperature), and the quantity of mulch applied on the ground (1 to 8 Mg $ha^{-1}$). The contrasting tree foliage were that of *Dactyladenia barteri* and *Flemingia congesta*. *Dactyladenia* foliage is known to decompose at a much slower rate than *Flemingia* (Van der Kruijs *et al.*, 1989).

# Materials and methods

## Experimental site and plant material

The experiments were conducted in the field, at the High Rainfall Station of the International Institute of Tropical Agriculture, in Onne (4° 51'N; 7° 03'E), near Port Harcourt, in the humid forest zone of S. E. Nigeria. Rainfall at the site is monomodal with a rainy season lasting from March to December and a mean annual rainfall of 2.4 m. Relative humidity remains high throughout the year (78 to 89 %) and mean annual temperature is 25 °C. The soil on site is a typic Ultisol, with a pH of 4.1 and 1.4 % C in the top 5 cm.

Experiment I was conducted in alley-cropping systems established 7 years earlier with either *Dactyladenia barteri* or *Flemingia congesta* as hedgerow species. The alley-cropping systems consisted of 5 rows of trees of the same species, separating alleys 4.5 m wide and 20 m long in which maize and cassava were planted. They were replicated 4 times in a block design. Experiment II was conducted on a clean-weeded plot (9 x 5 m), outside of the alley-cropping systems.

*Dactyladenia* and *Flemingia* leaves used in both experiments were collected from the hedgerow trees. In the case of Experiment I, the leaves were used fresh, within a day after collection. In the case of Experiment II, the leaves were air-dried. Their chemical compositions are given in Table 2-1.

Table 2-1. Chemical composition (in %) of Flemingia and Dactyladenia mulch used in Exp. (I) and (II).

| Leaves | N | lignin | K | Ca | Mg | P |
|---|---|---|---|---|---|---|
| Flem. (I) | 2.7 | 21 | 0.77 | 0.59 | 0.19 | 0.18 |
| Flem. (II) | | | 0.80 | 0.67 | 0.21 | 0.18 |
| Dact. (I) | 1.6 | 38 | 0.43 | 0.84 | 0.20 | 0.09 |
| Dact. (II) | | | 0.49 | 1.20 | 0.27 | 0.11 |

## Experiment I: Effect of soil fauna and micro-environment

Dry weight loss of *Dactyladenia* and *Flemingia* mulch was monitored from July 1992 to March 1993 using stainless-steel litterbags (0.3 x 0.3 x 0.02 m). Each litterbag was filled with an amount of fresh leaves corresponding to 2.3 Mg $ha^{-1}$ (dry weight basis) and set in the field at the same time as the hedgerow tree prunings, a few days before planting maize and cassava. Litterbags were consistently placed between the first and the second maize row away from the hedgerow trees (i.e., between 0.5 and 1 m from the hedgerows). At about 10, 20, 40, 50 and 130 days after placement, 2 litterbags of each treatment were randomly collected from each alley-cropping unit. In the case of *Dactyladenia* mulch, the collection period was extended to 210, 270, 330, and 410 days after placement in the field.

The treatments consisted of a combination of plant material (*Dactyladenia* or *Flemingia*), litterbag mesh sizes, and alley-cropping systems. The effect of the micro-environment was studied by placing litterbags containing *Flemingia* leaves in both *Flemingia*- and *Dactyladenia*-based alley-cropping systems. The effect of soil macrofauna was tested by using litterbags of different mesh sizes: 0.497 mm, which restricts access to all macrofauna, 1.99 mm, which allows entry of the smaller macrofauna, and 6.86 mm, which allows entry of all macrofauna (e.g., earthworms, termites, ants, and millipedes). As it was not believed that increasing the litterbag mesh size from 2 to 7 mm would affect significantly macrofauna access to the mulch (Tian *et al.*, 1992), litterbags of 7 mm-mesh size were set to be collected only at 2 sampling dates (40 and 50 days after placement) in order to compare the data with that from litterbags of 2 mm-mesh size.

## Experiment II: Effect of the quantity of leaves applied at the soil surface

Dry weight loss of *Dactyladenia* and *Flemingia* mulch was monitored from May to September 93 using 2 mm-mesh size stainless-steel littertubes (0.2 m ø, 0.2 m high, closed at the top and bottom by a disk of the same material). The littertubes were filled with amounts of fresh leaves corresponding to either 1, 2, 4, and 8 Mg $ha^{-1}$ on a dry weight basis and they were placed in the field in a complete random design. Littertubes rather than litterbags were used in this experiment in order to avoid compaction of the leaves at the highest application rates. To evaluate the potential difference between the litterbag and the littertube techniques, litterbags (0.3 x 0.3 x 0.02 m) in stainless steel of 2 mm-mesh size were filled with 2 Mg $ha^{-1}$ (dry weight basis) of either *Dactyladenia* or *Flemingia* mulch and placed in the field among the littertubes. At about 15, 30, 40, 65, and 130 days after placement, the contents of 5 littertubes and litterbags of each treatment were collected.

## Analytical and computational methods

The litterbag content was brushed gently to remove the excess of sand, dried at 60 °C for 48 h and weighed. A subsample of the original plant material and the material collected from the litterbags and littertubes were ground to pass a 0.5 mm sieve. Dry weights of the remaining mulch were corrected for ash content (combustion at 550 °C for 6 hours). Selected samples were analyzed for total N (Kjeldahl), fiber content (Goering and Van Soest, 1970), and Ca, Mg, K, and P contents after acid digestion (P by colorimetry with the molybdate blue method, Ca and Mg by atomic absorption, K by flame photometry). Dry weight loss constant K was obtained from the equation: $Y_t = Y_o e^{-Kt}$, where $Y_o$ and $Y_t$ represent residues remaining initially and at time t (Wieder and Lang, 1982).

The percentage of decomposition attributable to macrofauna was calculated with the formula: $((K_2-K_{0.5})/K_2)x100$, where $K_2$ and $K_{0.5}$ are the decomposition rate constants for the plant material placed in the 2 and 0.5 mm-mesh size litterbags, respectively. The percentage of *Flemingia* decomposition attributable to the micro-environment was calculated with the formula: $((K_{Dact.}-K_{Flem.})/K_{Dact.})x100$, where $K_{Dact.}$ and $K_{Flem.}$ are the decomposition rate constants for *Flemingia* leaves placed in alley-cropping systems with *Dactyladenia* and *Flemingia* as hedgerow trees.

# Results

## Effect of macrofauna

Decomposition of *Flemingia* was faster in the litterbags of 2 mm size compared to 0.5 mm size, indicating that macrofauna played a significant role in the decomposition process (Figure 2-1 and Table 2-2). The increase in decomposition attributable to macrofauna was 31 % in the alley-cropping systems with *Flemingia* as hedgerow trees and 38 % in those with *Dactyladenia*.

In the case of *Dactyladenia* mulch, in the 20 first weeks after placement in the field, there were no differences in decomposition between litterbags of 0.5 or 2 mm mesh-size. From about the 20th week to the end of the experiment, however, decomposition was faster in the litterbags allowing macrofauna entry (Figure 2-1 and Table 2-2), and although the differences in decomposition rate constants over the 17 month period were small (0.014 week $^{-1}$ in the 2 mm mesh-size bags vs. 0.010 in the 0.5 mm mesh-size bags), the amounts of litter remaining at the end of the 68 weeks of observation were significantly ($P = 0.007$) lower in the litterbags of 2 mm-mesh size (Figure 2-1).

Table 2-2. Decomposition rate constants K (week$^{-1}$) of mulches in relation to soil macrofauna access and alley-cropping system (Exp. I).

| | Mesh size of litterbags | | | |
|---|---|---|---|---|
| | 2 mm | | 0.5 mm | |
| Mulch | Flem. alleys† | Dact. alleys | Flem. alleys | Dact. alleys |
| Flemingia | 0.032 | 0.039 | 0.022 | 0.024 |
| Dactyladenia | | 0.022 | | 0.020 |
| Dact. (58)* | | 0.014 | | 0.010 |

†"Flem. alleys" refers to alley-cropping systems with Flem. as hedgerow trees.

*Rate constants were calculated over a 20 week period except in the case of Dact. (58) where they were calculated over a 58-week period.

There were no differences ($P > 0.6$) between the amounts of *Flemingia* or *Dactyladenia* mulch in litterbags of 2 and 7 mm mesh size, suggesting that the macrofauna affecting mulch decomposition on the site of the study was not restricted by 2 mm mesh size openings.

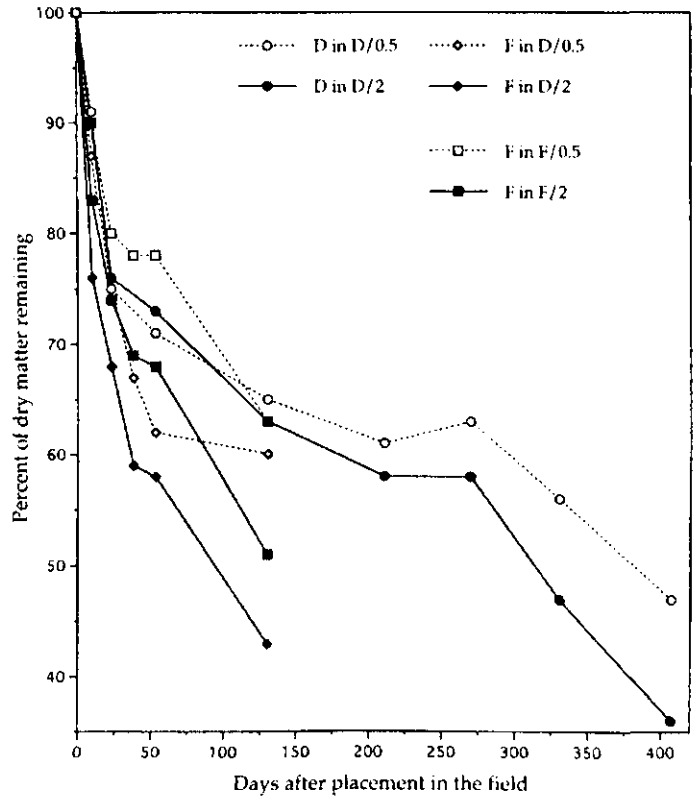


Figure 2-1. Effect of litterbag mesh size and alley-cropping type on dry matter losses of *Dactyladenia* (D) and *Flemingia* (F) mulches. In "F in D/0.5", "F" refers to the mulch type (*Flemingia*), "D" to the alley-cropping system (*Dactyladenia* as hedgerow trees), and "0.5" to the mesh size of the litterbags.

## Effect of the micro-environment

*Flemingia* decomposition rate (in litterbags of 2 mm mesh-size) was 18 % higher in alley-cropping systems with *Dactyladenia* as hedgerow trees (Figure 2-1 and Table 2-2). The fact that decomposition rate was also higher in alley-cropping systems with *Dactyladenia* when litterbags of 0.5 mm mesh size were used (Figure 2-1) indicates that the difference in decomposition rate was not due to a difference in effect of macrofauna between the two alley-cropping systems, but to a difference in micro-environment.

## Effect of the quantity of leaves applied at the soil surface

The amount of *Flemingia* or *Dactyladenia* leaves placed in the littertubes did not affect the rate at which the mulch decomposed (Figure 2-2 and Table 2-3). Only in the case of *Flemingia*, at day 30 and 40, the proportion of dry matter lost was greater in the littertubes containing 8 Mg ha-1 ($P < 0.01$).

Table 2-3. Decomposition rate constants K (week$^{-1}$) of mulch application rate (Exp. II).

| Application rate (Mg ha -1) | Flemingia mulch | Dactyladenia mulch |
|---|---|---|
| 1 | 0.036 | 0.020 |
| 2 | 0.049 | 0.024 |
| *2 (litterbag)* | *0.049* | *0.027* |
| 4 | 0.042 | 0.026 |
| 8 | 0.044 | 0.025 |

Decomposition in littertubes and litterbags with 2 Mg ha$^{-1}$ of mulch proceeded overall at the same rate (Table 2-3) although decomposition was significantly slower ($P < 0.01$) in the litterbags with *Dactyladenia* mulch during the first 20 days in the field (Figure 2-1).

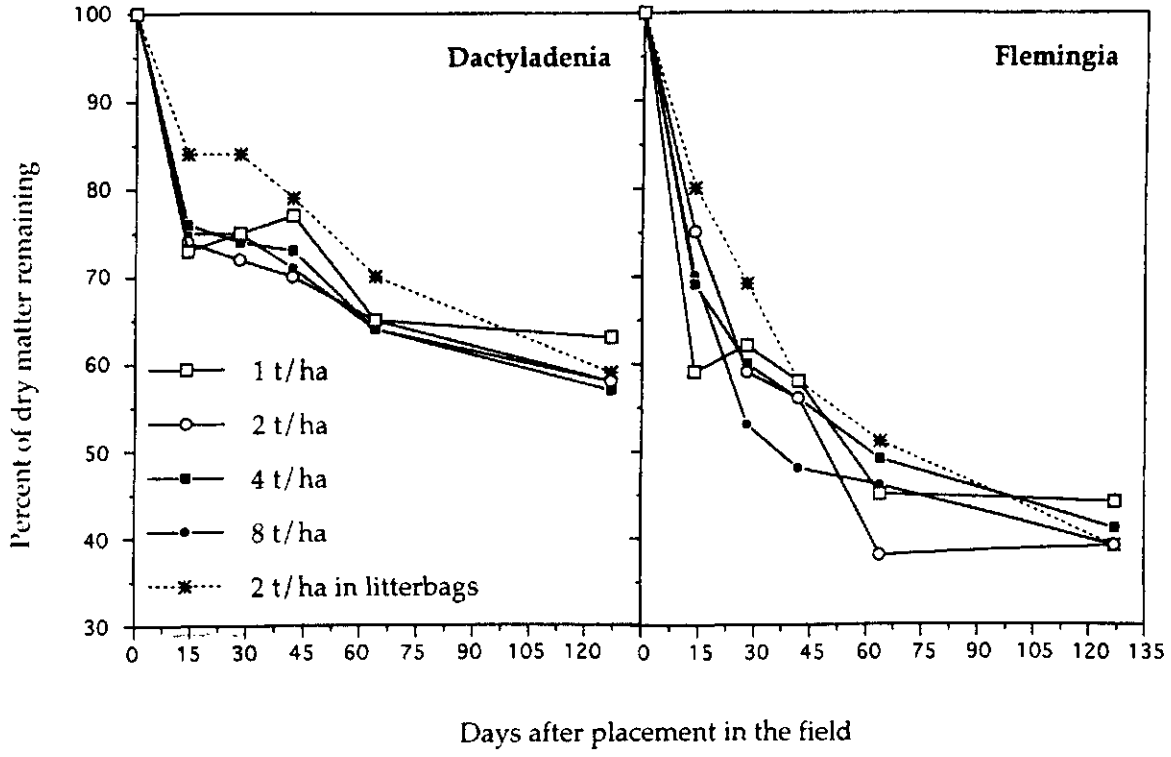


Figure 2-2. Effect of mulch quantity on dry matter losses of *Dactyladenia* and *Flemingia* mulches.

## Changes in nutrient and fiber content during decomposition

There were little changes in N, Ca, and Mg content of *Dactyladenia* and *Flemingia* during decomposition (Table 2-4) indicating that the release of these nutrients proceeded at a rate similar to the loss of dry matter and, therefore, that the parameters affecting the rate of decomposition (macrofauna and micro-environment) affected similarly the rate of release of these nutrients. Potassium, in contrast, was released much faster than the other plant nutrients and most of the K of *Dactyladenia* and *Flemingia* was released within the first 50 days of decomposition (Table 2-4).

Lignin content of *Flemingia* increased by 73 % within the first 10 days of decomposition, suggesting that early decomposition affected primarily compounds that were more easily broken down (Table 2-4). This trend was not observed in the case of *Dactyladenia*.

Table 2.4. Changes in nutrient and fiber content during decomposition. Content is expressed in percent of dry weight.

| | mm† | days* | N | Ca | Mg | K | lignin | cellulose |
|---|---|---|---|---|---|---|---|---|
| Dactyladenia mulch | | | | | | | | |
| in | | 0 | 1.6 ± 0.0 | 0.8 ± 0.0 | 0.20 ± 0.00 | 0.4 ± 0.0 | 38 ± 2 | 29 ± 1 |
| Dact. a. c.** | 2 | 10 | 1.6 ± 0.1 | 1.3 ± 0.2 | 0.23 ± 0.02 | 0.4 ± 0.1 | 42 ± 7 | 32 ± 4 |
| Dact. a. c. | 2 | 53 | 1.6 ± 0.0 | 1.5 ± 0.1 | 0.23 ± 0.02 | 0.1 ± 0.0 | 47 ± 6 | 35 ± 6 |
| Dact. a. c. | 2 | 130 | 1.7 ± 0.1 | 1.3 ± 0.2 | 0.21 ± 0.00 | 0.1 ± 0.0 | 44 ± 6 | 29 ± 6 |
| Flemingia mulch | | | | | | | | |
| in | | 0 | 2.9 ± 0.1 | 0.6 ± 0.0 | 0.19 ± 0.00 | 0.8 ± 0.0 | 22 ± 1 | 24 ± 2 |
| Flem. a. c. | 2 | 10 | 3.2 ± 0.1 | 0.7 ± 0.1 | 0.25 ± 0.03 | 0.8 ± 0.1 | 37 ± 0 | 22 ± 0 |
| Flem. a. c. | 2 | 53 | 3.7 ± 1.1 | 1.4 ± 0.9 | 0.40 ± 0.32 | 1.0 ± 1.5 | 37 ± 5 | 30 ± 5 |
| Flem. a. c. | 2 | 130 | 3.0 ± 0.4 | 0.8 ± 0.1 | 0.22 ± 0.05 | 0.6 ± 0.7 | 38 ± 7 | 24 ± 7 |
| in | | 0 | 2.9 ± 0.1 | 0.6 ± 0.0 | 0.19 ± 0.00 | 0.8 ± 0.0 | 22 ± 1 | 24 ± 2 |
| Flem. a. c. | 0.5 | 10 | 3.1 ± 0.2 | 0.8 ± 0.0 | 0.25 ± 0.01 | 0.5 ± 0.7 | 34 ± 1 | 28 ± 1 |
| Flem. a. c. | 0.5 | 53 | 3.6 ± 0.4 | 0.9 ± 0.1 | 0.28 ± 0.05 | 0.2 ± 0.1 | 39 ± 6 | 26 ± 6 |
| Flem. a. c. | 0.5 | 130 | 3.1 ± 0.2 | 1.1 ± 0.1 | 0.25 ± 0.02 | 0.7 ± 0.5 | 42 ± 3 | 22 ± 3 |
| in | | 0 | 2.9 ± 0.1 | 0.6 ± 0.0 | 0.19 ± 0.00 | 0.8 ± 0.0 | 22 ± 1 | 24 ± 2 |
| Dact. a. c. | 2 | 10 | 3.0 ± 0.5 | 1.0 ± 0.2 | 0.25 ± 0.00 | 0.4 ± 0.4 | 42 ± 2 | 21 ± 2 |
| Dact. a. c. | 2 | 53 | 3.2 ± 0.1 | 1.1 ± 0.0 | 0.24 ± 0.01 | 0.2 ± 0.0 | 39 ± 6 | 20 ± 6 |
| Dact. a. c. | 2 | 130 | 3.5 ± 0.2 | 0.9 ± 0.1 | 0.27 ± 0.02 | 0.2 ± 0.0 | 40 ± 3 | 21 ± 3 |
| in | | 0 | 2.9 ± 0.1 | 0.6 ± 0.0 | 0.19 ± 0.00 | 0.8 ± 0.0 | 22 ± 1 | 24 ± 2 |
| Dact. a. c. | 0.5 | 10 | 3.1 ± 0.3 | 0.6 ± 0.1 | 0.30 ± 0.10 | 1.7 ± 0.7 | 40 ± 2 | 25 ± 2 |
| Dact. a. c. | 0.5 | 53 | 3.6 ± 0.3 | 0.9 ± 0.1 | 0.29 ± 0.03 | 0.2 ± 0.1 | 45 ± 1 | 21 ± 1 |
| Dact. a. c. | 0.5 | 130 | 3.2 ± 0.1 | 0.7 ± 0.0 | 0.27 ± 0.01 | 0.1 ± 0.0 | 40 ± 6 | 24 ± 6 |

† mesh-size of litterbags; * days after placemement in the field; **a.c. = alley cropping system

# Discussion

## Effect of macrofauna

The effect of macrofauna on *Flemingia* decomposition was large: 31 and 38 % of the decomposition rate was attributable to macrofauna access to the mulch in the *Flemingia* and *Dactyladenia* alley-cropping systems, respectively. The magnitude of the macrofauna effect was similar to that observed by Tian (Tian *et al.*, 1992) on prunings of Gliricidia sepium and Leucaena leucocephala, maize stover and rice straw placed in a cleared grass field in S. E. Nigeria. In his study, 34, 58, 36, and 32 % of the decomposition rate was attributable to macrofauna (calculated from the tabulated data). It is interesting that the effect was similar in spite of the large differences between the two studies: dryer macroclimate (1.2 m annual rainfall compared to 2.4 in the present study), different soil fauna (more earthworms, (Henrot and Brussaard, 1996)), different chemical plant compositions (e.g., 3.6, 3.6, 1.0, and 0.8 % N, respectively, vs. 2.7 for *Flemingia*), and considerably higher decomposition rate constants (0.19, 0.15, 0.13, 0.16 vs. 0.03 for *Flemingia*).

In the case of *Flemingia*, decomposition was affected by soil macrofauna from the time decomposition started. In contrast, in the case of *Dactyladenia*, the increase of decomposition rate by the soil macrofauna started only after bacterial and fungal decomposition had taken

place for about 20 weeks. This explains the absence of macrofauna effect observed on *Dactyladenia* (formerly *Acioa*) pruning over a 14 week period by Tian *et al.* (1992), whereas it was 29 % over a period of 60 weeks in our study.
The outstanding difference between *Dactyladenia* and the other mulches (*Flemingia* and those used by Tian) is *Dactyladenia*'s lignin content: close to 40 % compared to 22 % for *Flemingia*, about 10 % for *Gliricidia* and *Leucaena* and about 5 % for maize stover and rice straw. An hypothesis that requires further investigation: it is a high lignin content (> 25 %), rather than lignin content per se or other factors, that retards degradation of mulches by macrofauna.

## Effect of micro-environment

The alley-cropping systems with *Dactyladenia* provided a micro-environment where decomposition of *Flemingia* mulch was faster. In general, soil temperature (at 15 cm depth) was lower and soil water content (at 10 cm depth) was higher in the alley-cropping with *Dactyladenia* as hedgerow tree compared to those with *Flemingia* (Henrot and Hauser, in prep.).
The proximity of *Dactyladenia* mulch cannot explain the faster decomposition of *Flemingia* in the *Dactyladenia* alley-cropping systems because when *Dactyladenia* and *Flemingia* mulches were placed together in a litterbag (1:1 *Flemingia:Dactyladenia*), the mixture decomposed more slowly than predicted from the decomposition rate of *Flemingia* or *Dactyladenia* alone (Henrot and Hamadina, 1996). Decomposition of the mixture (1:1 *Flemingia:Dactyladenia*) was also influenced by the micro-environment, its decomposition rate constant was 16 % higher in the alley-cropping systems with *Dactyladenia* than in those with *Flemingia* (Henrot and Hamadina, 1996).

Knowledge about the effect of mesofauna (< 2mm in size) on decomposition is too scanty to debate if differences in mesofauna between the 2 alley-cropping systems could explain the faster decomposition rate in the *Dactyladenia* alley-cropping, however microarthropod densities have been found to be very similar below different types of mulch, including *Dactyladenia*, on an Alfisol in S.W. Nigeria (Badejo *et al.*, 1995).

## Effect of the quantity of leaves applied at the soil surface on decomposition rate

Visual observations in the field had suggested that decomposition occurred at a faster rate when only a thin layer of leaves was present on the soil surface, which could have been explained by a better contact between the leaves and the soil. Experiment II, however, demonstrated that it was not the case: even if in the early stage of decomposition there was a slightly higher decomposition rate of *Flemingia* at the higher application rate (suggesting that thin layers of leaves might be subject to more desiccation and a retarded decomposition), the effect disappeared after 6 weeks and overall, the quantity of leaves present at the soil surface did not affect the rate at which the leaves decomposed.
The fact that no differences were observed between the decomposition rates in litterbags and littertubes with 2 mm mesh-size (Figure 2-2 and Table 2-3) indicates that the micro-environment in the two devices were similar. The effect of macrofauna on mulch decomposition can be large (30 to 40 %) and should be taken into account in the predictions of mulches decomposition rates for given field conditions. What determines the magnitude of the macrofauna effect is not clear but a very high lignin content (> 25 %) could be responsible for the retardation of mulch decomposition by macrofauna. More research is needed on that aspect.

# Conclusions

Micro-environment (temperature and moisture at the soil surface) can have a pronounced effect on decomposition rate. Because differences in micro-environment are not easily described by a parameter, they are difficult to use to predict decomposition rate of a given mulch in a given environment. They participate, therefore, to the inherent error of the K values.

Decomposition rate constants are not affected by the quantity of mulch added at the soil surface.

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# 3. DECOMPOSITION OF MIXTURES OF FOLIAGE OF CONTRASTING QUALITY IN THE HUMID TROPICS

J. Henrot and M.K. Hamadina

## Abstract

In the humid tropics plant residues are applied to agricultural soils to limit soil erosion and water loss, to supply nutrients to crops, and to maintain or increase soil organic matter content. Generally, plant residues with high nitrogen contents are good suppliers of nutrients, but they decompose too fast to have a positive effect on soil quality. In this chapter it is investigated whether mixtures of plant residues with high and low N contents are able to contribute to both the nutrient supply to crops and improvement of soil quality. In a field experiment the decomposition of a mixture of prunings of the trees *Dactyladenia* (low N content, slow decomposition rate) and *Flemingia* (high N content, high decomposition rate) and of a mixture of *Dactyladenia* and residues of the cover crop *Mucuna* (high N content, very high decomposition rate) has been studied.
Decomposition of the mixture of *Flemingia* and *Dactyladenia* foliage was about 20 % slower than what could be predicted if the two mulches decomposed without affecting one another. Decomposition of the faster decomposing mulch (*Flemingia*) was therefore delayed by the presence of the slower decomposing mulch (*Dactyladenia*). It is concluded that this delay may cause an inadequate supply of nutrients to crops.
*Mucuna* mulch decomposed faster than that of *Dactyladenia* mulch and the decomposition of their mixture was intermediate. *Mucuna* mulch decomposed at a rate which was 4 times faster than that of *Dactyladenia* mulch and 1.5 times faster than the mixture of *Dactyladenia*: *Mucuna*. Inclusion of a N-fixing cover crop to a *Dactyladenia* alley-cropping system during a period of fallow could thus be an amelioration of the system, although a even more retarded decomposition and N release from *Mucuna* in the *Dactyladenia*:*Mucuna* mixture would have been preferable.

**Keywords:** humid tropics, decomposition, plant residues mixtures, nutrient supply, *Dactyladenia*, *Flemingia*, *Mucuna*

## Introduction

In agricultural fields of the humid tropics, organic mulch is used to fulfill different purposes: (1) to provide a soil cover that limits erosion and soil water losses, (2) to supply nutrients to the growing crops during its decomposition, and (3) to increase soil organic matter content. Plant materials that can be used as mulch vary wildly in nutrient contents and decomposition rates. Because decomposition rate is positively correlated with N content (Melillo *et al.*, 1982), mulch that would be good suppliers of N are decomposing too fast to have a long-term effect on (1) and (3). Often, they are also decomposing too fast to release their N content in synchrony with crop demand and large amounts of the N released by the mulch is leached rather than taken up by the crop. In contrast, mulches that are low in nutrients and high in fiber decompose

slowly and fulfill purpose (1) and probably as well purpose (3). Since a mulch material fulfilling all 3 purposes at once is difficult to find, applying mixtures of mulches rather than a single mulch could provide a attractive combination.

In S. E. Nigeria, alley-cropping systems have been developed with some success (Gichuru *et al.*, 1990). They consist of rows of trees between which crops are planted. The trees are pruned regularly and their pruning is applied as surface mulch. Two tree species are particularly suited as hedgerows: *Dactyladenia barteri*, a Euphorbiaceae with low N content (Table 3-1) and very slow foliage decomposition rate (0.022 $week^{-1}$) and *Flemingia congesta*, a *Leguminosae*, with 1.5 times the N content of *Dactyladenia* and a much faster foliage decomposition rate (0.039 $week^{-1}$). A single alley-cropping system combining the two tree species might be an improvement over the current systems.

Another alternative to bring N fixed from the atmosphere in an alley-cropping system with *Dactyladenia* as hedgerow tree is to grow a leguminous cover crop (e.g., *Mucuna pruriens* var. utilis) in the alleys during a period of fallow.

The purpose of this study was to determine if a 1:1 mixture of *Dactyladenia:Flemingia* mulch or a 1:1 mixture of *Dactyladenia:Mucuna* mulch decompose and release their nutrients as could be predicted from the individual decomposition and nutrient release rates of their components.

# Materials and methods

The experiment was conducted at the High Rainfall Station of the Institute for Tropical Agriculture, in Onne (4° 51'N; 7° 03'E), near Port Harcourt, in the humid forest zone of S. E. Nigeria. Rainfall at the site is monomodal with a rainy season lasting from March to December and a mean annual rainfall of 2.4 m. Relative humidity remains high throughout the year (78 to 89 %) and mean annual temperature is 25 °C.

Dry weight loss of *Dactyladenia*, *Flemingia* and a 1:1 mixture of *Flemingia:Dactyladenia* leaves (chemical composition in Table 3-1) was monitored from July 1992 to March 1993 using stainless-steel litterbags (0.3 x 0.3 x 0.02 m) of 2 mm mesh-size. The litterbags were filled with an amount of fresh leaves corresponding to 2.3 Mg $ha^{-1}$ (dry weight basis) and placed in alley-cropping systems established 7 years earlier with either *Dactyladenia barteri* or *Flemingia congesta* as hedgerow species. The alley-cropping systems consisted of 5 rows of trees of the same species, separating alleys 4.5 m wide and 20 m long in which maize and cassava were planted. They were replicated 4 times in a block design. The litterbags were placed in the field at the same time as the hedgerow tree prunings, a few days before planting maize and cassava. At about 10, 20, 40, 50 and 130 days after placement, 2 litterbags of each treatment were randomly collected from each alley-cropping unit.

Dry weight loss of *Dactyladenia*, *Mucuna* and a 1:1 mixture of *Dactyladenia:Mucuna* leaves (chemical composition in Table 3-3) was monitored from June 1994 to September 1994 using the same stainless-steel litterbags as described above. The litterbags were filled with 45 g of dry leaves (corresponding to 5.0 Mg $ha^{-1}$) and placed in a weeded open field. At 5, 10, 20, 30, 45, 60, and 90 days after placement, 3 litterbags of each treatment were randomly collected.

Table 3-1. Changes in nutrient and fiber content during decomposition. Content is expressed in percent of dry weight.

| Days* | N | Ca | Mg | K | Lignin | Cellulose |
|---|---|---|---|---|---|---|
| Dactyladenia mulch | | | | | | |
| 0 | 1.6 ± 0.0 | 0.8 ± 0.0 | 0.20 ± 0.00 | 0.4 ± 0.0 | 38 ± 2 | 29 ± 1 |
| 10 | 1.6 ± 0.1 | 1.3 ± 0.2 | 0.23 ± 0.02 | 0.4 ± 0.1 | 42 ± 7 | 32 ± 4 |
| 53 | 1.6 ± 0.0 | 1.5 ± 0.1 | 0.23 ± 0.02 | 0.1 ± 0.0 | 47 ± 6 | 35 ± 6 |
| 130 | 1.7 ± 0.1 | 1.3 ± 0.2 | 0.21 ± 0.00 | 0.1 ± 0.0 | 44 ± 6 | 29 ± 6 |
| Flemingia mulch | | | | | | |
| 0 | 2.9 ± 0.1 | 0.6 ± 0.0 | 0.19 ± 0.00 | 0.8 ± 0.0 | 22 ± 1 | 24 ± 2 |
| 10 | 3.0 ± 0.5 | 1.0 ± 0.2 | 0.25 ± 0.00 | 0.4 ± 0.4 | 42 ± 2 | 21 ± 2 |
| 53 | 3.2 ± 0.1 | 1.1 ± 0.0 | 0.24 ± 0.01 | 0.2 ± 0.0 | 39 ± 6 | 20 ± 6 |
| 130 | 3.5 ± 0.2 | 0.9 ± 0.1 | 0.27 ± 0.02 | 0.2 ± 0.0 | 40 ± 3 | 21 ± 3 |
| Mixture 1:1 Dact.:Flem. | | | | | | |
| 0 | 2.2 | 0.7 | 0.20 | 0.6 | 30 | 26 |
| 10 | 2.3 ± 0.1 | 0.7 ± 0.0 | 0.23 ± 0.01 | 0.6 ± 0.1 | 34 ± 1 | 25 ± 1 |
| 53 | 2.4 ± 0.1 | 0.9 ± 0.0 | 0.25 ± 0.02 | 0.2 ± 0.1 | 43 ± 3 | 21 ± 3 |
| 130 | 2.5 ± 0.2 | 0.9 ± 0.0 | 0.23 ± 0.02 | 0.1 ± 0.0 | 48 ± 6 | 22 ± 6 |
| Predicted for 1:1 mixture Dact.:Flem. | | | | | | |
| 0 | 2.2 | 0.7 | 0.20 | 0.6 | 30 | 26 |
| 10 | 2.3 | 0.9 | 0.26 | 1.0 | 41 | 28 |
| 53 | 2.6 | 1.2 | 0.26 | 0.2 | 46 | 28 |
| 130 | 2.5 | 1.0 | 0.24 | 0.1 | 44 | 26 |

* Days after placement in the field

The litterbag contents were brushed gently to removed the excess of sand, dried at 60 °C for 48 h and weighed. A subsample of the original plant material and the material collected from the litterbags were ground to pass a 0.5 mm sieve. Dry weights of the remaining mulch were corrected for ash content (combustion at 550 °C for 6 hours). Selected samples were analyzed for total N (Kjeldahl), fiber content (Goering and Van Soest, 1970), and Ca Mg K and P contents after acid digestion (P by colorimetry with the molybdate blue method, Ca and Mg by atomic absorption, K by flame photometry). Dry weight loss constant K were obtained from the equation: $Yt = Yoe^{-Kt}$, where Yo and Yt represent residues remaining initially and at time t (Wieder and Lang, 1982).

# Results and discussion

Decomposition of the mixture of *Flemingia* and *Dactyladenia* foliage was about 20 % slower than what could be predicted if the two mulches decomposed without affecting one another (Table 3-2 and Figure 3-1). Decomposition of the faster decomposing mulch (*Flemingia*, richer in N) was therefore delayed by the presence of the slower decomposing mulch (*Dactyladenia*).

Table 3-2. Decomposition rate constants K (week$^{-1}$) of Flemingia and Dactyladenia mulches and of a 1:1 mixture of Flemingia and Dactyladenia.

| Mulch | Placement in Flem. alleys | Dact. alleys |
|---|---|---|
| Flemingia | 0.032 | 0.039 |
| Dactyladenia | n.r. | 0.022 |
| Mixture 1:1 Flem.:Dact. (observed) | 0.021 | 0.025 |
| Mixture 1:1 Flem.:Dact. (calculated)† | *0.026* | *0.030* |

†calculated assuming independent decomposition of Flem. and Dact.

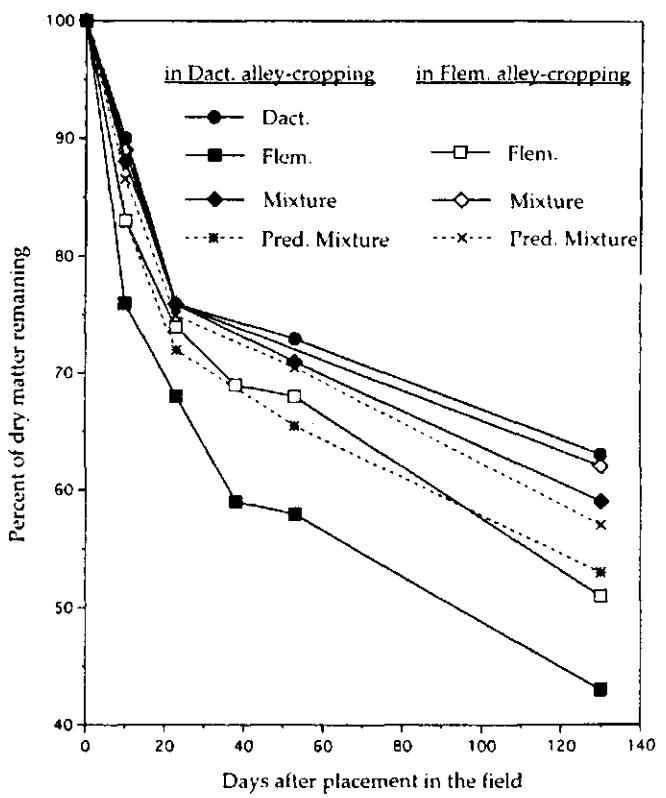


Figure 3-1. Decomposition of mulches of *Dactyladenia*, *Flemingia* and of a 1:1 *Dactyladenia*:*Flemingia* mixture. The litterbags were placed in alley-cropping systems with either *Dactyladenia* or *Flemingia* as hedgerow trees. "Pred. Mixture" refers to the predicted decomposition of the mixture if *Flemingia* and *Dactyladenia* mulches decomposed independently.

The effect of intimately mixing 2 mulches of contrasting quality is distinct from the effect of the micro-environment on the decomposition of a given mulch type. If *Flemingia* mulch is mixed intimately with *Dactyladenia* mulch, it decomposes more slowly than alone but if it is placed in alley-cropping systems with *Dactyladenia* as hedgerow trees, it decomposes faster than in systems with *Flemingia* as hedgerow trees. Both the *Flemingia* mulch and the 1:1 *Flemingia*:*Dactyladenia* mixture decomposed faster in alley-cropping systems with *Dactyladenia* as hedgerow trees than in alley-cropping systems with *Flemingia* as hedgerow trees (Figure 3-1, Table 3-2). This can be explained by the higher humidity and lower temperature in the systems with *Dactyladenia* trees compared to those with *Flemingia* (Henrot and Hauser (in prep.); Henrot and Brussaard, 1996).

The changes in nutrient content of the mixture during decomposition is not far from the predicted values if *Dactyladenia* and *Flemingia* decomposed without interacting with one another (Table 3-1). Lignin content, in contrast, had a different dynamics than the predicted mixture and cellulose had a consistently lower content in the mixture (Table 3-1).

*Mucuna* mulch decomposed faster than that of *Dactyladenia* mulch and the decomposition of their mixture (1:1) was intermediate (Figure 3-2). Over the study period (90 days), < 40 % of the original *Mucuna* mulch and > 60 % of the *Dactyladenia* mulch remained undecomposed, compared to about 50 % of the 1:1 mixture of *Dactyladenia*:*Mucuna*. *Mucuna* mulch decomposed at a rate which was 4 times faster than that of *Dactyladenia* mulch and 1.5 times faster than a 1:1 mixture of *Dactyladenia*: *Mucuna* (Table 3-3).

Table 3-3. Composition, decomposition and N release constants K (week$^{-1}$) of *Mucuna*, *Dactyladenia* and a 1:1 mixture of *Mucuna* and *Dactyladenia*.

| | N (%) | Lignin (%) | C:N | Decomposition K | N-release K |
|---|---|---|---|---|---|
| *Mucuna* | 2.06 | 18.1 | 17.6 | 0.175 | 0.093 |
| *Dactyladenia* | 1.77 | 25.5 | 22.4 | 0.040 | 0.081 |
| Mixture 1:1 | 1.87 | 21.8 | 21.4 | 0.069 | 0.055 |

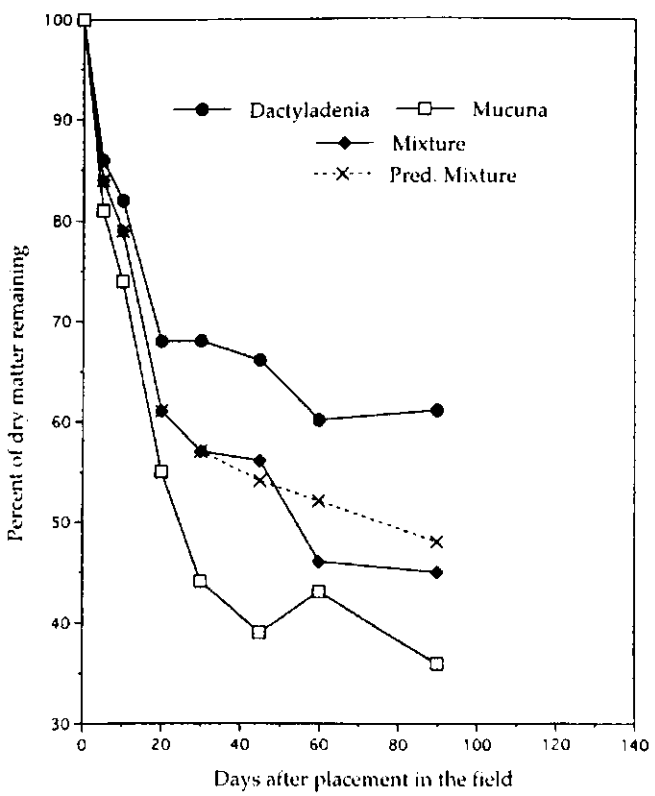


Figure 3-2. Decomposition of mulches of *Dactyladenia*, *Mucuna* and of a 1:1 *Dactyladenia*:*Mucuna* mixture. "Pred. Mixture" refers to the predicted decomposition of the mixture if *Dactyladenia* and *Mucuna* mulches decomposed independently.

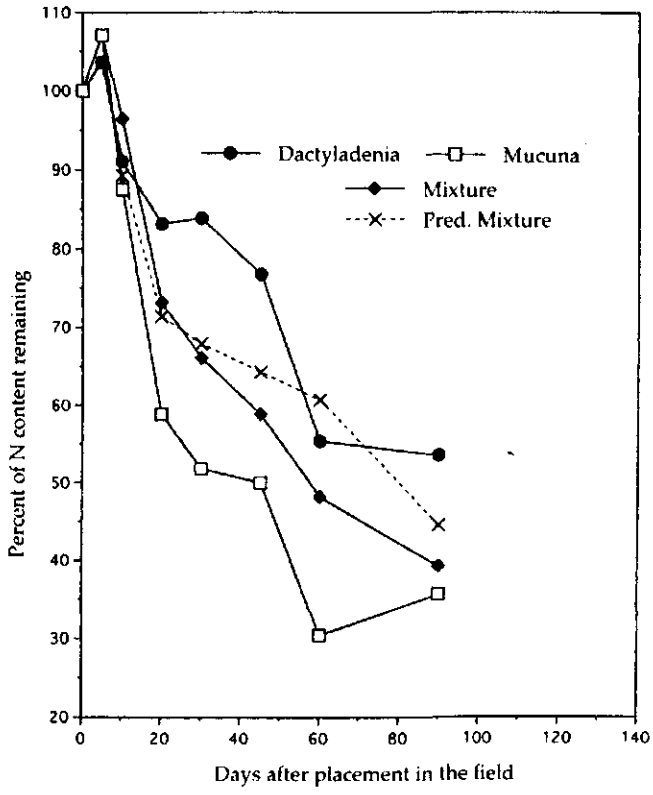


Figure 3-3. Nitrogen release from mulches of *Dactyladenia* , *Mucuna* and of a 1:1 *Dactyladenia*: *Mucuna* mixture. Pred. Mixture refers to the presicted N release of the mixture if *Dactyladenia* and *Mucuna* decomposed independently

The release of N from the decomposing shoots followed a pattern similar to their dry weight loss (Figure 3-3). However, N release was preceeded by an immobilization of N during the first week of decomposition. More than 50 % of N in *Mucuna* mulch and < 20 % of N in *Dactyladenia* mulch were released within the first 30 days, whereas their mixture lost about 30 % of their initial N in the same period.

The predicted curves for the 1:1 mixture were calculated assuming independent decomposition of the two mulches. The predicted decomposition and N release K for the 1:1 mixture did not differ from the observed one, indicating that mixing the two residues did not affect their decomposition rate.

It was hypothesized that mixtures of mulch of fast and slow decomposition rates may mineralize N slowly at first then rapidly later (Swift, 1987) because the N released by the fast decomposing mulch would be initially immobilized by the slow decomposing mulch. Field studies, however, have shown that mulch mixtures follow a variety of patterns: either the one described above (Myers *et al.*, 1994, data of Bandara and Anderson: mixture of straw and *Gliricidia*), or an increased decomposition and N mineralization compared to the values calculated on the assumption that no interaction occurred between the mulches during decomposition (Williams and Alexander, 1990, using Sitka spruce and Scots pine litter), or no interaction between the mixture components (*Mucuna pruriens* shoots and *Dactyladenia barteri* leaves, this study), or a retarded decomposition and N release over an extended period of time (4 months, this study).

This experiment contributes to the growing evidence that the decomposition and N-release patterns of mixtures are varied and that, unless the mechanisms regulating them are understood, they are not predictable.

In the case of the alley-cropping systems with *Flemingia* and *Dactyladenia*, the prolonged retardation on *Flemingia* decomposition induced by the contact with *Dactyladenia* mulch is not a desirable effect. *Flemingia* decomposition and N release is already much slower than that of most legumes (K decomp. = 0.03 $week^{-1}$ compared to 0.10 or above for most legumes) and should not be decreased in order to provide adequate N supply to the crops. Addition of a N-fixing cover crop to the *Dactyladenia* alley-cropping system during a period of fallow, on the other hand, could be an amelioration of the system, although one would have wished, in this case, a retarded decomposition and N release from *Mucuna* in the *Dactyladenia*:*Mucuna* mixture.

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# 4. DECOMPOSITION AND NUTRIENT RELEASE FROM RESIDUES OF *CALLIANDRA CALOTHYRSUS, ALCHORNEA CORDIFOLIA, PENNISETUM PURPUREUM* AND *CHROMOLAENA ODORATA*

J. Kanmegne, B. Duguma, J. Henrot and N.O. Isirimah

## Abstract

The decomposition rate and nutrient release patterns of four fallow species, *Calliandra calothyrsus, Alchornea cordifolia, Pennisetum purpureum* and *Chromolaena odorata* were assessed. *Pennisetum* and *Chromolaena* had more K, *Alchornea* more Ca and *Calliandra* more N. *Chromolaena* decomposes fast, only 36 % of the biomass remained after 14 weeks, compared to 41 % for *Pennisetum*, 50 % for *Calliandra* and 53 % for *Alchornea*. There was a flush of nutrients, especially K, during the decomposition of *Chromolaena* and *Pennisetum*, immobilization of N from *Calliandra* and a very slow release of Ca from *Alchornea*. It is therefore suggested that *Chromolaena* and *Pennisetum* mulches should be used during high K demand periods, or enriched with long lasting residues for efficient nutrient management in short fallow systems.

**Keywords**: humid tropics, fallow, decomposition, *Calliandra, Alchornea, Pennisetum, Chromolaena*

## Introduction

Bush fallowing is the traditional way to maintain soil fertility and reduce proliferation of weeds, pests and diseases (Sanchez, 1976). During the fallow period, nutrients are taken up by the vegetation from various depths of soil, and stored in the biomass, then returned to the surface soil through litterfall, root decomposition, and root exudates or residue decomposition after slashing (Webster and Wilson 1987). The role of plant residues in regenerating soil nutrient and ameliorating soil fertility is well known, but little information is available on the role of dominant fallow species occurring in short fallows of the humid tropics. The increased diversity of the fallow species leads to a wide range of litter quality, decomposition rates, and nutrient release patterns. This study is initiated to evaluate the contribution of four dominant short fallow species of the humid forest to nutrient cycling and soil fertility restoration. It is hoped to provide information in synchronizing the period of specific nutrient release with optimum requirement of the food crop during the following cropping phase.

The decomposition rate is known to be influenced by a number of factors including the macroclimate, the nature and type of soil organisms involved in the process, and the quality of the decomposing material. Litter quality is defined as the chemical composition, including concentrations of chemical elements and of various organic compounds. The mass loss weight is controlled by the nitrogen content (Muller *et al.*, 1988; Janzen and Kucey, 1988; Melillo *et al.*, 1982) and the C/N ratio of the decomposing material (Bary *et al.*, 1989). The microorganisms

involved in the litter decomposition depend largely on the original nitrogen content of the decomposing tissues for their survival. When the N reserve is exhausted, lignin becomes an important plant component influencing the decomposition rate (Melillo *et al.*, 1982; Laishram and Yadava, 1988). Wieder and Lang (1982) and Bary *et al.* (1989) reported that high C/N ratio indicates the relatively greater recalcitrant fractions (cellulose, fats, waxes, and tannins) which are lost at a relatively low rate. Its effects are similar to those of polyphenols, that form complex structures by bridging with N-containing groups or act as tanning agents capable of preserving proteins from rapid decomposition, or by slowing the activity of organisms and enzymes (Palm and Sanchez, 1991). Lignin also interferes with the enzymatic degradation of carbohydrates and proteins (Alexander, 1977; Mellilo *et al.*, 1982).

During decomposition, soluble compounds such as sugar, starch, and proteins decompose rapidly during the first four weeks, while more recalcitrant material are lost at relatively slower rate (Wieder and Lang, 1982). Different patterns of release of mineral nutrient have been devised. N, P, and Mg parallel the weight loss, K is released more quickly and Ca more slowly than others (Swift, 1986). Singh and Shekhar,(1989) observed a K-P-N mobility series where K is the readily released element and N the least mobile. Although a temporary increase in the absolute quantity of nitrogen and phosphorus relative to the amount originally present can be observed during decomposition, the absolute stock of all nutrient decrease during decomposition period due to the overriding influence of greater weight loss (Singh and Shekhar, 1989). Then if the recycling of plant nutrient in short fallow systems can be achieved using leaf litter of dominant species as source of nutrients, the knowledge of the quality of plant residue and the process of its decomposition is necessary for efficient nutrient management in the short fallow system.

# Materials and methods

## Study site

The experiment was conducted in 1994 during the first rainy season (April-September), in Minkoameyos-Yaounde in Central Cameroon 3°51'-3°53' N and 11°25'- 11°27' E, 700 m above sea level. The rainfall pattern of the area is bimodal, with peak in May and October. The mean annual rainfall is 1600 m, with 80 % mean annual relative humidity and 23.5°C mean annual temperature. The soil is an Ultisol with pH between 5 and 6, an Al saturation of less than 40 % in the top 15 cm. The essentials of soil characteristics are summarized in Table 4-1.

Table 4-1. Characteristics of two years fallow soil in the humid forest zone of Cameroon.

| | Soil layers (cm) | | | |
|---|---|---|---|---|
| Soil properties | 0-5 | 0-15 | 15-30 | LSD |
| pH (water) | 6.3 | 6.2 | 5.7 | 0.9 |
| pH (BaCl2) | 5.6 | 5.6 | 5.1 | ns |
| Ca (meq/100g) | 9.60 | 7.05 | 3.63 | 5.70 |
| total N (%) | 0.228 | 0.179 | 0.131 | 0.065 |
| avail. P (ppm) | 11.23 | 5.58 | 4.11 | ns |
| K (meq/100 g) | 0.248 | 0.152 | 0.092 | 0.102 |
| org. C (%) | 3.37 | 2.14 | 1.43 | 0.89 |
| Mg (meq/100g) | 2.63 | 1.76 | 1.08 | 1.21 |

# Decomposition experiment

Leaves of *Alchornea cordifolia*, *Calliandra calothyrsus*, and the above-ground biomass of *Pennisetum purpureum* and *Chromolaena odorata* were used for the study. The four species are the dominant short fallow species in the humid lowlands of Cameroon (Kanmegne, 1995). The plant material was collected in 2 years fallows around Yaounde, air-dried, weighed and filled into stainless steel litter bags, with a shallow box like shape of 30 cm by 30 cm and with 2.0 mm mesh size. Each bag was filled with 45 g dry material, equivalent of 5 t $ha^{-1}$. The litter-bags were surface placed on the field. For each species, 24 bags were used in order to allow 6 sampling in 4 replicates.

The bags were placed on the field on April 7, 1994, and the plant material allowed to decompose for a period of 14 weeks (100 days), until July 22, 1994. Sampling was done at 1, 2, 3, 5, 11, and 14 weeks after placement of the bags on the field. At each sampling, 4 bags per species were carefully leafed in the field to reduce loss of plant residues, and enclosed in separate polytene bags for transport to the laboratory. The material was then hand sorted to remove the roots weed and soil, then over-dried, weighed and subsample taken to determine the ash-free dry weight following the procedures described by Anderson and Ingram (1992). The remaining biomass was expressed as a percentage of the initial mass. At alternate sampling dates 0, 2, 5, and 14 weeks after placement, the residues were analyzed for N, K, Ca, lignin and cellulose content.

## Plant analysis

Samples of the original material were oven-dried at 65 °C till constant weight, and ground to pas 2 mm size sieve for analysis. At three sampling dates, 2, 5, and 14 weeks after placement, the remaining material was also sampled and analyzed for N, K, Ca, lignin and cellulose. Chemical analysis were done in triplicate. Total N was determined by micro Kjeldahl digestion, followed by distillation and titration. K was measured by flame photometry, and Ca measured using atomic absorption spectrophotometry (IITA, 1982). Lignin and cellulose were determined by the acid detergent fibber method as described by Anderson and Ingram (1992). Ash free dry weight was determined by ashing a plant sample in a muffle furnace at 550 °C for 3 hours.

## Data analysis

Data of the percent biomass remaining was subjected to ANOVA for a completely randomized design including a factorial arrangement of treatments: 6 sampling dates and 4 litter types. The decomposition rate constant (K) was determined from the negative exponential decay model of Olson (Anderson and Ingram 1992): $Wt / Wo = Wo\ e^{-kt}$ where Wo is the initial mass Wt is the remaining mass at time t, and e is the exponential function. The mean relative decomposition rate (RDR) was calculated, using the formula: RDR (mg $g^{-1}$ $day^{-1}$) = ln (Wt-Wo) / (t1 -to) where Wo = weight of the biomass at time to , Wt = weight of the biomass at time t1, (t2-t1) = sampling interval (days).

The decomposition time projection of the different plant residues was then estimated from the daily instantaneous decay rate (K). Then, the time required for 50, 95, and 99 % weight loss was calculated as: t50 = 0.693/K, t95 = 3/K, and t99 = 5/K. Partial correlation and regression analysis of nutrient release rate constants against the initial N, lignin, and cellulose were also performed.

# Results and discussion

## Chemical composition of plant residues

The four fallow species differed significantly ($P < 0.05$) for nitrogen, potassium and calcium concentrations. *Calliandra* leaves had the highest nitrogen content 3.2 %, compared others. *Pennisetum* was the least with only 1.6%. *Pennisetum* and *Chromolaena* rather had the highest level of initial K, 2.7 % and 2.5 % respectively, compared to those of *Calliandra* (0.8 %) and *Alchornea* (0.7%). The Ca concentration in the plant samples showed similarities between *Calliandra* (1.9 %) and *Alchornea* (1.8 %). *Pennisetum* had the lowest Ca but the highest lignin content. The chemical characteristics of plant residues are summarized in Table 4-2.

Table 4-2. Chemical composition of residues of four fallow species in the humid forest zone

| Residue type | N % | K % | Ca % | Lignin % | Cellulose % |
|---|---|---|---|---|---|
| Call. leaves | 3.23 | 0.16 | 0.73 | 12.51 | 17.09 |
| Call. wood | 0.71 | 0.54 | 0.71 | 20.73 | 47.23 |
| Alch. leaves | 2.68 | 0.81 | 1.08 | 23.75 | 17.41 |
| Alch. wood | 0.99 | 0.95 | 1.90 | 17.39 | 39.12 |
| Chromolaena | 1.37 | 1.19 | 0.84 | 18.34 | 39.28 |
| Pennisetum | 0.87 | 2.00 | 0.29 | 12.06 | 41.38 |
| LSD | 0.71 | 0.59 | 2.28 | 6.06 | 9.72 |

The high N content in *Calliandra* can be attributed to its ability to fix $N_2$; although *Alchornea* is not a legume species it has as much as 2.68 % N in the leaves, indicating the potential of the species to be used especially on highly acidic soils were the establishment of legumes is restricted. *Pennisetum* and *Chromolaena* had a high concentration of K, indicating their potential to accumulate specifically this nutrient, and to contribute to soil K after slash and burn.

## Decomposition patterns of the residues

Over the decomposition period of 14 weeks, the variation was significant ($P<0.05$) for both sampling times and fallow species. *Chromolaena* residues decomposed faster than the residues from the other fallow species (Figure 4-1). After 14 weeks, only 36 % of the original weight of *Chromolaena* remained, compared to 53.4% for *Alchornea* and 50.5% for *Calliandra*. *Pennisetum* had intermediate decomposition rate, with 41% remaining biomass. The lowest relative decomposition rate was observed for *Alchornea*, 1.0 mg/g/day, compared to 1.39 for *Chromolaena*. The daily instantaneous decay rate (K) followed the same trend, allowing the following ranking of the different species for the decomposition rate: *Chromolaena* > *Pennisetum* = *Calliandra* > *Alchornea*. The half life the four fallow species is estimated between 69 days (for *Chromolaena*) and 128 days (for *Alchornea*). Table 4-3 summarizes the decomposi-tion characteristics of the four fallow species.

Table 4-3. Decomposition characteristics of four fallow species in the humid forest zone of Cameroon

| Parameters | Alch. | Call. | Chrom. | Penn. | LSD |
|---|---|---|---|---|---|
| Lignin (%) | 15.83 | 25.54 | 14.95 | 9.52 | 6.12 |
| Cellulose (%) | 18.93 | 21.47 | 32.38 | 34.58 | 3.18 |
| K value (10-2) | 0.64 | 0.70 | 1.04 | 0.68 | |
| t 50 (days) | 128.3 | 99.0 | 69.3 | 101.91 | |
| t 99 (months) | 26 | 23 | 16 | 24 | |

Thus *Chromolaena* biomass accumulated during two years of fallow may not provide enough organic matter during the second cropping season, compared to the three other species. *Alchornea*, because of its low decomposition rate can remain longer in the soil and supplement the soil organic matter provided burning is avoided after slashing. Then *Alchornea* fallows can be particularly recommended in Ultisols where soil organic matter plays the leading role in nutrient availability of the soil.

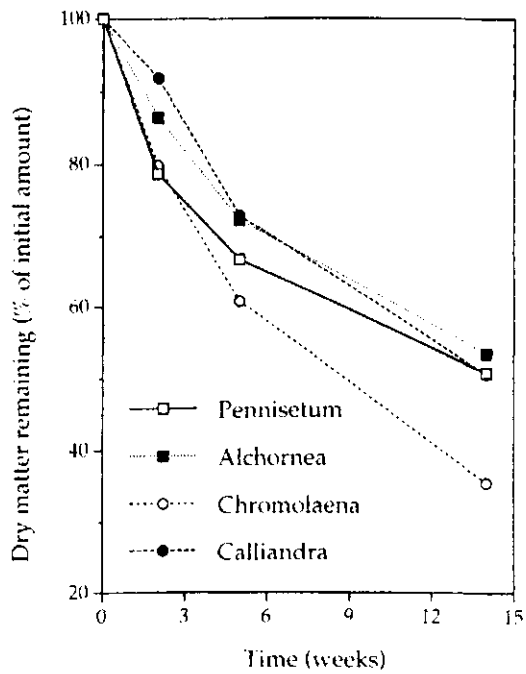


Figure 4-1. Dry matter loss during decomposition.

## Nutrient release from the biomass

Most of the *Calliandra* N was released after 5 weeks and thereafter the N release from *Calliandra* and *Alchornea* were similar. For *Pennisetum* and *Chromolaena*, the N release patterns were similar, but a high increase was observed in *Pennisetum* N between week 2 and week 5. The relative increase in N concentration may be due to N fixation , uptake from the surroundings by fungal hyphae growing in the litter (Melillo *et al.*, 1982; Laishram *et al.*, 1988) or preferential retention of N while other materials are being rapidly lost from the decomposing material, particularly carbon (Singh and Shekhar, 1989) (Figure 4-2). Changes in K concentration during decomposition showed that K is very mobile during the first two weeks especially for *Chromolaena* and *Pennisetum*. After the two week period the four fallow species had similar content of K remaining in the litter (Figure 4-3). Then the K accumulated in *Chromolaena* and *Penni-*

*setum* is released the first two weeks of decomposition, which is indicative of the potential use of the two species as mulch material during high K requiring periods by crops. During the decomposition Ca was less mobile in *Alchornea* and *Pennisetum* than in the other species. The highest release rate was observed for *Calliandra* (Figure 4-4). Generally there was an accumulation of Ca in the decomposing leaves and it was released more slowly than other nutrients. Palm and Sanchez (1991) observed the same pattern of Ca release of decomposing residues. Potassium was released more quickly and calcium more slowly than nitrogen. Similar patterns are reported by Swift (1986) and Singh and Shekhar (1989), who observed that K is the most readily released element, compared to N. The initial content of Ca in the decomposing residues seems to have influence the rate of release. The lignin content affected negatively and significantly the N release from *Alchornea* ($R^2 = 0.88$), and from *Chromolaena* ($R^2 = 0.93$). It had similar effects on K release from *Alchornea* ($R^2 = 0.73$) and *Chromolaena* ($R^2 = 0.99$).

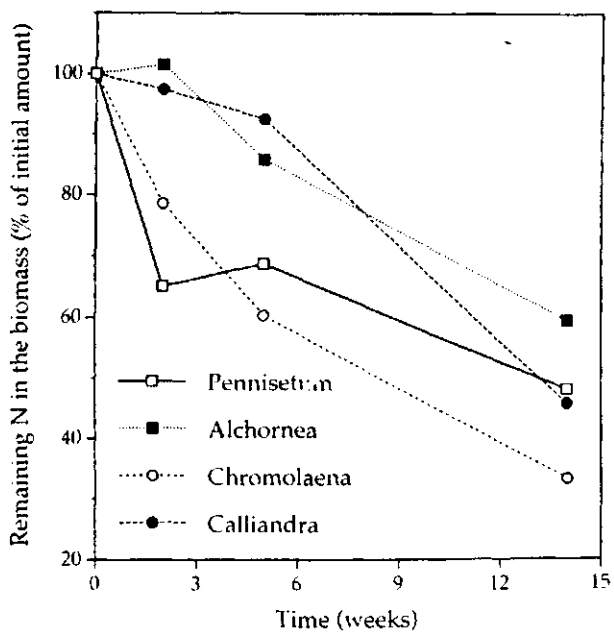


Figure 4-2. Nitrogen loss during decomposition.

# Conclusions

*Pennisetum* produced a deal of biomass P and K in a relatively shorter time than other species. It has a moderate decomposition rate and a rapid release of K. *Alchornea* has a high Ca and N in the biomass, the leaves have a low decomposition rate, slowing down the nutrient release, especially for Ca. *Calliandra* is a nitrogen fixing species and therefore accumulates more nitrogen in the biomass than other species. *Chromolaena* produces K rich biomass, but decomposes too fast, therefore inducing a flush of nutrients in the early days of decomposition, and a poor residual biomass for long cycle crops. *Chromolaena* fallows then need to be associated with low decomposing species to improve the nutrient use efficiency of *Chromolaena* fallows, especially in areas where fallow length is too short to allow the coming back of the secondary forest.

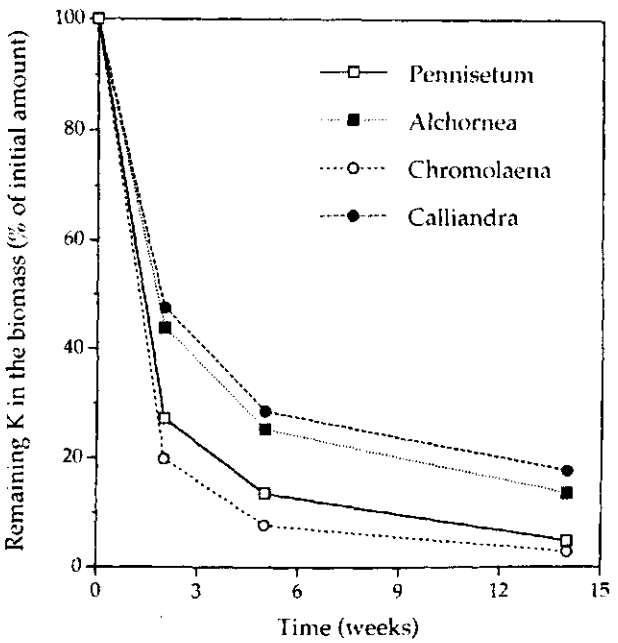


Figure 4-3. Potassium loss during decomposition.

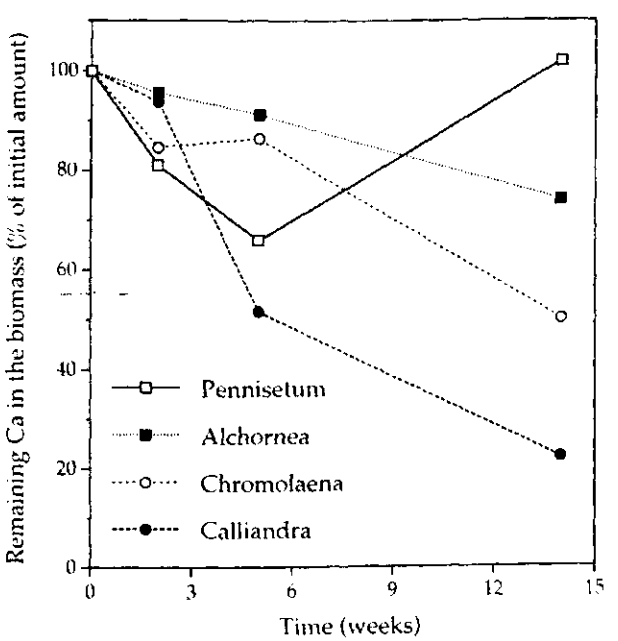


Figure 4-4. Calcium loss during decomposition.

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# 5. DECOMPOSITION OF FINE ROOTS: A FIELD METHOD REQUIRING SMALL AMOUNTS OF ROOT MATERIAL

J. Henrot, M.K. Hamadina and M. Van Noordwijk

## Abstract

For agricultural systems in the humid tropics little information exists on the contribution of roots to soil organic matter build-up and nutrient supply to crops. In this chapter two experiments are described in which a simple technique ("the clay-pot technique") was used to determine the decay rate of fine roots. In the first experiment, the technique was used to obtain information on fine-root decay of the trees *Flemingia* and *Dactyladenia* in agroforestry systems (alley-cropping). The second experiment was designed to estimate the N contribution of fine roots of the cover crop *Mucuna* to the following maize crop in a maize/cover crop rotation system.
*Flemingia* fine roots, which had an about three times higher N content than *Dactyladenia* fine roots, decomposed three times faster than *Dactyladenia* roots. Decomposition constant rates were found to be 0.069 and 0.024 week$^{-1}$, respectively. It is therefore expected that *Flemingia* fine roots contribute little to soil organic matter build-up.
*Mucuna* fine roots decomposed and lost their N at an extremely fast rate. The decomposition constant rate was 0.910 week$^{-1}$. Within 20 days after placement in the field, the roots had lost 80 % of their N and dry matter. This suggests that N contribution of *Mucuna* fine roots to the following maize crop is insignificant or small, depending on the rainfall pattern.

**Keywords:** humid tropics, fine roots, clay-pot technique, root decay, *Flemingia*, *Dactyladenia*, *Mucuna*

## Introduction

In agricultural systems of the humid tropics, below-ground processes are frequently overlooked because their study is either destructive, labor- and time-consuming or it requires sophisticated material and expertise (Taylor, 1987), which is out of reach of most national research centers. However, one of the paramaters of fine root dynamics, root decay rate, can be measured by a simple field technique requiring only small amounts of fine roots (Van Noordwijk, 1993; Van Noordwijk *et al.*, 1994). Known amounts of excised roots are placed in clay pots filled with sieved root-free soil. The pots are covered with a tightly knit cloth, buried in the experimental site, and retrieved at desired time intervals. Their content is subsequently washed over a fine-mesh sieve.

This method is an improvement over buried litterbags because (1) no losses of fine roots are possible from the buried clay pots and (2) the amount of roots required is small and, therefore, can be collected from plants grown in the field. In order to acquire enough material to fill litterbags, roots are often collected from potted plants. Given the difference in age and root development between potted and field plants, their root quality might differ substantially.

Two examples of the potential use of the clay pot technique are given in this paper. In the first experiment, the technique was used to obtain information on tree root decay in agroforestry systems (alley-cropping) where crops are grown between lines of trees. In S.E. Nigeria, *Dactyladenia barteri* and *Flemingia congesta* are promising hedgerow tree species for alley-cropping (Gichuru *et al.*, 1990). The tree contributions to soil organic matter build-up and nutrient supply to the crop depend, among others, on the decomposition rates of its above- and below-ground inputs. Foliage decomposition rate of *Flemingia* and *Dactyladenia* differ drastically: K of 0.039 and 0.022 $week^{-1}$, respectively (Henrot and Brussaard, 1996). We compared their fine root decomposition and nutrient release rates.

The second experiment was designed to estimate the N contribution of cover crop fine roots to the following maize crop in a maize/cover crop rotation system in S. E. Nigeria. At the end of the rainy season, the above ground parts of the cover crop (*Mucuna pruriens* var. utilis) dry up after flowering and hardly any decomposition of *Mucuna* shoots take place during the dry season (Hamadina *et al.*, 1996). The same is assumed for fine roots. Fine roots were collected at the end of the rainy season and their decomposition was followed in the field at the beginning of the following rainy season.

# Materials and methods

## Experimental site

The experiment was conducted at the High Rainfall Station of the Institute for Tropical Agriculture, in Onne (4° 51'N; 7° 03'E), near Port Harcourt, in the humid forest zone of S. E. Nigeria. Rainfall at the site is monomodal with a rainy season lasting from March to December and a mean annual rainfall of 2.4 m. Relative humidity remains high throughout the year (78 to 89 %) and mean annual temperature is 25 °C.

## Experiment I

Fine roots (1- 2 mm ø) of *Flemingia congesta* and *Dactyladenia barteri* were obtained by washing gently, with water and over a fine sieve, blocks of soil (0.4 x 0.4 m and 0.1 m deep) that were collected under 7 year-old trees bordering an alley-cropping experiment. The tree roots, which were easily recognizable from weeds', were cut into 3 cm pieces after removal of nodules (in the case of *Flemingia*) and kept in a moist box at 5 °C for a maximum of 6 days before use. Root density was between 12 and 21 g dry weight/$m^2$ (over 10 cm depth) for *Flemingia* and between 25 and 45 for *Dactyladenia*. Soil (0-10 cm depth) was collected from an adjacent location, sieved free of roots and air-dried. The soil on site is a loamy siliceous typic Ultisol with, in the top 10 cm, 73 % sand, 4 % silt, 23 % clay, 1.4 % C, 0.12 % N, and a pH of 4.1.

The equivalent of 0.9 g root dry weight (6.0 g fresh *Flemingia* roots or 2.1 g fresh *Dactyladenia* roots) were mixed to 445 g air-dried soil and placed in a baked clay pots (commonly used for flowers, about 250 $cm^3$: 9.5 cm ø at the top, 4.75 at the bottom, and 8.5 cm height) subsequently covered with a tightly knitted cloth maintained with a large rubber band. The pots were generously watered and buried, large opening downwards and at a depth of 15 cm, in alley-cropping systems established 7 years earlier with either *Dactyladenia* or *Flemingia* as hedgerow species. The alley-cropping systems consisted of 5 rows of trees of the same species, separating alleys 4.5 m wide and 20 m long in which maize and cassava were planted. They were replicated 3 times in a block design.

On 5 selected dates between July 3 and November 23, 1992, 2 pots were removed at random from each alley-cropping replicate (i.e., 6 pots per specie). The content of the pot was washed over a 0.5 mm-mesh sieve and the root fragments were collected with forceps, rinsed briefly, and dried at 60 °C. Root recovery with this method (estimated with fresh roots) was close to 95 %.

For chemical analyses, given the small amount of material, the roots collected from 6 pots (2 per alley-cropping unit x 3 block replicates) were pooled together. The pooled samples were analyzed for total N (Kjeldahl) and Ca Mg K and P contents after acid digestion (P by colorimetry with the molybdate blue method, Ca and Mg by atomic absorption, K by flame photometry). Dry weight loss constant K were obtained from the equation: $Yt = Yoe^{-Kt}$, where Yo and Yt represent residues remaining initially and at time t (Wieder and Lang, 1982).

## Experiment II

Fine roots (1- 2 mm ø) of *Mucuna* were collected in a 9-month old flowering *Mucuna* field, at the end of the rainy season (December 1993). The roots were oven-dried at 60 °C and stored in an air-tight container. In April 1994, at the beginning of the rainy season, the roots were cut into 5 cm long pieces, 2 g (dry weight) were mixed with sieved root-free moist soil, placed in baked clay pots, and buried in a field just planted with maize. At 5, 9, 13, 20, and 28, and 60 days after burial, 3 pots were retrieved at random and their content subjected to the treatments described above. with the exception that samples were not pooled for chemical analyses.

# Results and discussion

## Experiment I

*Flemingia* fine roots, which had an about 3 times higher N content than *Dactyladenia* fine roots decomposed 3 times faster (Table 5-1). The dynamics of N, Mg, and P release also differed between the 2 species: whereas *Flemingia* mineralized N at the same rate it lost dry matter, *Dactyladenia* immobilized N during the 15 weeks of the observation (Figure 5-1). *Dactyladenia* fine roots immobilized also Mg (for 4 weeks) and P (for 3 weeks) but to a lesser extent than N (Figure 5-1). Both species lost very rapidly the K content of their fine roots (Figure 5-1 and Table 5-1). The expected contribution of *Flemingia* fine roots to soil organic matter build up and nutrient supply to the crop is therefore different than that of *Dactyladenia*.
Fine root decay rate is not related to foliage decomposition rate: in the case of *Flemingia*, fine root decay was 1.5 times faster than foliage decomposition (0.069 vs. 0.039 $week^{-1}$) whereas the same (0.024 vs. 0.022) in the case of *Dactyladenia*.

## Experiment II

*Mucuna* fine roots decomposed and lost their N at an extremely fast rate (Table 5-1). Within 20 days after placement in the field, the roots had lost 80 % of their N and dry matter (Figure 5-1). This suggests that N contribution of *Mucuna* fine roots to the following maize crop is insignificant or small, depending on the rainfall pattern. Maize is planted at the beginning of the rainy season and its N requirement during the first weeks is low (germination and development of the young plant). Because the first rains are particularly violent in S.E. Nigeria, the N mineralized by *Mucuna* roots is likely to be leached completely from the soil during each rainfall event. The first rains are also often sporadic, therefore it is the alternation of rain and drier periods at the very beginning of the rainy season that is likely to determine the amount of *Mucuna* fine roots N that will remain in the soil long enough to be utilized by the young maize plants.

Table 5-1. Chemical composition and decomposition rate constants K of *Flemingia, Dactyladenia,* and *Mucuna* fine roots.

| | D. w.† | N | K | Ca | Mg | P |
|---|---|---|---|---|---|---|
| *Flemingia* | | | | | | |
| Composition (%) | | 2.3 | 1.05 | 0.58 | 0.19 | 0.20 |
| K (week$^{-1}$) | 0.069 | 0.087 | 0.310 | | | |
| *Dactyladenia* | | | | | | |
| Composition (%) | | 0.7 | 0.97 | 0.35 | 0.14 | 0.07 |
| K (week$^{-1}$) | 0.024 | | 0.296 | | | 0.254 |
| *Mucuna* | | | | | | |
| Composition (%) | | 2.0 | | | | |
| K (week$^{-1}$) | 0.910 | 0.395 | | | | |

† D.w. = dry weight

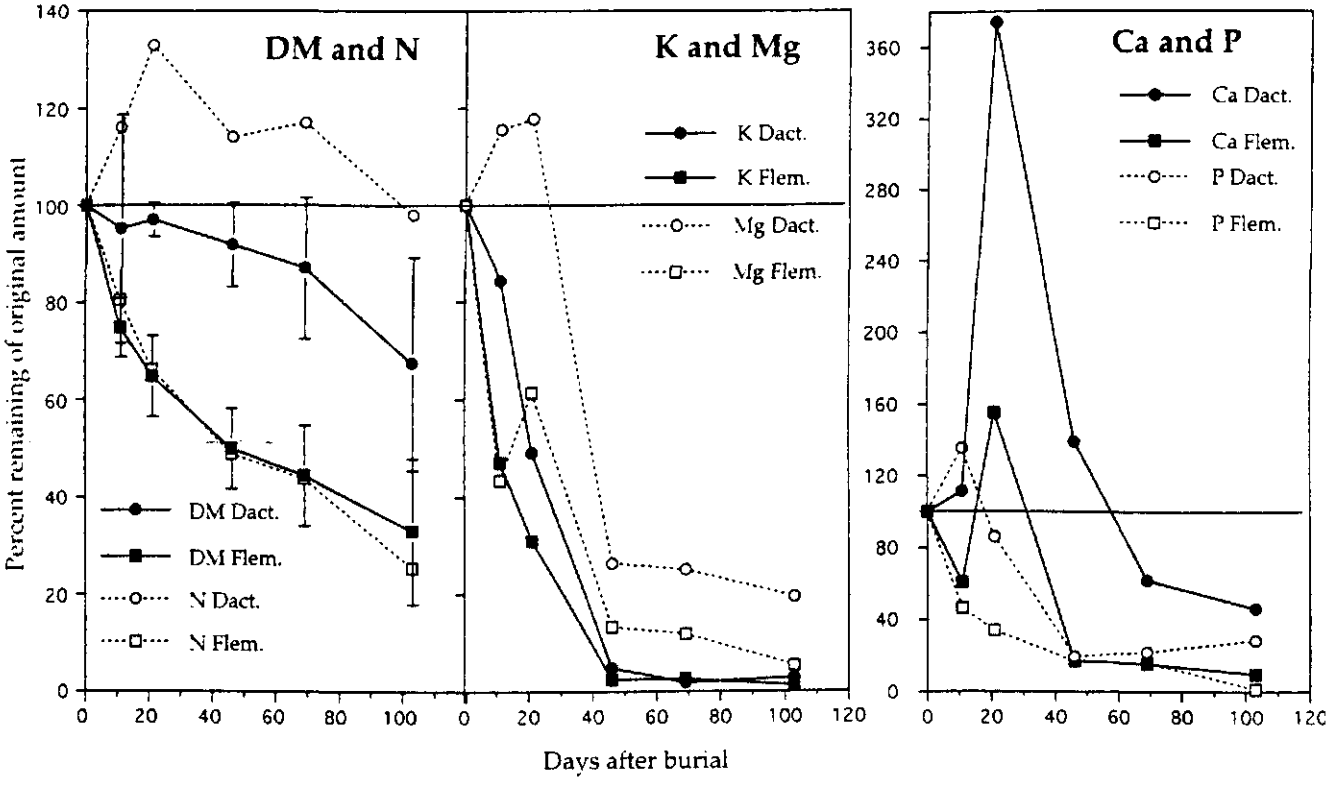


Figure 5-1. Changes in dry matter and nutrient content of *Dactyladenia* fine roots during decomposition; DM = dry matter.

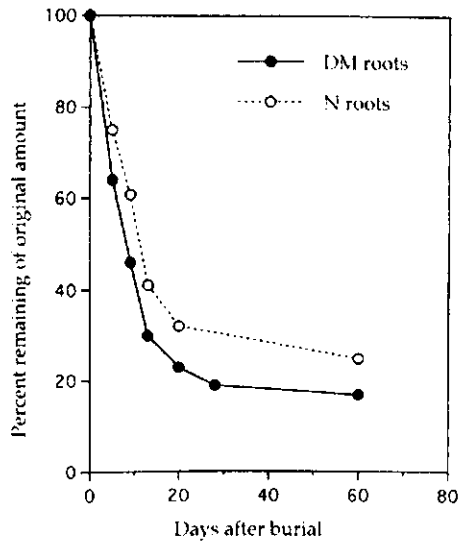


Figure 5-2. Changes in dry matter and N content of *Mucuna* fine roots during decomposition; DM = dry matter.

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# 6. ABUNDANCE AND ACTIVITY OF EARTHWORMS IN AN ACID ULTISOL UNDER ALLEY-CROPPING IN THE HUMID TROPICS

J. Henrot and L. Brussaard

## Abstract

The density of earthworms, their surface cast production and the composition of surface casts were studied on an acid Ultisol in S.E. Nigeria. Maize and cassava were grown as food crop, continuously or every other year in a maize/fallow rotation, in alley-cropping systems with *Flemingia congesta* or *Dactyladenia barteri* as hedgerow trees. Except in the unproductive *Flemingia* continuous cropping system, > 60 earthworms $m^{-2}$ were recorded in spite of the low soil pH($H_2O$) of 4.1, but biomass was low (approximately 2 g $m^{-2}$). Surface casts consisted of tubular, up to 3 cm high casts of Pontoscolex corethrurus and some other large earthworm species and small granular casts of Eudrilidae earthworms. The standing mass of casts after 5 months of activity (May - September) ranged between 260 and 570 kg $ha^{-1}$. Tubular cast production between September and December dropped from 97-18 g $m^{-2}$ $d^{-1}$. In spite of the lower biomass than reported in literature for less acid soils, and in light of the low nutrient status of the soil, the estimated amounts of C and nutrients returned to the surface in casts were considerable: 750 kg C, 51 kg N, 16 kg Ca, 2.5 kg Mg and 2 kg K $ha^{-1}$ $yr^{-1}$ on average. It is concluded that introduction and manipulation of earthworms, in particular during fallow periods, could have a beneficial impact on nutrient recycling in acid Ultisols.

**Keywords**: humid tropics, Ultisol, alley cropping, earthworms, casts, nutrients

## Introduction

Because most of the research on tropical earthworms has been carried out in the savannas, there is still little information available on earthworm abundance, diversity, and importance in the humid tropics. Common belief is that earthworms are not abundant in acid soils, which would exclude their potential effect on soil fertility from a large part of the humid tropics. Because acid soils of the humid tropics are particularly poor, the beneficial effects of earthworms under these conditions, however, could be large and earthworm manipulations could have a high return. This study was designed to assess earthworm abundance, activity and potential role in nutrient cycling in an acid Ultisol (pH 3.5) under cultivation in S.E. Nigeria.

Recent studies have shown that the proximity of trees, shade and quality of the leaf litter are parameters affecting earthworm abundance and activity (Hauser, 1993; Tian *et al.*, 1993). Our data were collected in alley-cropping systems (crops grown in-between lines of trees) with either *Dactyladenia barteri* (slow decomposing litter, high in lignin and probably not palatable to earthworms) or *Flemingia congesta* (fast decomposing litter, high in N, low in lignin and probably more palatable to earthworms) as hedgerow trees. Since some of the alley-cropping systems were cropped only one year out of two, we were also able to assess the impact of a period of fallow (development of a tall grass cover) on earthworms.

# Materials and methods

## Field site and treatments

The experiment took place at the High Rainfall Station of the International Institute of Tropical Agriculture, in Onne (4° 51'N; 7° 03'E), near Port Harcourt, in the humid forest zone of S. E. Nigeria. Rainfall at the site is monomodal with a rainy season lasting from March to December and a mean annual rainfall of 2.4 m. Relative humidity remains high throughout the year (78 to 89 %) and mean annual temperature is 25 °C. The soil on site is a loamy siliceous isohyperthermic Typic Ultisol derived from coastal sediment with the top 10 cm consisting of 73 % of sand, 4 % silt, and 23 % clay (Hulugalle *et al.*, 1990).

Data on earthworms and soil were collected in 1992 and 1993 from 2 alley-cropping systems established in 1987 with *Dactyladenia barteri* and *Flemingia congesta* as hedgerow species. Each alley-cropping unit consisted of 5 rows of trees of the same species separating 4 alleys 4.5 m wide and 20 m long in which maize and cassava were planted. Hedgerow trees were planted 1 m apart. From 1989 onwards, two alleys out of 4 were cropped continuously with maize and cassava as in the previous years (cont. crop. treatments) while the two others were cropped only one year out of two, i.e., in 1989 and 1991 (fallow/crop. treatments). The 4 treatments: alley-cropping with *Dactyladenia* as hedgerow tree cropped continuously (Dact. cont. crop or DC), alley-cropping with *Dactyladenia* as hedgerow tree cropped one year out of 2 (Dact. fallow/crop. or DF), alley-cropping with *Flemingia* as hedgerow tree cropped continuously (Flem. cont. crop or FC), and alley-cropping with *Flemingia* as hedgerow tree cropped one year out of 2 (Flem. fallow/crop. or FC) were replicated 4 times in a block design, but in some instances data were collected from 3 blocks only. In 1992, the fallow/crop. treatments were under fallow and a tall herbaceous vegetation developed in the alleys. In 1993, all alleys were cropped.

The hedgerow trees were pruned only if the alleys were cropped, once a year, at the beginning of the rainy season, just before planting maize and cassava. Above-ground biomass production and pruning quality differed considerably between the two tree species. In 1992, 7.2 Mg $ha^{-1}$ of leaves (78 %) and twigs were applied on the Dact. cont. crop. plots whereas only 1.6 Mg $ha^{-1}$ (53 % leaves) on the Flem. cont. crop. plots. Data on pruning quality are given in Table 6-1.

Table 6-1. Chemical composition of the tree prunings (% dry weight).

| | N | | K | | Ca | | Mg | | lignin |
|---|---|---|---|---|---|---|---|---|---|
| | leaf | wood | leaf | wood | leaf | wood | leaf | wood | leaf |
| Dactyladenia | 1.6 | 0.5 | 0.78 | 0.42 | 0.73 | 0.26 | 0.17 | 0.11 | 38 |
| Flemingia | 2.9 | 1.1 | 0.86 | 0.47 | 0.60 | 0.32 | 0.18 | 0.15 | 21 |

For comparison with the alley-cropping, similar data on earthworms and soil were collected in triplicate areas of a 7 year old bush fallow located nearby, which had the physiognomy of a young secondary forest (SF).

## Earthworm casts and soil collection

The onset of earthworm cast production at the soil surface coincided with the onset of the rainy season. On 19 August 1992, the standing mass of earthworm casts that had accumulated for the preceding 5 months was collected in each treatment of the 4 blocks in an area 1.5 m wide across the width of the alley (i.e. 6 $m^2$).

Casts were present in 2 forms: tubular (more common) and granular. The production rate of tubular casts was estimated in the 4 blocks from September 10 to November 26, at different distances from the hedgerow trees. Three metal frames of 0.20 m width x 2.25 m long were placed in each plot across the width of the alley, with one end against the base of an hedgerow tree. The frames had transversal subdivisions at 0.10, 0.30, 0.60, 1.00, and 2.25 m away from the hedgerow. Earthworm casts were collected weekly from each frame subdivision, dried at 105 °C, weighed and analyzed for nutrient content.

To compare the chemical composition of casts with that of the underlying topsoil, at the end of November, a soil sample (5 cm depth) was taken in the middle of each frame subdivision. For chemical analysis, casts and soil samples collected from the 3 frames on the same plot were pooled, respecting their distance from the tree, i.e., either at 0 to 10, 10 to 30, 30 to 60, 60 to 100, or 100 to 225 cm from the hedgerow. Casts and soil were ground and sieved through a 2 mm sieve before analysis for pH (1:1 soil:H2O), total C (Walkley-Black), total N (Kjeldhal), and Ca, Mg (Atomic Absorption Spectrophotometer), and K (flame photometer) after extraction with 1 N $NH_4OAc$ + 0.01 M EDTA (2:5 soil:extractant). Total C in the casts measured by Walkley-Black was in agreement with concentrations obtained with the CHN analyzer.

## Earthworm collection

In May 1992 (before planting, beginning of the rainy season), August 1992 (6 weeks after planting), November 1992 (end of the rainy season) and May 1993, August 1993, and November 1993, earthworms were collected, from all the treatments (in 3 blocks only), using a monolith method adapted from Anderson and Ingram (1993). Given the size of the alleys and the presence of crops, the monoliths were limited to 0.4 x 0.4 m x 0.3m deep to avoid too much destruction. A 3-sided steel frame was driven into the soil at 0.8 to 1.2 m from the hedgerow, the soil in front of the open face of the frame was removed, and the volume of soil contained in the frame was collected in 4 layers, from 0 to 5, 5 to 10, 10 to 20, and 20 to 30 cm depth. The soil samples were placed in plastic bags and hand-sorted for earthworms within one day after collection.

Earthworms were measured, weighed, and grouped according to their appearance. Subsamples of the most commonly occurring species were conserved in 4 % formaldehyde and sent to Prof. P. Lavelle (ORSTOM, France) for identification.

# Results

## Production of surface casts by earthworms

The standing mass of earthworm casts collected 5 months after the beginning of the rainy season was made out of 2 distinct cast types: small granular casts and large (up to 3 cm tall) tubular casts. Tubular casts were more abundant, they made up 65 to 84 % of the total in all treatments (Figure 6-1). The total mass of casts collected ranged between 0.26 and 0.57 Mg $ha^{-1}$ of casts and was larger in the alleys under fallow than under cropping and larger in the Flem. fallow than in the other treatments (Figure 6-1). The standing mass of casts is the net result of cast production and cast destruction by heavy rainfall and it is therefore an underestimation of the actual production. Furthermore, the impact of rainfall on the casts is reduced by the growing grasses in the fallow treatment, thus the data on standing mass after 5 months reflect the amount of cast which has resisted destruction by rainfall and may contribute to the improvement of soil structure. Cast production was assessed by the weekly removal of casts from each treatment in the subsequent 10 weeks and limited to tubular casts.

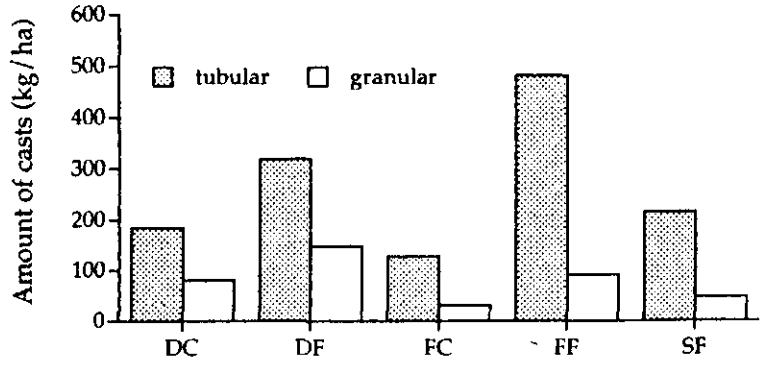


Figure. 6-1. Amount of casts (tubular and granular) collected 5 months after the onset of the rainy season. DC = *Dactyladenia* alley-cropping system under continuous cropping; DF = *Dactyladenia* alley-cropping system under fallow, FC = *Flemingia* alley-cropping system under continuous cropping; FF = *Flemingia* alley-cropping system under fallow, SF = secondary forest.

The amount of casts collected during the 10 weeks of weekly collection was 10 times greater (between 1.5 and 5.3 Mg $ha^{-1}$ of casts) than the amount of standing casts collected after the first 5 months of rainfall, suggesting that indeed a large amount of the casts are destroyed by rainfall. The pattern of response to treatments, however, remained similar: there were about 3 times more casts produced in the treatments under fallow than under cropping, there was, however, no difference between the two hedgerow species (Figure 6-2).

The amount of casts produced in the secondary forest was similar to that produced in the alley-cropping systems under cropping and much inferior to the amount produced in the herbaceous fallow (Figure 6-2)

The rate of cast production declined as the rain became less abundant (Figure 6-3), dropping from 97 to 18 $g\,m^{-2}\,day^{-1}$.

The rate of cast production was considerably higher under the hedgerow trees than towards the middle of the alley (Figure 6-4). The casts produced between 0 and 10 cm from the hedgerow trees accounted for 54, 43, 46, and 37 % of the total cast production for DF, FF, DC, and FC, respectively and there was hardly any cast production further than 50 cm from the hedgerow trees (Figure 6-4).

## Earthworm density and seasonal movement in the top 30 cm of the soil

The earthworms collected at 6 sampling dates between May 1992 and November 1993 were mostly small, 95 % less than 3 cm in the alley-cropping with *Dactyladenia* and in the bush fallow (Figure 6-5). In alley-cropping with *Flemingia*, the amount of larger individuals was higher: up to 30 % of the total of the earthworms collected were larger than 3 cm.

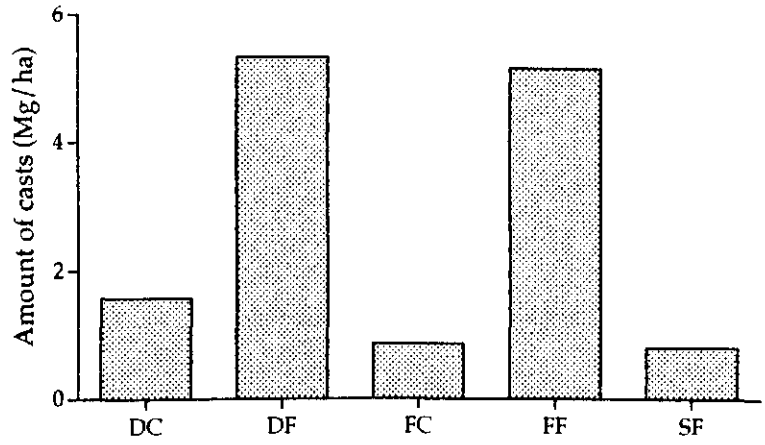


Figure 6-2. Amount of tubular casts collected between September and December 1992. Legend of X-axis as in Figure 6-1.

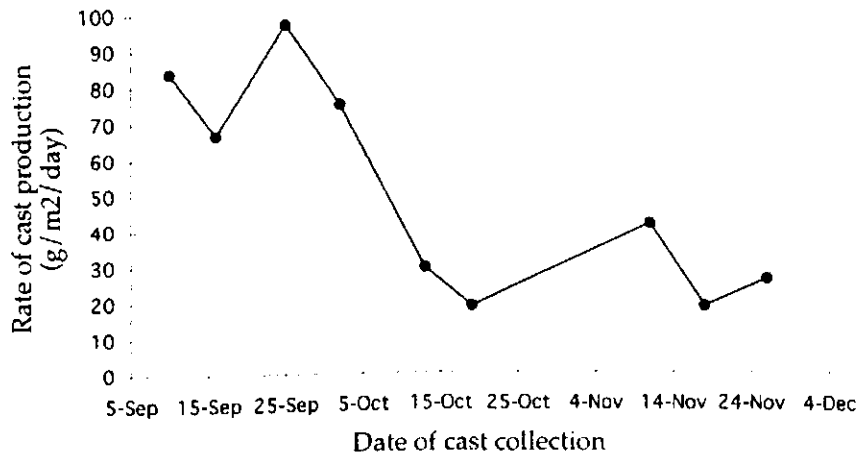


Figure 6-3. Change in cast production rate from the height of the rainy season (September) to the onset of the dry season (December). The rates are means over all treatments.

The small earthworms were identified by Prof. P. Lavelle as belonging to the family of Eudrilidae. These worms live close to roots and produce at the surface small granular turricules, in a more or less agglomerated structure, that are easily dispersed by the rain. Among the larger earthworms, *Pontoscolex corethurus*, *Hyperiodrilus africanus*, and *Buttneriodrilus* sp. were found.

When the soil was moist, at the beginning (May) and middle (July, August) of the rainy season, most of the earthworms (85 % and 76 % of the total worm count) were found in the top 10 cm of the soil (Figure 6-6). At the beginning of the dry season (November), most of them (73 % of the total worm count) had moved to a soil depth of 10 to 30 cm below the surface. In November 1992, a substantial amount of worms was found in the 20 to 30 cm depth, which suggests that some large earthworms may have moved deeper than 30 cm depth and that the density of earthworms recorded on that date underestimates the actual figure.

The density of earthworms collected from the soil in 1992, when half of the alley-cropping systems were under fallow, followed a pattern similar to the pattern of surface cast production in 1992: more earthworms were present in the systems under fallow than in the systems under cropping, and there were fewer worms in the secondary forest than in the alley-cropping

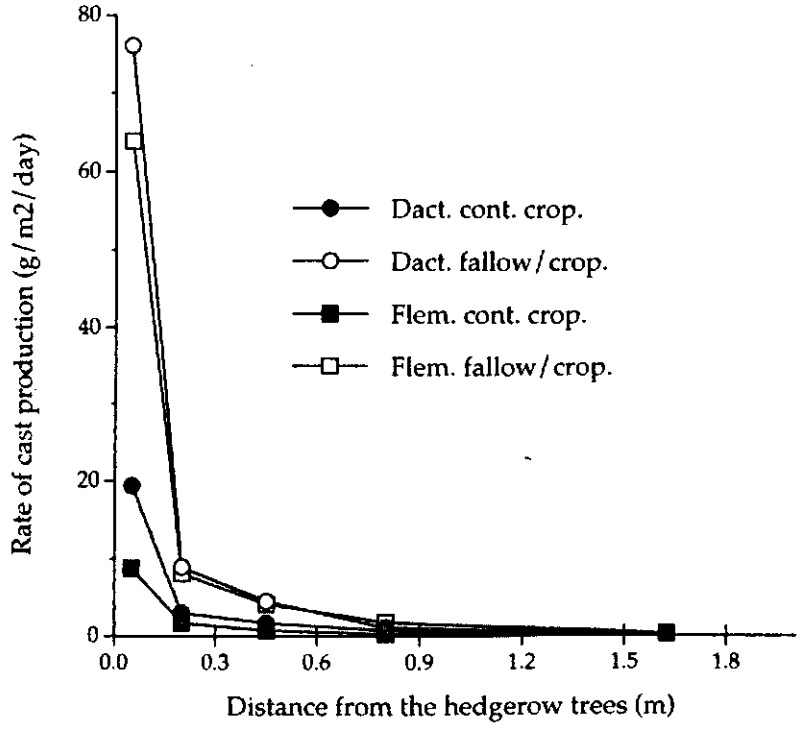


Figure 6-4. Rate of cast production from the hedgerow trees to the middle of the alley. The rates are calculated over the 10 weeks of cast collection.

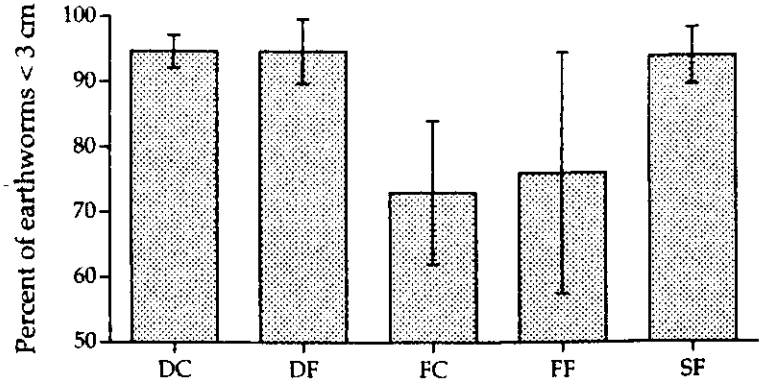


Figure 6-5. Percentage of earthworms < 3 cm in length. Legend of X-axis as in Figure 6-1.

systems (Figure 6-7). In 1993, when all the alley-cropping systems were cropped, there were still slightly more earthworms in the systems which had been under fallow the preceding year than in the systems continuously cropped. Overall earthworm density was greatest in the alley-cropping system with *Dactyladenia* under fallow/cropping rotation and lowest in the secondary forest.

Earthworm biomass was not measured because the presence of occasional large worms rendered the data highly variable and meaningless. The Eudrilidae, which made up most of the worm count, weighed about 3.5 g for 100 individuals. Using this number, the biomass of Eudrilidae can be approximated to about 2 to 7 g $m^{-2}$ in the alley-cropping systems.

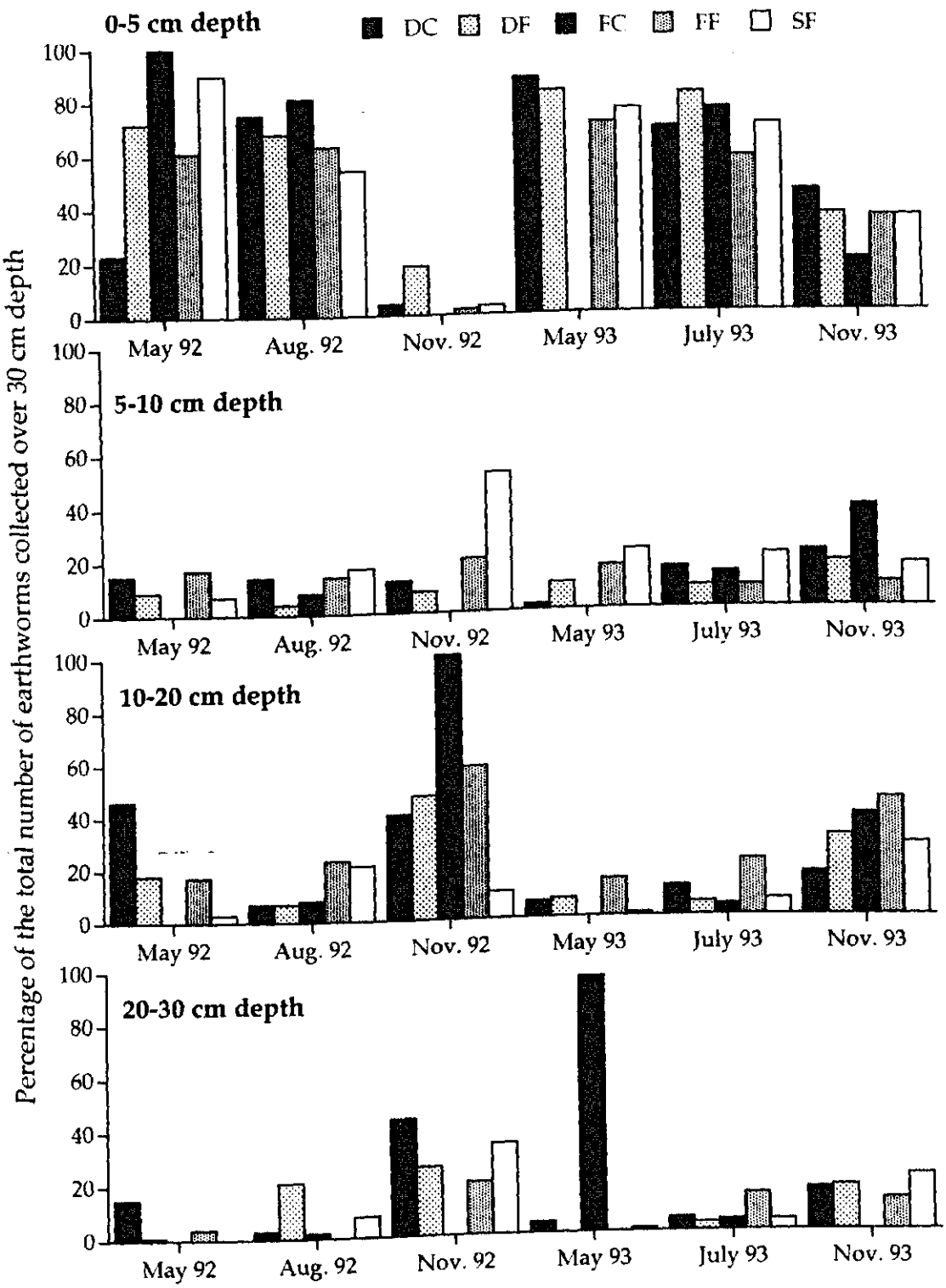


Figure 6-6. Vertical distribution of earthworms at the 6 sampling dates.

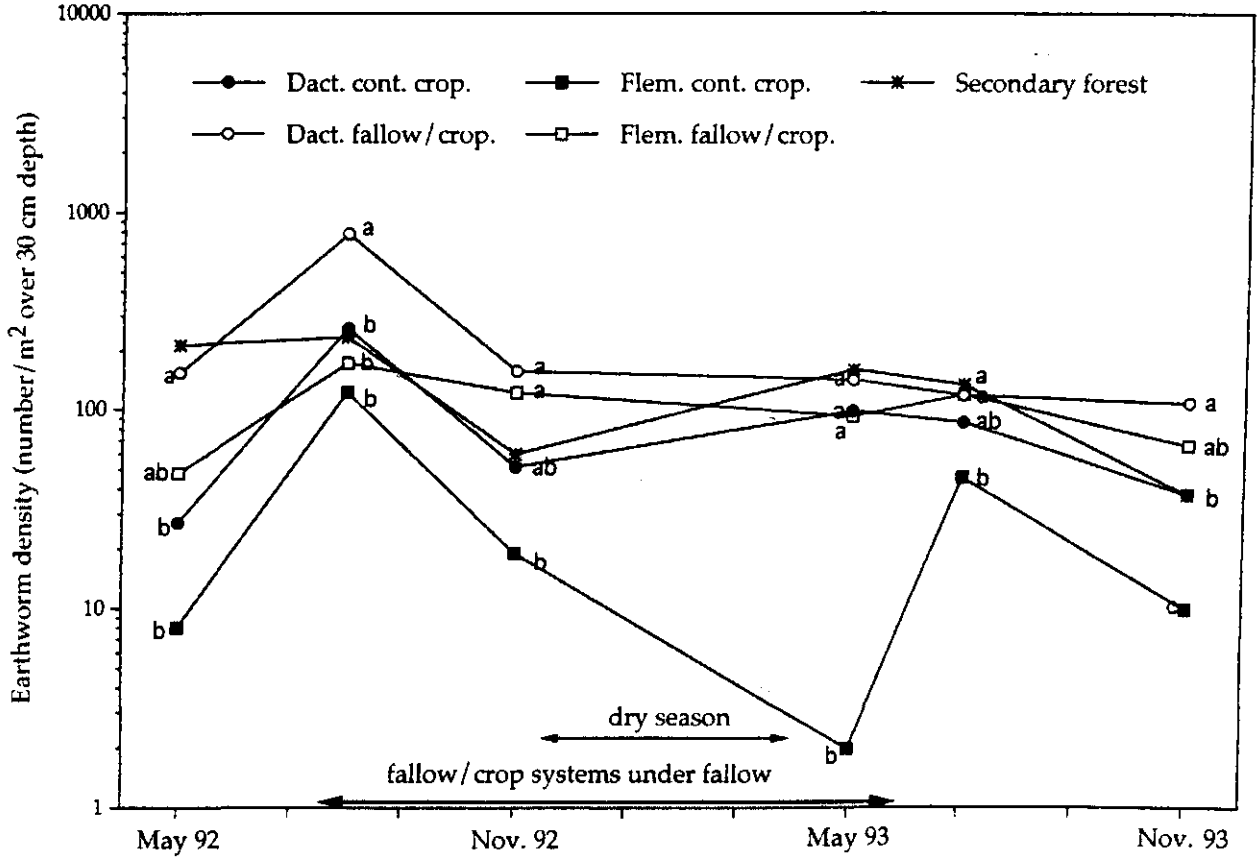


Figure 6-7. Earthworm density at the 6 sampling dates. Different letters indicate significant differences ($P < 0.05$) between means (Fisher LSD).

## Earthworm cast composition

The casts collected after the first 5 months of rainfall had a high organic C and total N content (Table 6-2). The granular casts had slightly higher C and N contents than the tubular casts and the casts collected from the secondary forest had higher C and N contents than the casts collected from the alley-cropping systems. There were small differences in cast quality between alley-cropping systems but not statistically significant ($P > 0.05$, Table 6-2).

The earthworm casts collected during the second part of the rainy season had similar C and N contents to those collected in the first 5 months (Table 6-3). Earthworm casts, compared to the underlying soil, were overall 4 times higher in organic C, 3 times higher in total N, 6 times higher in Ca and Mg, and 4 times higher in K (Tables 6-3 and 6-4, average values). The C/N ratio of casts was higher than that of the soil (on average 15 vs. 12).

Table 6-2. Chemical composition of tubular and granular casts collected 5 months after the onset of the rainy season (organic C and total N in % of dry weight).

| Treatment | pH | | Organic C | | Total N | |
|---|---|---|---|---|---|---|
| | Tubular | Granular | Tubular | Granular | Tubular | Granular |
| Dact. cont. crop. | 4.3 | 4.7 | 4.7 b | 4.5 ab | 0.28 a | 0.35 b |
| Dact. crop/fallow | 4.4 | 4.7 | 4.7 b | 5.8 c | 0.37 b | 0.45 a |
| Flem. cont. crop. | 4.4 | 4.7 | 3.3 a | 3.7 a | 0.26 a | 0.25 b |
| Flem. crop/fallow | 4.4 | 4.5 | 3.7 a | 4.6 b | 0.33 a | 0.40 b |
| On average | 4.4 | 4.7 | 4.1 | 4.7 | 0.31 | 0.36 |
| $P < 0.01$:**, $< 0.05$:* | NS | NS | ** | ** | * | NS |
| Secondary forest | 3.9 | 4.1 | 5.6 | 6.58 | 0.49 | 0.54 |

a, b, c: different letters indicate significant differences ($p < 0.05$) between means (Fisher LSD)

Table 6-3. Chemical composition of tubular earthworm casts collected weekly in the second part of the rainy season (organic C and total N in % of dry weight; Ca, K, Mg in Eq/100 g soil).

| Treatment | pH | Org. C | Tot. N | Ca | Mg | K |
|---|---|---|---|---|---|---|
| Dact. cont. crop. | 3.7 | 4.8 b | 0.32 ab | 3.1 b | 1.00 b | 0.31 ab |
| Dact. crop/fallow | 3.7 | 6.4 c | 0.38 b | 5.3 c | 1.40 c | 0.34 b |
| Flem. cont. crop. | 3.7 | 4.2 a | 0.22 a | 1.6 a | 0.80 ab | 0.22 a |
| Flem. crop/fallow | 3.9 | 4.8 b | 0.35 ab | 2.5 a | 0.72 a | 0.29 a |
| On average | 3.7 | 5.0 | 0.34 | 3.36 | 0.99 | 0.29 |
| $P < 0.01$:**, $< 0.05$:* | * | ** | NS | ** | ** | ** |
| Secondary forest | 3.7 | 6.4 | 0.35 | 3.6 | 0.58 | 0.28 |

a, b, c: different letters indicate significant differences ($p < 0.05$) between means (Fisher LSD)

The nutrient content of earthworm casts was affected by the cropping treatment: casts were higher in organic C, total N, Ca, K, and Mg in the alley-cropping system with *Dactyladenia* under fallow/cropping rotation and lowest in the continuously cropped system with *Flemingia* as hedgerow (Table 6-3). Organic C and total N contents of casts were similar in the Dact. fallow/crop. treatment and the secondary forest.

The soil C and N contents were little affected by the treatments, however, the treatments with *Dactyladenia* as hedgerow tree had a higher base cation (Ca and Mg) content (Table 6-4). Calcium and Mg contents in the casts correlated positively with Ca and Mg contents of the soil ($R^2$ = 0.9 in the case of Ca and 0.7 in the case of Mg).

Table 6-4. Chemical composition of the soil top 5 cm in the different treatments (organic C and total N in % of dry weight; Ca, K, Mg in mEq/100 g soil).

| Treatment | pH | Org. C | Tot. N | Ca | Mg | K |
|---|---|---|---|---|---|---|
| Dact. cont. crop. | 4.1 | 1.44 b | 0.10 a | 0.58 b | 0.19 b | 0.11 b |
| Dact. crop/fallow | 4.1 | 1.46 b | 0.11 ab | 0.85 c | 0.21 b | 0.05 a |
| Flem. cont. crop. | 4.1 | 1.49 b | 0.12 b | 0.25 a | 0.09 a | 0.06 a |
| Flem. crop/fallow | 4.1 | 1.34 a | 0.12 ab | 0.40 b | 0.09 a | 0.07 ab |
| On average | 4.1 | 1.43 | 0.12 | 0.52 | 0.15 | 0.07 |
| $P < 0.01$:**, $< 0.05$:* | NS | * | ** | ** | ** | ** |
| Secondary forest | 4.1 | 1.22 | 0.14 | 0.50 | 0.11 | 0.06 |

a, b, c: different letters indicate significant differences ($p < 0.05$) between means (Fisher LSD)

Neither cast nor soil quality were affected by the distance from the hedgerow, except in the case of the system with *Dactyladenia* trees under fallow where the content in C and Ca only followed the pattern shown in (Figure 6-8): high concentrations towards the base of the tree and the middle of the alley and a dip around 0.5 m from the hedgerow trees.

# Discussion

We found two types of earthworm populations in the acid Ultisol under investigation: large earthworms, among which the peregrine geophagous *Pontoscolex corethrurus* which probably colonized the area when the soil was placed under cultivation, and small earthworms belonging to the Eudrilidae family. The large earthworms were probably too active to be adequately sampled by the monolith technique (monolith size of 0.4 x 0.4 x 0.3 m), therefore earthworm numbers describe mostly the Eudrilidae population. The tubular casts deposited at the surface, on the other hand, describe the activity of the larger worms. The small granular casts, less abundant and easily destroyed are produced by the Eudrilidae.

In spite of the low soil pH (4.1), the abundance of earthworms on the site was considerable: 60 individuals $m^{-2}$ or more, except in the case of the Flem. cont. crop. treatment, which had a very low soil fertility and hardly any crop growth. These values compare well with average earthworm densities reported for the humid tropics by Lavelle *et al.* (1994): 19 ind. $m^{-2}$ for crops, 77 for tropical rainforests, and 310 for pastures. In terms of biomass however, the worms from the alley-cropping systems and the 7 year bush fallow would amount only to about 2 g $m^{-2}$, compared to the average values of 1.1 for crops, 13.9 for tropical rainforests, and 59.7 for pastures (Lavelle *et al.*, 1994).

In the alley-cropping systems, the positive effect of a one-year herbaceous fallow on earthworm biomass and activity was obvious. Pastures are known to be favorable to earthworms if they occur in forest areas with high rainfall and earthworm biomass and density are much higher under pastures than under crops or forests (Lavelle *et al.*, 1994). The mechanism for the stimulation of worms is probably the higher root biomass than in the systems under cropping and the shade provided by the grasses. Shading was identified as the most important factor enhancing casting activity in an alley-cropping experiment in an Alfisol of the African subsavanna (Hauser, 1993).

The response of casting activity to shading also explains the spatial variability of casting within the alleys. Hauser (1993) found 5 times more casting in the vicinity of the hedgerow trees than in the middle of the alley. In our case, the pattern was even more pronounced, especially in the case of alleys under fallow, where there were 50 times more casts produced in the vicinity of the trees than in the middle of the alley.

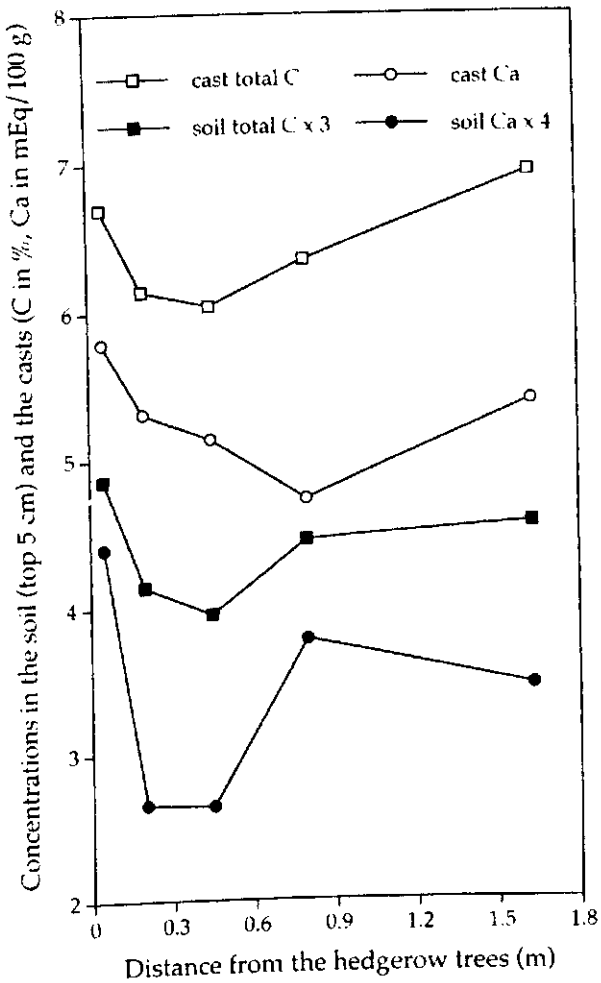


Figure 6-8. Concentrations in soil and cast C and Ca from the hedgerow trees to the middle of the alley in the *Dactyladenia* alley-cropping system under fallow.

Two factors contributed to a higher soil shading in the systems with *Dactyladenia*. First, although the soil pH, organic C, and total N differed little between treatments, crop production was considerably lower in the systems with *Flemingia* and the *Flemingia* trees themselves grew less vigorously. Second, the litter decomposition rate also decreases with increasing ratios of lignin: N and, in the systems under cropping (which had received hedgerow tree prunings at the beginning of the rainy season), the soil coverage with *Dactyladenia* prunings lasted longer. In consequence, in the rainy season, soil temperature (at 10 cm depth) was slightly higher and soil water content slightly lower in the alley-cropping systems with *Flemingia* compared to *Dactyladenia* (Henrot and Hauser, in prep.). In addition, the systems under fallow had always a slightly lower soil temperature and higher soil water content than their equivalents under cropping. During the dry season, the differences in soil temperature between alley-cropping systems were considerably larger and in the case of the Flem. cont. crop. treatment, soil temperature at 10 cm depth reached up to 38 °C at mid-day. Even though the worms had migrated to higher depths in the dry season, such temperatures might be sufficient to keep the earth-

worm populations low. Kang *et al.* (1994) also found higher casting activity of *Hyperiodrilus africanus* under *Dactyladenia barteri* than under leguminous trees and related it to microclimatic effects.

Epigeic worm populations (feeding on surface litter) should respond to litter quality. As palatability of the foliage decreases with increasing ratios of lignin: N (Tian *et al.*, 1993), the litter of *Flemingia* (ratio of 7) should be preferred to that of *Dactyladenia* (ratio of 23). We found, however, higher populations of worms and higher casting activity in the alley-cropping systems with *Dactyladenia* as hedgerow trees. Higher shading, lower soil temperature and higher moisture were therefore relatively more important for the distribution of earthworms than litter palatibility.

The data collected in the present study on a Ultisol (pH 4.1) in S. E. Nigeria (2.4 m rainfall) can be compared with data collected on an Alfisol (pH 6.7) in S. W. Nigeria (1.2 m rainfall) where *Hyperiodrilus africanus* and *Eudrilus eugeniae* are the dominant species. The amount of cast produced on the Alfisol were estimated to 0.75 Mg $ha^{-1}$ year in a cassava field (Hulugalle and Ezumah, 1991), 42.8 Mg $ha^{-1}$ $year^{-1}$ in an alley-cropping system with *Leucaena leucocephala* as hedgerow species (Hauser, 1993), and 26.4 Mg $ha^{-1}$ $year^{-1}$ in an alley-cropping system with *Dactyladenia barteri* as hedgerow (Kang *et al.*, 1994). On the Ultisol, the alley-cropping systems under cropping produced only about 1 Mg $ha^{-1}$ over the 10 weeks of weekly collection whereas the systems under fallow produced 5. Given that the rainy season is 8 months on the site, the annual production of casts could be estimated to about 3 Mg $ha^{-1}$ in the system under cropping and about 15 Mg $ha^{-1}$ in the systems under fallow, which is much less than what is reported in the alley-cropping systems on the Alfisol.

In terms of C and N content, the earthworm casts collected on the Ultisol (5 % C and 0.34 % N) are similar to those collected in the past on the Ultisol under a *Pueraria* cover crop: 3.7 % C and 0.43 % N (Mulongoy and Bedoret, 1989) and to the ones collected on the Alfisol: 2.5 % C and 0.24 % N (Hulugalle and Ezumah, 1991), 3.8 % C and 0.38 % N (Hauser, 1993), and 5.2 % C% (Kang et al., 1994), % N not determined ). Cast contents in Ca, Mg, and K, however were substantially lower on the Ultisol (33, 10, and 3 mEq $kg^{-1}$ of cast) compared to 178, 22, 6 (Hulugalle and Ezumah, 1991), 34, 17, 9 (Hauser, 1993), and 160, 32, 8 (Kang *et al.*, 1994) on the Alfisol, probably reflecting the lower content of these elements in the soil: about 40, 8, and 3 mEq $kg^{-1}$ of soil of Ca, Mg, and K in the Alfisol compared to 5, 1.5, and 0.7 in the Ultisol. The cation content of casts collected on the Ultisol under *Pueraria* cover crop by Mulongoy and Bedoret (1989) was considerably higher than our figures (80, 35 and 7 mEq $kg^{-1}$ cast for Ca, Mg, and K, respectively), but the soil cation content of their study plot was also remarkably high (22, 12, and 2.4 mEq $kg^{-1}$ soil for Ca, Mg, and K, respectively).

Given their quality, in the alley-cropping under fallow, the casts brought at the surface in one year could represent about 750 kg of organic C, 51 kg of N, 16 kg of Ca, 2.5 kg of Mg, and 2 kg of K per hectare (calculated on 15 Mg casts $ha^{-1}$ $year^{-1}$). In the systems under continuous cropping, the values would be more than 5 times lower because not only cast production but also the nutrient content of the cast were lower (Table 6-3).

# Conclusions

Contrarily to the common belief, earthworms abundance and casting activity can be reasonably high in an acid Ultisol if proper conditions are met, i.e., those prevailing in alley-cropping systems under fallow. Given the strong enrichment of nutrients in the casts compared to the soil and the low nutrient content of the soil, casting activity during the fallow period can play an important role in soil fertility restoration since it brings a non-negligible quantity of N and base cations back to the soil surface. Introduction and manipulation of earthworm populations during fallow periods could have a beneficial impact on nutrient recycling in acid Ultisols.

# Acknowledgements

Dr. S. Hauser designed the frames for earthworm cast collection, Prof. P. Lavelle identified the earthworms, C. Philemon, M. Normakoh, I. Stellamaris, C. Akalonu, E. Ile, C. Gu-o, E. Ollube, and O. Iro helped in the collection of casts and soil and in the hand-sorting of worms (6.8 tons of soil !).


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# 7. A PILOT ANALYSIS OF GUT CONTENTS IN TERMITES FROM THE MBALMAYO FOREST RESERVE, CAMEROON

F. Sleaford, D.E. Bignell and P. Eggleton
Submitted to Ecological Entomology

## Abstract

Gut content analysis was carried out on nine species of higher termites representing the four included subfamilies and notional soil-feeding and wood-feeding forms.
Pooled homogenates equivalent in weight to 20 hindguts of *Thoracotermes macrothorax* were diluted, stained and scored present/absent in 500 haemacyctometer fields for 10 content item categories: macerated organic material, lignified tissue, plant tissue fragments, fungal mycelium, arthropod parts, plant roots, safranin +ve, gentian violet +ve, humus and silica. For interspecific comparisons, the occurrence of each category was expressed as a proportion of the total haemacytometer cells examined.
A hierachical classification of the species, based on gut contents, was prepared using a two way indicator species analysis, and suggested the following rank order of species along a hypothetical humification gradient (soil to sound wood): *Thoracotermes macrothorax; Astalotermes quietus* (both soil-feeders); *Termes hospes ; Amalotermes phaecocephalus ; Pseudacanthotermes militaris ; Microtermes congoensis ; Nasutitermes lujae ; Microcerotermes parvus ; Schedorhinotermes putorius* (all notional wood-feeders). Arthropod parts, silica and humus were identified as indicator factors.
It is proposed that wood-feeding forms can be subdivided into a group consuming some silica and humus (5 species: humified wood-feeders) and a second group of sound wood-feeders (2 species).
Pianka's equations for diet breadth and diet overlap were also applied to the data. These identified *Microtermes congoensis, Schedorhinotermes putorius,* and *Pseudacanthotermes militaris* as the most specialized feeders, i.e. that they can extract their nutrients from the least heterogeneous substrates.

**Keywords**: termites, gut content analysis, soil-feeding, wood-feeding, decomposition, niche separation, trophic guild, multivariate analysis

## Introduction

The roles of termites as direct mediators of organic decomposition and as important components of tropical soil faunas influencing humification, soil conditioning, nitrogen fixation, aggregate binding and the formation of clay-mineral complexes are widely recognized (Lee and Wood,1971; Wood and Sands, 1978; Wood, 1988; Collins, 1983; DeBruyn and Connacher, 1992; Martius, 1994; Brussaard,1995). While most studies have concentrated on savannas, fewer data are available for tropical forests where, paradoxically, both species richness and biomass appear to be higher (Wood and Johnson, 1986; Martius, 1994; Eggleton *et al.*, 1995a, b).
In the tropical forests of Africa the high biodiversity of termites is particularly reflected in the abundance of soil-feeding forms. With thorough regimes of sampling it can be demonstrated that these forms (chiefly associated with the subfamilies Apicotermitinae and Termitinae)

dominate faunas where forest disturbance is light (Eggleton *et al.*, 1995a, b). Consequently, interest in defining the community roles of termites in forest ecosystems and in understanding the relationship between biodiversity and ecosystem processes necessarily focusses on this functional group (Wood *et al.*, 1982; Kreselman and Bouwman, 1994; Eggleton and Bignell, 1995; Lawton *et al.*, 1995). It is argued elsewhere that soil-feeding is a major and repeated trend in termite evolution, possibly reflecting very long-term competitive interactions amongst macrofaunal decomposers (Noirot, 1992; Bignell and Eggleton,1995).

Accurate information on the natural history and feeding habits of termites is scarce, especially for soil-feeders, and it has not yet proved possible to assign species unambiguously to functional groups that are ecologically robust (Eggleton and Bignell, 1995). Recent literature recognizes four broad trophic categories to which most termites can be allocated empirically: soil-feeders; soil/wood interface feeders; wood feeders and litter foragers (Martius, 1994; De Souza and Brown, 1994; Eggleton *et al.*, 1995; also see below). Criteria employed to make such allocations include sites of discovery, colour of abdomen, mound characteristics (where materials are of faecal origin) and known biology (dietary requirements).

Gut content analysis in predators usually rests on the identification of items at family, genus or even species level and can thus have high resolution. Studies of the diets of detritivores necessarily lack this precision, since food material is often already extensively decomposed before ingestion and cannot be allocated to a particular source or origin with any certainty. Allocation of invertebrate decomposers to feeding guilds has, predominantly, rested on detailed studes of mouthparts and associated pharyngeal structures (e.g. Christiansen, 1964; Twinn, 1974; Swift *et al.*, 1979), or on experimental challenges with candidate food items (Dowding, 1967; Luxton, 1972). Gut content analysis by microscopical observation has concentrated on invertebrates where a single item, or up to three or four items, predominate in the food selected, for example mixtures of fungal spores, fungal hyphae, non-lignified plant tissue and humus (Anderson and Healey, 1972; Luxton, 1972; Anderson, 1975; Mitchell and Parkinson, 1976; Findlay, 1985). Gut content itemizations for dipteran generalist feeders have been reported by Healey and Russell-Smith (1971), for mites by Harding and Stuttard (1974) and for collembolans by Takeda and Ichimura (1983).

In this paper we report a staining, itemizing and counting protocol for termite gut contents. Using a two-way indicator species analysis (TWINSPAN) of these data we have produced a hierachical classification which we compare with the existing functional (feeding) group classification. New provisional functional group allocations are proposed.

# Methods

## Study Site

Termites were sampled live from locations within the Mbalmayo Forest Reserve of Southern Cameroon, an area of semi-deciduous moist tropical forest on a gently undulating plateau about 650 m above sea-level. A full site description and comprehensive species lists are given in Eggleton *et al.* (1995a, b). Laboratory facilities provided within the Reserve by the Humid Forest Station of International Institute of Tropical Agriculture (IITA) permitted analyses to be carried out on fresh material, within one hour of collection in the field. Nine species were selected as representative of existing notional trophic groups, but also incorporating wide taxonomic variety (Table 7-1).

Table 7-1. Functional group classification of 9 termite species from the Mbalmayo Forest Reserve, based on site of discovery, abdominal colour and known (feeding) biology.

| Functional group | Species | Taxonomic group |
|---|---|---|
| Soil feeders | *Astalotermes quietus* (Silvestri) | Apicotermitinae |
| | *Thoracotermes macrothorax* (Sjöstedt) | Termitinae |
| Soil/wood interface feeders | *Amalotermes phaecocephalus* Sands | Apicotermitinae |
| | *Termes hospes* (Sjöstedt) | Termitinae |
| Litter feeders | *Pseudacanthotermes militaris* (Hagen)[1] | Macrotermitinae[2] |
| Wood feeders | *Microtermes congoensis* (Sjöstedt) | Macrotermitinae[2] |
| | *Nasutitermes lujae* (Wasmann) | Nasutitermitinae |
| | *Microcerotermes parvus* (Haviland) | Termitinae |
| | *Pseudacanthotermes militaris* (Hagen)[1] | Macrotermitinae[2] |
| | *Schedorhinotermes putorius* (Sjöstedt) | Rhinotermitidae[3] |

[1] *Pseudacanthotermes militaris* is both a litter and a wood feeder.

[2] The Macrotermitinae are all functionally distinct as fungus-growers.

[3] Lower termite.

## Gut content preparations

The principle was to dissect, homogenize, dilute and stain a pooled sample of guts, making a fluid preparation in which items of the contents could be categorized and enumerated using a haemacytometer. Preliminary studies were carried out on *Thoracotermes macrothorax* to determine the optimum dilution, including the addition of stain, which would permit the recognition of individual items, while at the same time producing acceptable reproducibility between replicates. The protocol established for this species was: 20 worker caste guts were dissected and the main hindgut chambers (P1, P3) added with exactly 0.5 ml of purified mineral water (the best quality water available) to a clean dry microcap tube and gently macerated with a sharp syringe needle for 30 seconds. Simultaneously, an additional number of guts (about 6) were dissected and mean gut volume of the same hindgut chambers estimated by the method of Bignell (1977). 20 guts (= hindgut chambers) were estimated to have a mean total volume of 63.4 µl; and to weigh 0.094 g. 0.346 µl of mineral water were then added to the homogenate, making a total volume of exactly 0.909 ml . The final volume therefore comprised the combined volumes of 20 guts plus a volume of water equivalent to 9 x the combined weights of the guts.

An aliquot of the diluted homogenate (at least 0.1 ml) was then added to an exactly equal volume of dilute aqueous gentian violet (ca. 0.005%) and the mixture placed in a haemacytometer (0.1 mm platform depth). An additional aliquot was mixed with dilute aqueous safranin (ca. 0.005%) and similarly examined. A third aliquot of exactly 0.1 ml was mixed with 0.1 ml of 1% alcoholic phloroglucinol and allowed to evaporate to dryness by exposure to the open air. 0.2 ml of concentrated (35%) HCl was then added and after thorough mixing with a dissection needle, the solution was also placed in a haemacytometer.

The haemacytometer platform was viewed at low power magnification with a transmission light microscope fitted with a 10x10 eyepiece graticule grid. 5 fields of 100 grid squares each were then scored (present/absent) for each of the following items:

***Macerated organic material*** : fibres not having an obvious cellular structure and not staining with phloroglucinol/HCl.

***Lignified tissue*** : fibres or other material giving a red colour with phloroglucinol/HCl. Colour may vary from bright scarlet to maroon.
***Plant tissue fragments*** : material with a recognizable cellular structure and not staining with phloroglucinol/HCl (i.e. without secondary thickening). Generally stains lightly with safranin.

***Fungal mycelium*** : living or recently dead hyphal material in the diameter range 5-30 µm and having a rigid cell wall. Usually a light brown colour (dermateacious soil fungi). Does not stain.

***Arthropod parts*** : setae and fragments of sclerotized (darkened) cuticle (such items are common soil components and do not imply carnivory).

***Plant roots*** : fine hyaline tubular material with cellular structure, not staining with phloroglucinol/HCl. Generally stains lightly with safranin.

***Safranin +ve items*** : large or small items staining red with safranin including identifiable plant tissue fragments and plant roots. Generally stains microbial tissue and unthickened plant cells.

***Gentian violet +ve items*** : large or small items staining blue with gentian violet. Generally restricted to microbial tissue (excluding fungal mycelium), when the stain is highly diluted.

***Humus*** : amorphous material having a natural brown colour and generally associated with mineral fractions.

***Silica*** : translucent, crystalline mineral grains.

The item categories are not mutually exclusive in all cases. To equalize sampling for each category, all items except lignified tissue and gentian violet +ve were scored in the safranin-stained aliquot. Lignified tissue and gentian violet +ve were then scored in the additional aliquots stained with phloroglucinol/HCl and gentian violet, respectively. The differentiation achieved by safranin and gentian violet depends on these stains being very dilute. The advantage of making homogenates from the large hindgut chambers only is that relatively little gut wall material is incorporated into the final preparation.

A similar procedure was employed for the remaining species (excepting *Amalotermes phaecocephalus* and *Microtermes congoensis)* but the number of guts utilized was in each case that required to give a total pooled volume of hindgut chambers as close to 63.4 µl as possible. These guts were then homogenized and diluted with exactly 0.846 ml of water. The slight variations in final volume produced are listed in Table 7-2. *Amalotermes phaecocephalus* and *Microtermes congoensis* were not available in sufficient numbers to make a dilution to ca 0.9 ml of equivalent conentration. The available number of guts were therefore directly homogenized in 50 µl of stain and the resulting solution placed on an ordinary glass microscope slide, covered with a glass slip and examined in the microscope. Correction factors for dilution differences (relative to *Thoracotermes macrothorax* = 1.0000) are also listed in Table 7-2.

Table 7-2. Number of guts dissected for the preparation of pooled gut homogenates. Except for *Amalotermes phaecocephalus* and *Microtermes congoensis*, the number of guts used is that closest in fresh weight to the weight of 20 guts of *Thoracotermes macrothorax*. Homogenates from *A. phaecocephalus* and *M. congoensis* were made with the maximum number of guts available. The correction factor for these species (applied to occurrence proportions for each category of contents in Table 7-2) is derived from the relative differences (compared to *T. macrothorax*) in the dilution employed to make the homogenates; for other species from the relative differences in the total volume of pooled guts (also compared to *T. macrothorax*).

| Termite | Number of guts dissected | Volume of gut (µl) | Total volume of pooled guts (µl) | Final volume of homogenate (µl) | Correction factor for dilution and depth of field |
|---|---|---|---|---|---|
| *Thoracotermes macrothorax* | 20 | 3.17 | 63.40 | 909.40 | 1.0000 |
| *Astalotermes quietus* | 109 | 0.58 | 63.22 | 909.22 | 0.9998 |
| *Amalotermes phaecocephalus* | 6 | 0.20 | 1.20 | 51.20 | 0.3360 |
| *Termes hospes* | 129 | 0.50 | 63.34 | 909.34 | 1.0000 |
| *Schedorhinotermes putorius* | 83 | 0.76 | 63.08 | 909.08 | 0.9996 |
| *Microcerotermes parvus* | 62 | 1.03 | 63.86 | 909.86 | 1.0009 |
| *Nasutitermes lujae* | 66 | 0.96 | 63.36 | 909.36 | 0.9995 |
| *Pseudacanthotermes militaris* | 28 | 2.36 | 66.08 | 912.08 | 1.0030 |
| *Microtermes congoensis* | 30 | 0.02 | 0.60 | 50.60 | 0.1700 |

## Calculations and analyses

For each category of item the raw data consist of 5 scores for occurrence, each score having a maximum of 100 and a minimum of zero. These were averaged and divided by 100 to produce the mean proportion of grid cells examined in which the item occurred. (Table 7-2). Occurrence scores were then summed to give an arbitrary total which reflects the total number of occurrences of items (in all categories). Since absence scores zero, the sum of scores is different for each species, but the proportions of individual item occurrences in this total (i.e. the % of the total number of occurrences recorded as present) provides a basis for comparing species and reflects the relative heterogeneity of the gut contents. For analysis a test of association was carried out on untransformed data by deriving the G-statistic, followed by non-parametric analysis of variance by the Kruskal-Wallis procedure (Sokal and Rohlf, 1973), with conventional feeding group assignments (Table 7-1) as the grouping variable.

A two-way indicator species analysis (Gauch, 1982) was used to produce a hierachical classification of the species based on gut contents. Contents and species data were prepared in PC-ORD format and run using the PC-ORD TWINSPAN programme (McCune, 1987). For this purpose, classes of proportions of gut contents were defined as pseudospecies by establishing cut levels (terminology of McCune (1987)) at 0, 0.02, 0.05, 0.1 and 0.2. (TWINSPAN technically only deals with presence/absence data). The results are presented as a hierachical classification (dendrogram). Diet breadth and diet overlap indices were derived from the equations of Pianka (1973).

# Results

## Graphical presentation and statistical analyses

Table 7-3 shows the proportion of occurrences of each gut content item in 500 haemacytometer cells, together with the number of different items identified in each species. Figure 7-1 shows these proportions in a graphical form which also illustrates the heterogeneity of materials consumed in each case. The data presented in Table 7-3 and Figure 7-1 are the same, except that proportions of zero are excluded from Figure 7-1. The greatest number of content items occurred in the notional soil-feeders and soil/wood interface feeders (9 or 10), plus *Pseudacanthotermes militaris* (10 items). The least number (4) was observed in the single lower termite examined, *Schedorhinotermes putorius*. The high heterogeneity of gut contents in *Pseudacanthotermes militaris* is in accordance with the observation that it is both a litter and a wood feeder, and with the known behaviour of older workers in other species of Macrotermitinae, where mineral material is consumed (Badertscher *et al.*, 1983). Arcsine transformation of the data, frequently recommended for percentages and proportions (e.g. Sokal and Rohlf, 1973), failed to normalize them or to provide a more satisfactory graphical illustration of the content item occurrences (not shown).

The differences in the composition of the gut contents between species which are evident from an inspection of Table 7-3 were confirmed by a test of association, which showed that the frequency of gut content item occurrences was dependent on the species of termite (G-value = 984; $Chi^2_{(72)} = 106.65$, $P < 0.005$). However, a further analysis by Kruskal-Wallis one-way ANOVA, using the functional group assignments of Table 7-1 as the grouping variable, was not significant for any gut component ($P > 0.05$). This is probably due to the small sample size of 5 fields per homogenate.

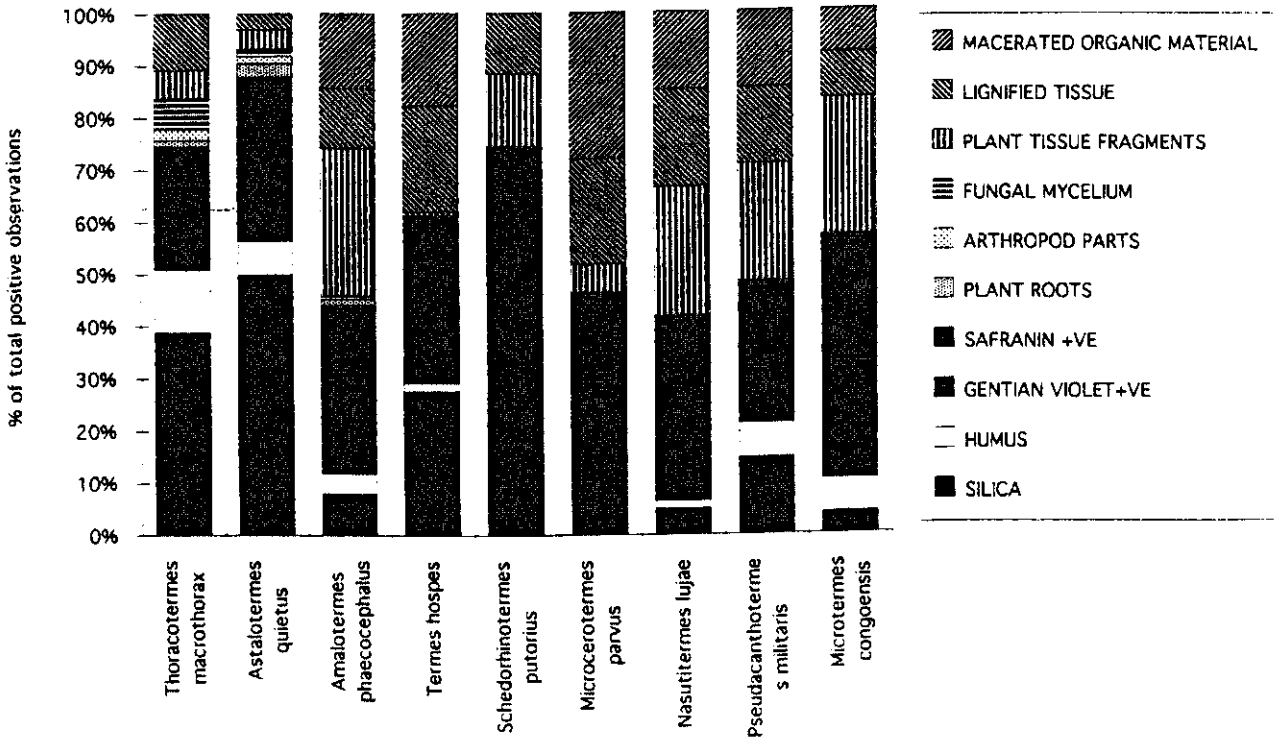


Figure 7-1. Gut contents of nine termite species, shown as the proportionate occurrence of ten content item categories, excluding proportions of zero.

Table 7-3. The occurrence of each category of gut contents as a proportion of the total haemacytometer cells examined (500). See Material and Methods for the definition of gut content items.

| Termite | Silica | Humus | Gentian violet+ve | Safranin +ve | Plant roots | Arthropod parts | Fungal mycelium | Pl. tissue fragm. | Lignified tissue | Macerated org. mat. | Total content items |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Thoracotermes macrothorax* | 1.000 | 0.314 | 0.124 | 0.482 | 0.034 | 0.052 | 0.150 | 0.142 | 0.280 | 0.000 | 9 |
| *Astalotermes quietus* | 0.932 | 0.122 | 0.174 | 0.410 | 0.048 | 0.026 | 0.026 | 0.070 | 0.058 | 0.000 | 9 |
| *Amalotermes phaecocephalus* | 0.280 | 0.140 | 0.130 | 0.992 | 0.040 | 0.001 | 0.022 | 0.992 | 0.398 | 0.504 | 10 |
| *Termes hospes* | 0.904 | 0.056 | 0.140 | 0.906 | 0.001 | 0.001 | 0.000 | 0.022 | 0.664 | 0.584 | 9 |
| *Schedorhinotermes putorius* | 0.000 | 0.000 | 0.488 | 0.992 | 0.000 | 0.000 | 0.000 | 0.276 | 0.232 | 0.000 | 4 |
| *Microcerotermes parvus* | 0.001 | 0.001 | 0.100 | 1.000 | 0.000 | 0.000 | 0.000 | 0.132 | 0.480 | 0.670 | 7 |
| *Nasutitermes lujae* | 0.162 | 0.052 | 0.172 | 0.984 | 0.000 | 0.000 | 0.001 | 0.822 | 0.614 | 0.492 | 8 |
| *Pseudacanthotermes militaris* | 0.644 | 0.293 | 0.175 | 1.000 | 0.020 | 0.001 | 0.001 | 1.000 | 0.648 | 0.654 | 10 |
| *Microtermes congoensis* | 0.152 | 0.244 | 0.762 | 1.000 | 0.001 | 0.000 | 0.000 | 1.000 | 0.330 | 0.316 | 8 |

## TWINSPAN analysis

Figure 7-2 shows the taxa as ordered by the TWINSPAN analysis. The rank order (right to left) is consistent with a gradient of increasing humification in the material with which each termite is principally associated, ranging from sound wood to humus within the soil. The classification confirms the close relationship between the two notional soil-feeding species (*Thoracotermes macrothorax* and *Astalotermes quietus* ) and the two notional soil/wood interface species (*Termes hospes* and *Amalotermes phaecocephalus* ), but indicates a closer relationship between the latter group and *Pseudacanthotermes militaris* than might be assumed from its known feeding biology. The habit of covering feeding sites with soil sheeting is a well established feature of Macrotermitinae and may account for the presence of mineral particles and humus in the gut contents at levels of occurrence comparable to those of *Termes hospes* and *Amalotermes phaecocephalus* (Figure 7-1). In other respects the gut contents of *Pseudacanthotermes militaris* more closely resemble those of exclusively wood-feeding forms. The positioning of *Termes hospes* next to the soil-feeding species in rank order is also noteworthy. This species is sometimes considered a wood-feeder (e.g. Johnson *et al.*, 1982) as it is most commonly encountered in larger items of very well rotted wood and relatively rarely in the soil column itself.

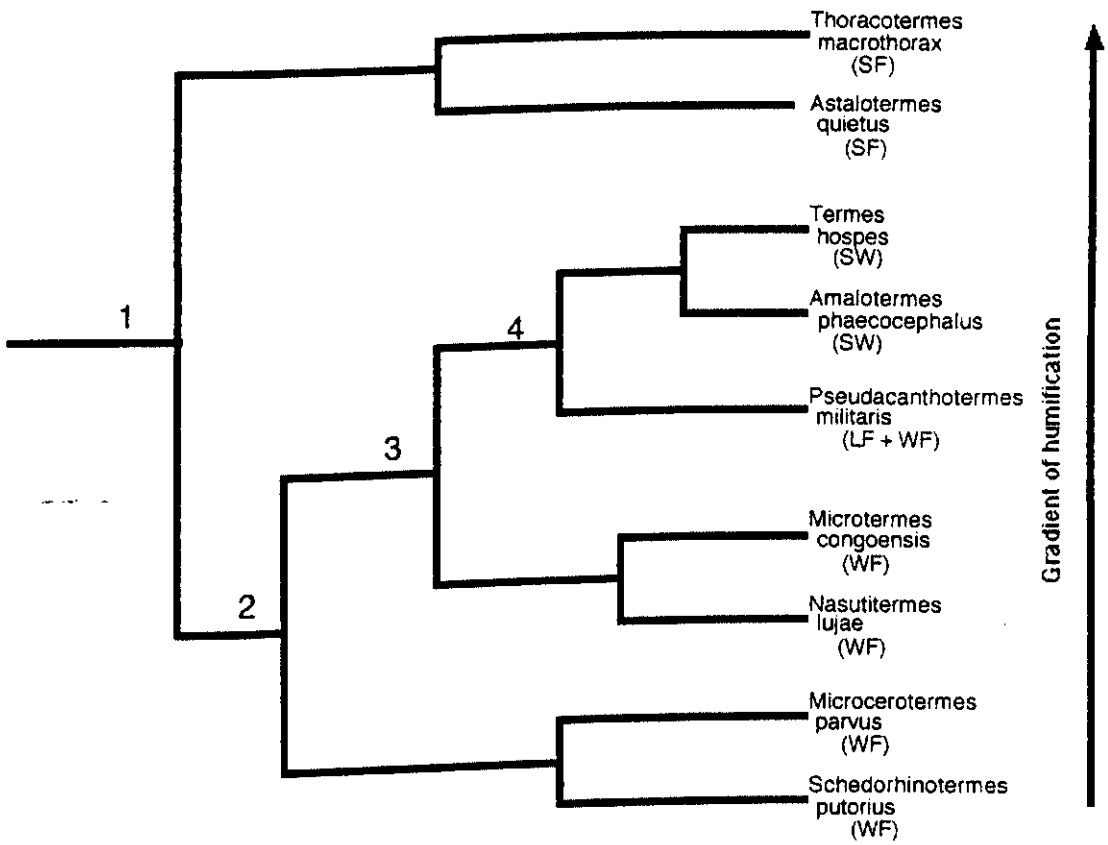


Figure 7-2. Taxa ordered by the TWINSPAN analysis, based on the proportionate occurrence of content items. The principal nodes numbered (in hierachical order) 1-4, respectively, and notional functional group assignments included. Key. SF, soil feeder; SW, soil/wood interface feeder; LF, litter feeder; WF, wood feeder.

## Diet breadth and diet overlap

The values obtained for diet breadth in each species using Simpson's index of diversity (quantity B of Pianka (1973)) are given in Table 7-4, ranked from greatest to least. The values derive from the same 10 gut content categories recognized in Table 7-3, again by numbers of items rather than their volumetric importance. Although the actual number of content items observed in the termite guts (Table 7-3) varied from 4 (*Schedorhinotermes putorius* ) to 10 (*Amalotermes phaecocephalus* and *Pseudacanthotermes militaris* ), the rank order of diet breadth indices is headed by *Astalotermes quietus* and *Thoracotermes macrothorax* (both 9 gut content items). The lowest positions (smallest indices) are occupied by *Schedorhinotermes putorius* (4 items) and *Microtermes congoensis* (8 items). *Microcerotermes parvus*, which has 7 content items, ranks third. There is a three-fold range of index values from 2.79 (*Microtermes congoensis* ) to 8.26 (*Astalotermes quietus* ). Any (theoretical) species with a single gut content item would have a diet breadth index of 1.00. The index therefore provides a rough indication of dietary diversity, but there is an undervaluation of low frequency occurrences which limits resolution, i.e. where additional items are found, but at very low frequency, the index is little changed.

Table 7-4. Calculation of Pianka's diet breadth index and comparison of rank orders of species produced by diet breadth index and TWINSPAN classification.

| Rank order of species by diet breadth | | Diet breadth index* | Notional rank order by TWINSPAN classification | |
|---|---|---|---|---|
| 1 | *Astalotermes quietus* | 8.26 | 1 | *Thoracotermes macrothorax* |
| 2 | *Thoracotermes macrothorax* | 6.13 | 2 | *Astalotermes quietus* |
| 3 | *Microcerotermes parvus* | 4.09 | 3 | *Termes hospes* |
| 4 | *Amalotermes phaecocephalus* | 4.00 | 4 | *Amalotermes phaecocephalus* |
| 5 | *Termes hospes* | 3.69 | 5 | *Pseudacanthotermes militaris* |
| 6 | *Nasutitermes luji* | 3.45 | 6 | *Microtermes congoensis* |
| 7¶ | *Pseudacanthotermes militaris* | 2.96 | 7 | *Nasutitermes luji* |
| 7¶ | *Schedorhinotermes putorius* | 2.96 | 8 | *Microcerotermes parvus* |
| 9 | *Microtermes congoensis* | 2.79 | 9 | *Schedorhinotermes putorius* |

* Standardized for differing numbers of $p_i$ categories by dividing $\Sigma p_i^2$ by n, the number of positive content categories (Pianka, 1973).

¶ Rank order 7th equal.

Table 7-4 also shows, for comparison, the notional rank order of species produced by TWINSPAN classification. Of the 9 termite species, only two, *Microcerotermes parvus* and *Microtermes congoensis*, differ by more than two places between the two orders, but only one, *Amalotermes phaecocephalus*, has the same place (4th) in each rank.

The approximate correspondence between the two rank orders suggests that termites feeding on more highly decomposed organic material will also show less dietary specialization.

Pianka's (1973) proportional utilization function (O) permits a measure of dietary overlap between any pair of species, giving a value between zero (indicating complete separation) and unity (identical diets). Although these coefficients within an assemblage are normally presented as a matrix (May, 1973), it is more straightforward with a small selection of species to derive a tree showing the clustering of relatedness (Figure 7-3), which may be compared with the TWINSPAN classification in Figure 7-2, which is also based on their proportional occurrences. Of particular interest is *Amalotermes phaecocephalus* , which is now removed from association

with soil-feeding and related species (*Thoracotermes macrothorax, Astalotermes quietus and Termes hospes*) and nested with the wood-feeders.

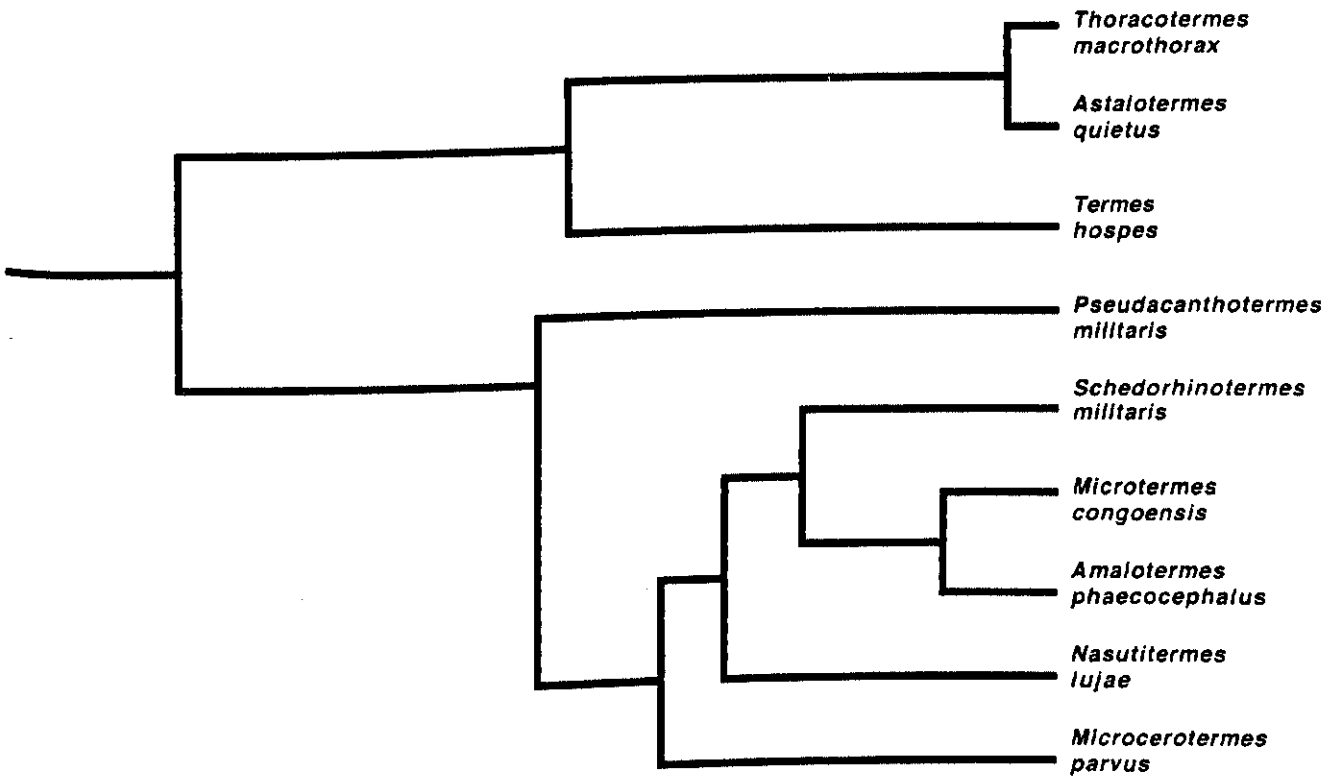


Figure 7-3. Species tree produced by the UPGMA algorithm, based on Pianka's proportional utilization function.

# Discussion

## Approaches to invertebrate gut content analysis

In many cases observations of gut content items in invertebrates have been purely qualitative, or at best semi-quantitative, but Anderson and Healey (1972) were able to wash the gut contents of collembolans through micropore filters which retained particulate components, largely fungal items, in an identifiable form and thus to determine the percentage composition of the food. In dealing with the more heterogeneous diets of enchytraeids, dipterous larvae and cryptostigmatid mites, Anderson (1975) determined mean proportions of particular food items from the sum of quartile grades (0 to 4) multiplied by the frequency of each grade score in a large sample of cleared, stained guts or gut boluses, but failed to find a satisfactory statistical method for analysis of interspecific differences in feeding habits. Anderson's graphical representation of species positions on three axes of a triangle scoring fungal items, plant tissues and amorphous materials, respectively, is a successful early form of the multivariate analyses attempted in the present study.

## Interpretation of TWINSPAN classification

Table 7-5 is a hierarchical reclassification of termites into functional groups based on the four principal dichotomies established by TWINSPAN. The most important ("indicator") and other important factors ("preferentials") which provide discrimination between the species at each node are identified. The basic distinction betweensoil-feeding and other feeding forms is maintained as the root of classification, but the analysis suggests that wood-feeders should be further divided into a group where the gut contents contain some silica and humus (humified wood-feeders) and another where they do not (sound wood-feeders). Further subdivision of the humified wood-feeder group (which contains five species) is unsatisfactory because of the anomolous position of *Pseudacanthotermes militaris*, but it is reasonably clear from their general biology that *Termes hospes* and *Amalotermes phaecocephalus* feed further down the gradient of humification than *Microtermes congoensis* and *Nasutitermes lujae*.

Arthropod parts, silica, fungal mycelium and humus can be recognized independently of the staining regime, and proved to be important discriminators in the TWINSPAN classification of species, even though the occurrences of arthropod parts, fungal mycelium and humus are generally fewer than for some other components of the gut contents. Only one stain, phloroglucinol, was used at a sufficiently high concentration to produce marked differences in colour intensity between stained items in the gut contents. Even here, though, there were consistencies within species; for example the colour developed in the gut contents of *Microcerotermes parvus* is a brighter red than in *Nasutitermes lujae,* which suggests either that the selection of woody material for consumption differs in each termite, or else the selection of food takes place at different points in the decomposition process.

## Niche breadth and overlap

The proportional utilization of particular segments of a resource gradient is particularly suitable for the estimation of diet (= niche) breadth, as it does not require that the gradient be either ordered or continuous and may therefore be derived from resource states that are different categories of food type found by gut content analysis (Southwood, 1978). Food item size selection, which is sometimes proposed as the basis of niche separation between species, is probably of little importance in detritivores where mouthparts and intestinal structures are designed to excavate and comminute the substrate. The extistence of overlap in the use of resources between pairs and larger groupings of species can be demonstrated, suggesting that co-existence rather than competition is the main interaction in the assemblage, at least at the level of food selection and processing. The possibility remains that particular resources are used by different species at different times or that competition between termite colonies for larger woody items turns more on their value as refugia and social centres than as finite food sources. On the limitied evdience available from the comparison of gut contents in *Thoracotermes macrothorax* and *Astalotermes quietus* , the high level of speciation amongst soil-feeding forms in the same assemblage is unlikely to reflect a tight species packing achieved by the competitive exclusion principle.

## Difficulties with termite gut content analysis

Gut content analysis in termites is complicated by the large population of resident microorganisms, including many actinomycete-like filaments, which can contribute more than 10% of the intestinal biovolume (Bignell *et al.*,1980). This makes it impossible to distinguish some types of ingested microbes from endogenous symbionts. The presence of numerous flagellates in lower termites presents a further difficulty, as the flagellate cells are delicate and do not survive the preparation procedure in an immediately recognizable form. Large quantities of living (or freshly dead) biovolume in gut content preparations reduces the usefulness of general vital

Table 7-5. Reclassification of termite species into functional groups based on the dichotomies established by TWINSPAN.

| Node | Group trend | Taxa | Indicator | Preferentials | Putative functional group |
|---|---|---|---|---|---|
| | +ve | *Thoracotermes macrothorax*<br>*Astalotermes quietus* | Arthropod parts | Arthropod parts<br>Fungal mycelium<br>Plant roots<br>Silica | SOIL FEEDING |
| | -ve | *Termes hospes*<br>*Amalotermes phaecocephalus*<br>*Pseudacanthotermes militaris*<br>*Microtermes congoensis*<br>*Nasutitermes lujae*<br>*Microcerotermes parvus*<br>*Schedorhinotermes putorius* | | Macerated organic material<br>Gentian violet +ve<br>Plant tissue fragments<br>Lignified tissue | WOODY MATERIAL FEEDERS |
| 2 | +ve | *Termes hospes*<br>*Amalotermes phaecocephalus*<br>*Pseudacanthotermes militaris*<br>*Microtermes congoensis*<br>*Nasutitermes lujae* | Silica | Silica<br>Fungal mycelium<br>Plant roots<br>Humus<br>Macerated organic material | HUMIFIED WOOD FEEDERS |
| | -ve | *Microcerotermes parvus*<br>*Schedorhinotermes putorius* | | Gentian violet +ve | SOUND WOOD FEEDERS |
| 3 | +ve | *Termes hospes*<br>*Amalotermes phaecocephalus*<br>*Pseudacanthotermes militaris* | Arthropod parts | Plant roots<br>Arthropod parts<br>Silica<br>Fungal mycelium | - (no clear functional group definable) |
| | -ve | *Microtermes congoensis*<br>*Nasutitermes lujae* | | Gentian violet +ve | DECAYED WOOD FEEDER |
| 4 | +ve | *Termes hospes*<br>*Amalotermes phaecocephalus* | | (Fungal mycelium) | SOIL/WOOD INTERFACE FEEDERS |
| | -ve | *Pseudacanthotermes militaris* | Humus | Plant tissue fragments<br>Plant roots<br>Humus | LITTER FEEDERS |

stains such as methylene blue and aniline blue in providing a resolution of heterogeneous ingested materials, but we have found safranin and gentian violet to be effective substitutes if used highly diluted. In preliminary experiments a number of other stains with affinity for components of plant tissue or storage products were examined. These included iodine in KI, Bismark Brown, aniline $SO_4$, Remasol Brilliant Blue, Millon's reagent, Fehling's solution, Haematoxylin, Light Green and Sudan black; however none proved satisfactory. The combination of safranin and gentian violet is useful as the latter stains microbial tissues but fails to stain plant tissues at the dilutions employed (< 0.005%). In termite gut homogenates it should therefore

be expected that the occurrence of safranin +ve items should exceed that of gentian +ve material. Figure 7-1 shows this is the case in every species examined. Further, the greatest proportions of gentian violet items occurred in the guts of *Schedorhinotermes putorius* and *Microtermes congoensis*, the two species which would be expected to contain most non-prokaryotic microbial tissue (protozoan and fungal, respectively).

# Conclusions

At a primary level of interpretation the data appear to provide a sensitive index of the dietary differences between species, although a statistical basis for pairwise and group comparisons could not be established with the sample sizes employed. No two species are identical and with 10 content item categories available the technique appears to provide scope for discrimination within otherwise well-defined groupings such as "soil-feeding" and "wood-feeding" guilds.

This is illustrated by a further comparison between two notional "wood-feeding" species, *Microcerotermes parvus* and *Nasutitermes lujae*, which shows that plant tissue fragments were more frequently observed in *Nasutitermes lujae*, while macerated organic material was more common in *Microcerotermes parvus*. These results suggest that the feeding habits of the two species differ, although there is the possibility that both species are omnivorous, but happened to be collected from different substrates. Some caution needs to be exercised as the analysis measures proportions of occurrences and not the absolute or the relative concentrations of gut content components. Two species could therefore show different proportional occurrences for a content item that was present at the same concentration in each species, if one species had a more heterogeneous diet than the other.

The greater usefulness of gut content analysis may lie at the assemblage level, where the results may assist the definition of trophic guild structure and diversity with greater accuracy. The analysis supports the putative distinction between soil-feeding and wood-feeding forms, but this is perhaps unsurprising in view of the many differences which are obvious from inspection. Greater interest attaches to the question of whether there is validity in subdividing the wood-feeding group, but with the observed heterogeneity of gut content items the confidence with which this can be done perhaps depends on the degree of agreement between the different forms of data analysis attempted. It is argued elsewhere that termite gut morphology and physiology are correlated with feeding position along the humification gradient (Bignell, 1994). Humified material is considered of poorer quality, but is more readily available than sound wood and fresh plant litters (Bignell and Eggleton, 1995).

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# 8. SCREENING OF LEGUMINOUS COVER CROPS FOR BIOMASS PRODUCTION AND NODULATION UNDER HUMID TROPICAL CONDITIONS

M.K. Hamadina, J. Henrot, N.O. Isirimah and N.M. Tariah

## Abstract

Four cover crop species, *Canavalia gladiata* (Jacq) DC (IITA N° TCg 3), *Canavalia ensiformis* (L.) DC, *Centrosema pascuorum* (Mart ex. Benth.) cv. cavalcade, and *Mucuna pruriens* var. *utilis* (L.) DC, were screened, for growth and nodulation, on an acid Ultisol under humid tropical conditions. The cover crop species were grown in 10 L PVC buckets for 12 weeks. Above-ground dry matter yields were in the order: *Centrosema pascuorum* > *Canavalia ensiformis* = *Canavalia gladiata* > *Mucuna pruriens* var. *utilis*. Below-ground biomass of *Centrosema pascuorum* and *Canavalia gladiata* constituted only 16.4 and 28.5 % of total (above- + below-ground) biomass respectively, as compared to 32.9 and 35.5 % for *Canavalia ensiformis* and *Mucuna pruriens* respectively. Nodules constituted 7.5 % of the total dry matter produced by M. *pruriens*, 4.0 to 5.0 % for the *Canavalia* spp. and only 2.6 % in the case of *Centrosema pascuorum*. In all cases more than 45 % of the nodules were actively fixing $N_2$.

**Keywords**: biomass, humid-tropic, N-fixation, leguminous cover crop, nodule, Ultisol

## Introduction

Farmers in the tropics use cover crops to protect the surface of soil against erosion, suppress weeds, and improve soil fertility. Due to their ability to fix atmospheric $N_2$, leguminous cover crops are preferred by farmers (for soil management) in the humid tropics (Reijntjes *et al.*, 1992). The usage of leguminous cover crops is most relevant in the humid tropics, where rainfall depletes soil nutrients (especially N) through leaching coupled with the fact that the soils are poorly structured and prone to erosion (Sanchez *et al.*, 1982); in addition to rapid and persistent weed growth (Akobundu, 1987).

The ability of herbaceous legumes to improve soil fertility vary with species. The fact that cultivated species (such as *Vigna* spp.) concentrate nutrients in their grains that would be harvested for food, makes them unsuitable for soil fertility management (Van der Heide and Hairiah, 1989; Reijntjes *et al.*, 1992). Wild leguminous species are, therefore, likely to be more efficient, in soil fertility improvement, than the cultivated ones. The reports of Agboola (1982) and Van der Heide and Hairiah (1989), e.g., showed that wild legumes contributed more N to soil than the cultivated ones.

In the humid tropical regions, however, acid soil conditions constitute an important problem in using leguminous cover crops for improving soil fertility (Haque, 1991). There are generally a complex of problems (Al and Mn toxicities, and Mo, Ca, Mg and K deficiencies) associated with acid soils (Adams, 1981). At very low soil pH many legumes fail to produce acceptable biomass and/or nodulate and fix atmospheric $N_2$ (Alva *et al.*, 1987). Fortunately, $N_2$-fixing leguminous species that can be grown as cover crops on the acid soils in the humid tropics exist (Rachie and

Roberts, 1974; Giller and Wilson, 1991). However, it is necessary to screen these species, to better evaluate their potentials in soil fertility management practices.

The objective of this work was to compare four leguminous cover crop species in terms of biomass production and nodulation in an acid Ultisol of the humid tropics.

# Materials and methods

The experiment was conducted at the High Rainfall Station of the International Institute of Tropical Agriculture (IITA) at Onne (4° 51'N; 7° 03'E; 10 m above sea level) southeastern Nigeria. Rainfall at the experimental site is monomodal and lasts from March to December with annual mean of 2400 mm. Mean annual minimum and maximum temperatures are 25 °C and 27 °C, respectively.

Surface soil (0-15 cm depth) was collected from a field under a natural fallow (dominated by short annual grass species), air -dried and sieved (2 mm-mesh) to remove plant detritus. Subsamples of soil were analyzed for pH (1:1 $H_2O$, glass electrode pH Meter), total N (Kjeldahl), organic C (Walkley and Black) and exchangeable Ca, Mg and K (Ca and Mg by Atomic Absorption Spectrophotometry, while K by flame ionization) and acidity (Al +H), and available P (Bray-1). Soil pH was 4.25, total N 0.14 %, while organic C was 1.64 % (C:N ratio of 11.5). The exchangeable Ca, Mg and K content of the soil were 0.61, 0.26 and 0.25 meq 100 $g^{-1}$, respectively, while exchangeable acidity (Al + H) was 0.58 meq 100 $g^{-1}$ soil. The available P content (47.1 µg $g^{-1}$ Bray-1 P) was fairly high. About 5.0 kg (dry weight equivalent) of the sieved soil was filled into 10 L PVC buckets (ø of 24 and 18 cm, top and bottom respectively; 21 cm high fitted with 6 drainage holes) and placed on wooden "board-walks" in a screen-house (roof covered with a 2 mm mesh-size plastic screen) in the field.

Four cover crop species, *Canavalia gladiata* (Jacq) DC (IITA N° TCg 3), *Canavalia ensiformis* (L.) DC, *Centrosema pascuorum* (Mart ex. Benth.) cv cavalcade and *Mucuna pruriens* var. *utilis*, were planted in the buckets and grown for 12 weeks. Two cultivars of non-nodulating *Glycine max* (IITA N° TGm 381 and TGm 808) were grown along with the cover crops to serve as reference plants for estimating $N_2$-fixation. About 3 to 9 seeds (depending on the size of seeds) of each species (including the reference plants) was planted into each of 9 buckets (thinned to 2 after 1 week) in a randomized design in January 1994. Buckets were watered on rainless days while weeds were manually removed when necessary. At the end of the experiment, above-ground biomass of cover crops were sampled by cutting at ground level. There-after, soil from each pot was washed over a 0.5 mm-mesh sieve, under a gently flowing tap, to recover roots and nodules. Nodules were separated into active and inactive nodules (active nodules identified by a pinkish-red coloration when sliced).

Plant N content was determined by the Kjeldahl method with an AutoAnalyzer (Technicon AAII), while total C was determined following the procedures of Amato (1983). Plant extracts for P, Ca, Mg and K determinations were obtained after sequentially digesting samples with concentrated $HClO_4$ + $HNO_3$ (1:2), then 6N HCl. The concentrations of P in the extracts were determined using an AutoAnalyzer (Technicon AAII), Ca and Mg using Atomic Absorption Spectrophotometer (Perkin-Elmer 703), and K using a Flame Photometer (Gallenkamp).

The amount of N the cover crops derived through atmospheric $N_2$-fixation was estimated using a modification of the N difference method described by Giller and Wilson (1991). In the modification, differences in % N concentration between the reference plants and the screened legumes were attributed to $N_2$-fixation.

# Results

## Biomass production

The biomass (dry weight in g $pot^{-1}$) production of the various cover crop species are shown in Table 8-1 and Figure 8-1. The reference plants yielded considerably lower amount of biomass than the cover crop species. In spite of the fact that *Centrosema pascuorum* had the smallest seed, its biomass above ground was higher than those of the *Canavalia* spp. and *Mucuna pruriens* var. *utilis*. Values of above-ground dry matter were in the order: *Centrosema pascuorum* > *Canavalia ensiformis* = *Canavalia gladiata* > *Mucuna pruriens* var. *utilis*.

Table 8-1. Biomass production of 12 week-old cover crop species grown on acid Ultisol in southeastern Nigeria.

| | Above-ground (g $pot^{-1}$) | Below-ground (g $pot^{-1}$) | Total (g $pot^{-1}$) | Above: below ratio |
|---|---|---|---|---|
| *Centrosema pascuorum* | 21.6±2.6$^{a}$ | 4.2±0.2$^{a}$ | 25.8±2.7$^{a}$ | 5.1±0.5$^{a}$ |
| *Canavalia gladiata* | 18.2±0.8$^{b}$ | 9.1±0.9$^{b}$ | 27.3±1.2$^{a}$ | 2.0±0.2$^{bc}$ |
| *Canavalia ensiformis* | 19.7±1.1$^{b}$ | 7.9±0.6$^{b}$ | 27.6±1.4$^{a}$ | 2.5±0.2$^{b}$ |
| *Mucuna pruriens* var. *utilis* | 15.9±0.8$^{c}$ | 8.7±0.9$^{b}$ | 24.6±1.5$^{a}$ | 1.8±0.2$^{c}$ |
| *Glycine max* (TGm 318) | 2.3±.2 | 1.3±0.3 | 3.6±0.5 | 1.8±0.5 |
| *Glycine max* (TGm 808) | 4.7±1.1 | 0.8±0.1 | 5.4±1.2 | 5.9±1.1 |

a, b, c: Fisher LSD significant at 95 % between species.

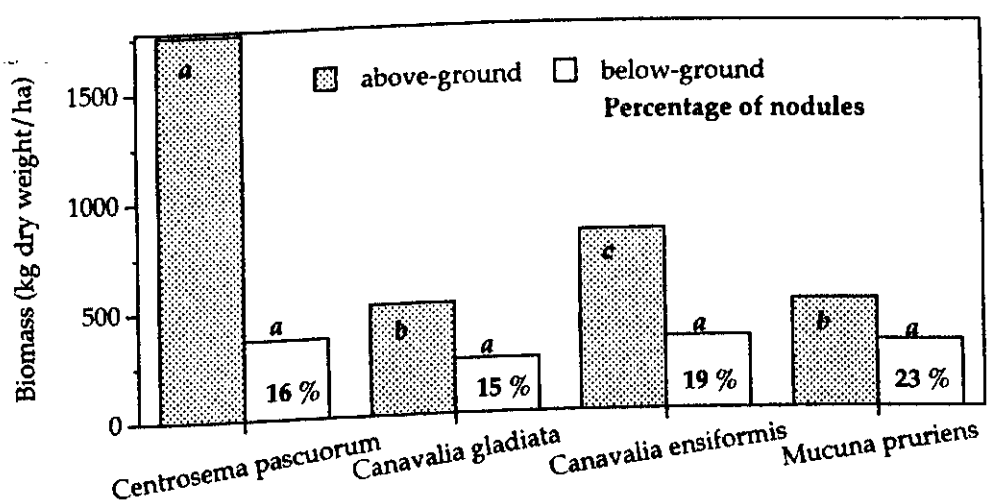


Figure 8-1. Cover crop biomass produced in 3 months of growth.

On the other hand, the below-ground biomass yield of *Centrosema pascuorum* was significantly ($P = 0.05$) lower than the rest of the species. The proportion of below ground biomass that were nodules (Table 8-2) varied widely among the species (16 % in *Centrosema pascuorum* and *Canavalia gladiata*, as compared to 18 and 23 % in *Canavalia ensiformis* and *Mucuna pruriens* respectively; Table 8-2). Similarly, the below-ground biomass of *Centrosema pascuorum* and *Canavalia gladiata* constituted only 16.4 and 28.5 % of total (above- + below-ground) biomass respectively, as compared to 32.9 and 35.5 % for *Canavalia ensiformis* and *Mucuna pruriens* respectively (Table 8-2). Values of above- to below-ground biomass ratio obtained for the various species ranged from 1.7 (for *Mucuna pruriens*) to 5.0 (for *Centrosema pascuorum*).

Table 8-2. Biomass and activity of nodules of cover crop species in an acid Ultisol.

| | Biomass (g pot$^{-1}$) | % of below-ground biomass | % of total biomass | % active nodules |
|---|---|---|---|---|
| *Centrosema pascuorum* | 0.7±0.1$^{a}$ | 16.4±2.4$^{a}$ | 2.6±0.2$^{a}$ | 57.2±3.4$^{b}$ |
| *Canavalia gladiata* | 1.3±0.2$^{b}$ | 14.5±1.5$^{a}$ | 4.3±0.4$^{b}$ | 46.5±3.5$^{a}$ |
| *Canavalia ensiformis* | 1.4±0.2$^{b}$ | 18.2±2.4$^{a}$ | 4.8±0.6$^{b}$ | 58.8±6.7$^{b}$ |
| *Mucuna pruriens* var. *utilis* | 2.0±0.1$^{c}$ | 24.1±1.7$^{b}$ | 8.2±0.4$^{c}$ | 47.1±2.8$^{a}$ |

a, b, c: Fisher LSD significant at 95 % between species

## Nodulation and nodule activity

The two *Canavalia* spp. did not show any significant differences, in terms of nodule dry weight (Table 8-2, Figure 8-1). Dry weight of nodules of the *Canavalia* spp. were lower than that of *Mucuna pruriens* (var. *utilis*). However, the *Canavalia* spp. and *Mucuna pruriens* var. *utilis*, yielded about twice and thrice respectively, the dry weight of nodules obtained from *Centrosema pascuorum*. Generally, nodule biomass ranged from 0.7 g pot$^{-1}$ (for *Centrosema pascuorum*) to 2.0 g pot$^{-1}$ (for *Mucuna pruriens*). Nodules constituted 7.5 % of the total dry matter produced by *M. pruriens*, while between 4.0 to 5.0 % of total dry weight of the *Canavalia* spp. were nodules. In contrast, nodules represented only 2.6 % of total biomass in the case of *Centrosema pascuorum* (Table 8-2).

More than 45 % of nodules in all species, turned pink when sliced open, indicating active $N_2$-fixation. *Canavalia ensiformis*, which showed the highest activity, was closely followed by *Centrosema pascuorum*, while *Mucuna pruriens* var. *utilis* and *Canavalia gladiata* ranked last.

## Nutrient concentration of residues

The percent nutrient concentration and C:N ratio of the various leguminous cover crops are presented in Table 8-3. The above-ground biomass of *Centrosema pascuorum* or *Mucuna pruriens* var. *utilis* had a higher (> 2.3 %) N content and lower C:N ratio (< 14.4) than either of the *Canavalia* spp. (< 1.94 % N; C:N ratio > 18.2). In contrast, the N content of the below-ground residues of the various species were comparable. On the other hand, the C:N ratio of the below-ground residues varied from 9.4 (for *Mucuna pruriens*) to 14.5 (for *Canavalia gladiata*).

Table 8-3. Nutrient content (%) of residues of leguminous cover crop species.

| | N | P | Ca | Mg | K | C:N |
|---|---|---|---|---|---|---|
| | | | Above-ground residue | | | |
| *Centrosema pascuorum* | 2.36 | 0.17 | 0.78 | 0.39 | 1.90 | 13.9 |
| *Canavalia gladiata* | 1.84 | 0.23 | 0.56 | 0.30 | 2.06 | 18.3 |
| *Canavalia ensiformis* | 1.93 | 0.14 | 0.51 | 0.33 | 1.38 | 18.8 |
| *Mucuna pruriens* var. *utilis* | 2.53 | 0.18 | 0.68 | 0.32 | 2.32 | 14.3 |
| *Glyxine max* (mean) | 1.79 | | | | | |
| | | | Below-ground residue[1] | | | |
| *Centrosema pascuorum* | 2.62 | 0.17 | 0.33 | 0.25 | 0.98 | 12.4 |
| *Canavalia gladiata* | 2.26 | 0.18 | 0.39 | 0.23 | 1.03 | 14.5 |
| *Canavalia ensiformis* | 2.60 | 0.18 | 0.29 | 0.26 | 1.03 | 12.2 |
| *Mucuna pruriens* var. *utilis* | 2.94 | 0.09 | 0.34 | 0.21 | 1.68 | 9.4 |
| *Glyxine max* (mean) | 1.68 | | | | | |

[1]: roots + nodules.

In all species, the below-ground residues contained higher N and lower Ca, Mg and K than the shoots. In contrast to N and the cations, the concentration and distribution of P differed between the species. While *Centrosema pascuorum* contained P in the same magnitude in both the above- and below-ground residue, shoots of *Mucuna pruriens* var. *utilis* and *Canavalia* spp. had higher P content than roots.
The total amount of N (Table 8-4) contained in the biomass ranged from 552 to 620 mg N $pot^{-1}$, with *Centrosema pascuorum* containing the highest while *Canavalia gladiata*, the least. Most of the N in all species were contained in the below-ground residues. The contribution of below-ground residue to total N ranged from 17.7 % (for *Centrosema pascuorum*) to 41.6 % (for *Mucuna pruriens* var. *utilis*).

Table 8-4. Total N yield (mg N $pot^{-1}$) and proportion (%) of the N derived from $N_2$-fixation, of leguminous cover crop species.

| | Above-ground | Below-ground | Total | Above: below ratio |
|---|---|---|---|---|
| *Centrosema pascuorum* | 510 | 110 | 620 (26.3)[1] | 4.64 |
| *Canavalia gladiata* | 340 | 206 | 546 (11.8) | 1.52 |
| *Canavalia ensiformis* | 380 | 205 | 585 (17.1) | 1.85 |
| *Mucuna pruriens* var. *utilis* | 359 | 256 | 615 (34.9) | 1.40 |

[1]: values in parenthesis represent % of N derived from $N_2$-fixation.

Due to the comparatively very low amount of biomass produced by the reference plants, the basic assumption of "comparative amount of biomass" of the N-difference method was not met. However, an estimate of atmospheric $N_2$-fixation was made, using the N (%) content of residues, based on the assumption that variations in N concentration between the cover crop species and the reference plants were due to $N_2$-fixation. Values obtained (Table 8-4) ranged from 11.8 % (*Canavalia gladiata*) to 34.9 % (*Mucuna pruriens*). The annual species (*Centrosema pascuorum* and *Mucuna pruriens* var. *utilis*) obtained a higher proportion of their N from the atmosphere than the perennials (*Canavalia* spp.)

# Discussion

Irrespective of their origin or reported adaptability to acid soils, all the species germinated well and did not show any specific symptoms throughout the experiment. The amount of biomass produced by the *Canavalia* spp. within 3 months can be considered high since they are perennial species. On the other hand, the low above-ground biomass yield of *Mucuna pruriens* var. *utilis* was most likely because its shoots had the highest fresh: dry weight ratio (data not shown). Although the below-ground biomass of all species (minus *Centrosema pascuorum*) were comparable, their nodule biomass differed significantly ($P = 0.05$), which probably reflected their level of acid soil tolerance. All the species, except *Centrosema pascuorum*, are adapted to the acid Ultisol (Rachie and Roberts, 1974), except *Centrosema pascuorum* which is a species of the sub-humid savanna (Clements *et al.*, 1983). Therefore, lower nodule dry weight obtained from *C. pascuorum* might be related to its acid sensitivity.

It is interesting to note that in spite of *Centrosema's* reported acid sensitivity, its nodules were actively fixing atmospheric $N_2$. In contrast, *Canavalia gladiata* which was reported to grow well in acid soils, had the lowest values of "percent active" nodules as compared to other species, suggesting that *C. gladiata* might be the least efficient in terms of $N_2$-fixation. The apparently low proportion (%) of active root nodules found on *M. pruriens* var. *utilis* was probably due to nodule senescence. Hairiah and Van Noordwijk (1986) reported that root nodules of *Mucuna pruriens* var. *utilis* start dying as from 8 weeks after emergence.

The higher N content of below-ground compared to above-ground residues was probably because the former included "active" root nodules which are known to have high N concentrations (Giller and Wilson, 1991). High N content of below-ground residues suggests that they would likely constitute a significant input of N to soil. However, due to variations in the shoot:root ratio, and therefore in the contribution of below-ground biomass to total residue-N, the removal of above-ground residues (e.g. during grazing) may affect the ability of the species to contribute N to soil. The species *Mucuna pruriens* var. *utilis* would be least affected since most of its N is contained in the below-ground biomass. On the other hand, the above-ground biomass contained most of the Ca, Mg and K, therefore removal of the above-ground from the field (e.g. for animal fodder) results in a loss of these nutrients for the soil.

Differences between species, in terms of P concentration and distribution, are somehow difficult to explain with our data. Additional work would be needed to determine whether there is any mychorrizal effect on tissue P content of any of the species. However, if shoot P content is assumed to be an index of P requirement, it may be speculated that the various species would respond differently to added P.

Although, the *Canavalia* spp. are well adapted to the humid tropics, the amount of N they derived from $N_2$-fixation, within 3 months, were low probably because of their slow growth. On the other hand, the *Centrosema pascuorum* that is well adapted to non-acid soils derived a high proportion of its tissue N from $N_2$-fixation. This suggests that comparisons for $N_2$-fixing ability of different species are better made if all the species have similar growth habit. Among the *Canavalia* spp., *C. ensiformis* was more efficient in terms of atmospheric $N_2$ fixation. Coupled with the fact that *C. ensiformis* is very common throughout West Africa and some parts of Central Africa (Rachie and Roberts, 1974), it may play a significant role as a cover crop in these regions.

On the other hand, the performance of *Centrosema pascuorum* in this experiment is worthy of note since it contradicts previous reports which showed that *C. pascuorum* performed poorly on infertile soils with pH < 5.0 (Clements *et al.*, 1983; Schultze-Kraft and Keller-Grein, 1985; Skerman *et al.*, 1988). It is likely that the poor performances observed by other workers were due to factors other than soil acidity. Schultze-Kraft and Keller-Grein (1985), e.g., conducted their studies on an acid Ultisol with high Al (90 %) saturation. High soil Al and Mn content are known to affect $N_2$-fixation by retarding the development of both the legume host and *Rhi-*

*zobium*, while high availability of P favors the abundance of *Rhizobium* spp. only (Giller and Wilson, 1991). The Ultisol used in this experiment contained low amounts of both extractable Al and Mn and high available P (Wilson, 1992). Therefore, a more critical evaluation of legumes that are reported to be acid sensitive (including *Centrosema pascuorum*), especially under field conditions, is recommended. *Centrosema pascuorum* also exhibited a vigorous growth (even among short annual grasses) and produced abundant seeds (data not shown) in plot established during the rainy season at our site.

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# 9. POTENTIAL BENEFITS OF A LEGUMINOUS COVER CROP AND A SLOW DECOMPOSING MULCH IN FALLOW MANAGEMENT ON A DEGRADED SOIL OF THE HUMID TROPICS

M.K. Hamadina, J. Henrot, N.O. Isirimah and N.M. Tariah

## Abstract

Soils in the humid tropics are highly weathered and a sustainable system of soil management for these regions is lacking. Three experiments were conducted to evaluate the potential benefits of leguminous cover crops (*Mucuna* and *Pueraria*) and a non-leguminous *Dactyladenia barteri* (Hook. f. ex Oliv.) Engl. mulch on highly degraded Ultisol in the S. E. of Nigeria

In the preliminary experiment, *Mucuna* established itself quickly, suppressed weeds, improved soil mineral N status and decomposed slowly during the dry season, and therefore constituted an input of plant residues in the next cropping season. Because of its slow decomposition, *Dactyladenia barteri* leaves provided a long-lasting mulch, which not only suppressed weeds, but also shifted weed composition from grasses to broadleaf species. *Dactyladenia* mulch also improved soil exchangeable cations. *Mucuna* reduced the density of weeds by 21.2 % while a combination of *Mucuna pruriens* var. utilis with *Dactyladenia* mulch reduced weed density by 31.3 %. The *Mucuna* relay cover crop succeeded in substituting low N containing residues (weeds) with plant material (*Mucuna*) more susceptible to provide N for crop uptake. The residual effect of *Mucuna* and *Dactyladenia* was an increase of maize grain yield by 75.3 and 85.1 %, respectively, while, in combination, they doubled the grain yield. Grain yield was correlated (at 5 %) to soil extractable $NO_3^-$-N ($r = 0.60$) and Mg ($r = 0.58$) content at planting, as well as to earleaf N ($r = 0.69$) and Mg ($r = 0.61$).

Data presented suggest that a combination of *Dactyladenia* mulch and *Mucuna* is a more efficient form of fallow than the natural regrowth. Therefore, the inclusion of a fast growing herbaceous legume into *Dactyladenia* mulched systems, could be a promising low input management practice for the highly degraded Ultisols.

**Keywords**: decomposition, fallow, humid tropics, low-external-input, Ultisol, weeds

## Introduction

Most of the humid tropical soils are highly weathered and acidic. The humid tropical soils, mostly Ultisols and Oxisols, require an annual addition of about 8 Mg $ha^{-1}$ of above-ground plant residues for sustained food crop production (Van Noordwijk and Guritno, 1992). Long fallow rests usually provide enough plant residues that rejuvenate the fertility of these soils. However, fallow periods required for soil fertility regeneration are compromised by increased demand to clear more lands due to growing population. Reduced fallow periods results in the reduction of the amount of residues returned to the soil hence, the ability of soils to sustain food production.

Efforts to achieve sustainable crop yields led to the development of different forms of soil management, e.g. alley-cropping and use of cover crops. Alley cropping is a promising agroforestry system that merges cropping and fallow phases: arable crops are grown in alleys formed by hedgerows of trees or shrubs (Kang, 1993). The pruning of the hedgerow trees serves as ground cover as well as nutrient source. Cover crops, which were initially used mainly to protect soil against erosion, later gained prominence in soil fertility management (Reijntjes *et al.*, 1992). In alley cropping as well as when cover crops are used on the acid Ultisol, the target of 8 Mg $ha^{-1}$ is hardly achieved. This necessitates additional sources of plant residues. Addition of mixed residues by combining cover cropping with mulch from trees/shrubs may help in achieving the required amount of plant residues. In addition, when non-leguminous agroforestry species are used, leguminous cover crop species are able to provide an appreciable N input through atmospheric $N_2$ fixation. Although this practice may involve additional cost and labor, it may eventually prove beneficial especially when soil become strongly degraded and other alternative inputs, very expensive and not readily available.

In this study, a managed fallow of leguminous cover crop species, and a slow decomposing mulch, was compared with a natural fallow regrowth (dominated by short annual grasses). Two leguminous cover crops (*Mucuna pruriens* var. *utilis* and *Pueraria phaseoloides*) were planted, late in the season in 1992, in order to measure biomass production and effect on soil N, in a situation similar to relay cropping. During the subsequent cropping season (in 1993), *Mucuna pruriens* var. *utilis* was planted into a *Dactyladenia barteri* mulched field to assess fallow biomass production and quality, weed suppression, and soil mineral N and base cations. The field was then planted with maize in April 1994, in order to assess the effect of the previous *Dactyladenia* mulch and *Mucuna* cover on crop performance. The cover crop species were $N_2$-fixing legumes while *Dactyladenia barteri* was a non-leguminous tree species, all of which grow very well in the southeastern part of Nigeria. The non-leguminous *Dactyladenia barteri* appears to be the best species, so far identified, for alley cropping on the acid soils in southeast Nigeria (Kang, 1993; Ruhigwa *et al.*, 1992).

# Materials and methods

## Experimental site

Field experiments were carried-out at the High Rainfall Station of the International Institute of Tropical Agriculture (IITA) in southeastern Nigeria (4° 51'N; 7° 03'E). Rainfall at the experimental site is monomodal and lasts from March to December with annual mean equaling 2400 mm. Relative humidity range from 78 % in February to 89 % in the months of July and September while mean annual minimum and maximum temperatures are 25 °C and 27 °C respectively.

The soil at the site is a coarse-loamy siliceous iso-hyperthermic Typic Paleudult derived from plio-Pleistocene coastal sediments of marine origin (Niger Delta). The soil is deep, freely drained and made up of low activity clays with kaolinite as the dominant clay mineral. Surface soil (0-10 cm) pH was 4.3, organic C 1.29 %, total N 0.098 % while available P was 58.1 µg $g^{-1}$. According to IITA (1993), the site is typical of highly degraded soils of the humid forest zone.

The field had been cropped continuously for the past 16 years, without fertilization, except on the 2nd and 6th year when 200 kg $ha^{-1}$ NPK were applied. On the sixth year of cropping, 750 kg $ha^{-1}$ of hydrated lime were applied along with the NPK. No other chemical inputs were used.

## Experiment 1 (October 1992 to April 1993)

The field (112 x 36 m) was slashed in August 1992, then divided into 3 blocks with 3 plots (36 x 8 m) each. In each block, one plot was planted with *Mucuna pruriens* var. *utilis*, another with *Pueraria phaseoloides*, by broadcasting seeds at the rate of 78 and 12 kg seeds $ha^{-1}$, respectively, while the third was left to re-vegetate naturally.
After 2 months of growth, the above-ground plant biomass was sampled by cutting the vegetation on a strip 1 m wide across the length of the plots (36 $m^2$ surface), on each plot, at ground level. Samples were then hand-sorted into weeds and cover crops, weighed fresh and sub-samples oven-dried at 60 °C to estimate dry weight.

At the beginning of the experiment, soil was sampled at 0-10, 10-20 and 20-30 cm depths, at 18 m interval across the length of the field, in 3 replicates, in order to estimate spatial variability in soil pH, total C, total and mineral N, exchangeable Ca, Mg, K, and exchangeable acidity (Al + H). After 2 months, soil (0-10 cm) was sampled and analyzed for mineral N and exchangeable cations (Ca, Mg and K). Each soil sample was a composite of 24 core samples kneaded in a polythene bag after sampling.

## Decomposition study (litterbag)

After taking biomass samples (experiment 1), the rest of the cover crops were harvested, air-dried and chopped to about 10 cm (leaf blade intact). Stainless-steel litterbags (30 x 30 x 2 cm, 2 mm-mesh size) were filled with 25 g of either *Mucuna pruriens* var. *utilis* or *Pueraria phaseoloides* residues and placed on the plots from which their contents were collected. On each plot, 2 litterbags were randomly sampled at 35, 63, 83, 97 and 107 days after placement. After sampling, litterbag content was manually cleaned with a soft brush, oven-dried at 60 °C and analyzed for total N and ash content.

## Experiment 2 (May 1993 to December 1993)

In the next rainy season (May 1993), an open-pollinated maize (*Zea mays*) variety was planted, at 20, 000 plants $ha^{-1}$, on the plots with *Mucuna pruriens* var. *utilis* and natural fallow regrowth in experiment 1 (weeded one week later).

One week after planting maize, air-dried *Dactyladenia barteri* leaves were applied, as mulch at 2 Mg $ha^{-1}$, on 4.5 x 8 m areas selected into plots of experiment 1. Maize harvest failed and weeds were allowed to grow on the field. Two months after planting maize, *Mucuna pruriens* var. *utilis* was planted, on selected 9 x 8 m areas into *Mucuna* plots of experiment 1, by broadcasting seeds at 78 kg seeds $ha^{-1}$.

Above-ground plant biomass was sampled, from a 1 m strip across the width of the plots (8 $m^2$ surface), at 3 and 5 months after planting *Mucuna*. Samples were hand-sorted into weeds and cover crops, weighed fresh, then sub-samples oven-dried at 60 °C for dry weight, and N analyses.

At the end of the dry season, roots were sampled, by taking a soil monolith, using an adapted Pinboard (60 wide, 40 deep with pins of 12 cm length) (Schuurman and Goedewaagen, 1971). After sampling, the soil monolith was split into 4 according to depth (0-10, 10-20, 20-30 and 30-40 cm) and vertically, into 3, at 20 cm intervals to obtain 3 replicate samples per depth. Individual root samples were then washed over a 0.5 mm mesh sieve, under a gently flowing tap, to recover roots and root nodules. Each root nodule was split open and separated into "active" and "inactive" (active nodules were identified by a reddish-pink coloration when sliced), before

drying at 60 °C. The below-ground biomass of *Mucuna* (roots + nodules) were identified, by its dark gray color when dry, and weighed separately.

At 2 and 5 months after mulching with *Dactyladenia* (before and 3 months after planting *Mucuna*), soil samples were taken at 10 cm depth. The first sample was analyzed for mineral N and exchangeable Ca, Mg and K, while the second, for mineral N.

## Decomposition study (litterbag)

About 2 weeks after mulch application in the field (experiment 2), air-dried leaves of *Dactyladenia* (2.0 Mg $ha^{-1}$, dry weight) were put into stainless-steel litterbags (30 x 30 x 2 cm, 2 mm-mesh size) and placed on the mulched plots. Two litterbags per plot were randomly sampled at 14, 28, 56, and 98 days after placement, cleaned with a soft brush, oven-dried at 60 °C and analyzed for ash content.

## Experiment 3 (April 1994 to August 1994)

At the onset of the next rainy season (April, 1994), all plots used for experiment 2 were planted with maize (*Zea Mays*, CV-Y) at 20,000 plants $ha^{-1}$. Two plots ( 8 x 9 m each) were selected on the fallow regrowth plots: one was treated with urea (40 kg N $ha^{-1}$, half incorporated at planting and the rest banded 4 weeks later), while the other was not.

At 6, 8, 10 and 12 weeks after maize planting, 5 maize plants were sampled by cutting at ground level per plot, and oven-dried at 60 °C, for dry matter estimation. At silking, 15 ear-leaves were sampled from each plot, oven-dried at 60 °C and analyzed for nutrient content. At harvest, grain and stover were sampled.

Composite (24 core samples homogenized in a polythene bag) soil samples were taken, at 0 - 10 cm depth, initially and at 8 weeks after planting maize. The first sample was analyzed for mineral N and base cations (Ca, Mg and K); the second for mineral N.

## Analytical methods

Soil pH was determined on 1:1 Soil:$H_2O$ solution using a glass electrode pH Meter, total N using the Kjeldahl method, organic C according to the Walkley-Black method and available P using Bray-1 method. Soil mineral N fresh was extracted, from soil samples, with 1N KCl (extractant) at 2: 5 soil:extractant ratio in duplicates. Extraction was done by shaking the mixture in tightly covered plastic cups and filtering through 0.2 µm pore-size membrane filters. Base cations (Ca, Mg and K) in soil were extracted with 1N $NH_4OAc$ + 0.01*M* EDTA, in the same way as mineral N, but separate apparatus were used to avoid contamination.

Mineral N concentrations in the respective extracts were measured using an AutoAnalyzer (Technicon AAII). The concentration of base cations were determined on 1N $NH_4OAc$ + 0.01*M* EDTA extracts, using an Atomic Absorption Spectrophotometer (Perkin-Elmer 703) for Ca, Mg, and a Flame Photometer (Gallenkamp) for K.

# Results

## Above-ground biomass production and weed suppression

### Experiment 1

After 2 months of growth, at the end of the dry season, the above-ground dry weight produced by either *Pueraria phaseoloides* or *Mucuna pruriens* var. *utilis* were 27 and 373 kg $ha^{-1}$, respectively (Figure 9-1). The total vegetation (weeds + cover crops) on the plots at the time

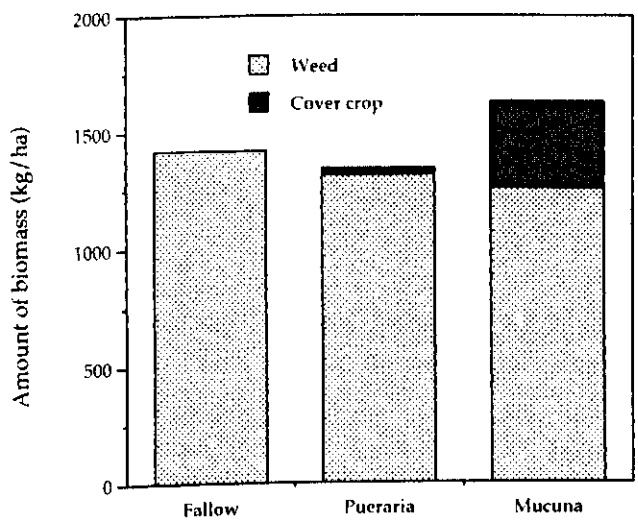


Figure 9-1. *Pueraria*, *Mucuna*, and weed biomass after 2 months of growth.

of harvesting the cover crops were not significantly different from one another but there were significant differences in the composition of the vegetation: weeds were 77 % of total biomass (weeds + cover crops) compared to 98 % of total biomass on *Pueraria* plots. On both plots, weeds were predominantly short annual grasses.

### Experiment 2

Prior to broadcasting *Mucuna* seeds, the experimental plots were covered with a standing vegetation of weeds. Two months later, in plots where mulch was applied, weed biomass and the composition of weeds significantly ($P = 0.05$) differed from plots with *Mucuna* only (Figure 9-2). About 60 % of the weeds on the mulched plots were broadleaf herbaceous species *Aspilia africana*, and *Argeratum conzyoides*). In contrast, grasses (*Cyperus rotundus*, *Cyperus tuberosus* and *Brachiaria deflexa*) constituted as much as 76 % the vegetation on plots that were not mulched.

Although *Mucuna* was broadcasted into a field of weeds, it germinated well, but its seedlings etiolated and took about 4 weeks to climb to the surface of the weeds. Three months after broadcast the *Mucuna* constituted 15.8 % of the total biomass on the un-mulched plots (Table 9-1). Mulching with *Dactyladenia barteri* significantly increased (by 12.8 %) the above-ground biomass yield of *Mucuna* and reduced ($P = 0.006$) weed biomass by 21.9 and 27.9 % on the fallow regrowth and *Mucuna* plots, respectively.

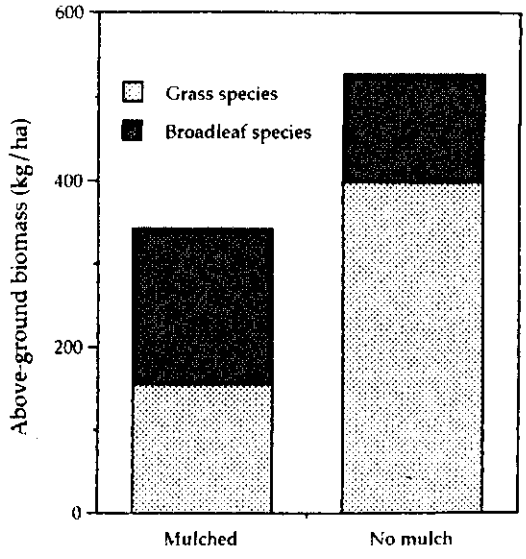


Figure 9-2. Biomass and composition of weeds 2 months after *Dactyladenia* mulch application (prior to planting *Mucuna*).

Table 9-1. Above-ground biomass (dry weight) at 3 and 5 months after the broadcast of Mucuna seeds, and amount of N in the above-ground biomass.

| | Fallow regrowth mulched[1] | Fallow regrowth no mulch | Mucuna mulched | Mucuna no mulch |
|---|---|---|---|---|
| | | Biomass,3 months after broadcast | | |
| Mucuna (kg ha$^{-1}$) | 0 | 0 | 584$^{b}$ | 509$^{a}$ |
| Weed (kg ha$^{-1}$) | 2173$^{b}$ | 2783$^{c}$ | 2010$^{a}$ | 2763$^{c}$ |
| Total (kg ha$^{-1}$) | 2173$^{a}$ | 2783$^{bc}$ | 2594$^{b}$ | 3272$^{c}$ |
| Percent weed | 100$^{c}$ | 100$^{c}$ | 77.4$^{a}$ | 84.2$^{b}$ |
| | | Biomass, 5 months after broadcast | | |
| Mucuna (kg ha$^{-1}$) | 0 | 0 | 857$^{b}$ | 762$^{a}$ |
| Weed (kg ha$^{-1}$) | 3003$^{b}$ | 3997$^{c}$ | 1906$^{a}$ | 2362$^{ab}$ |
| Total (kg ha$^{-1}$) | 3003$^{b}$ | 3997$^{c}$ | 2764$^{a}$ | 3124$^{bc}$ |
| Percent weed | 100$^{c}$ | 100$^{c}$ | 68.7$^{a}$ | 75.5$^{b}$ |
| | | Amount of N in above-ground biomass, 5 months after broadcast | | |
| Mucuna (% N) | -- | -- | 2.19$^{a}$ | 2.31$^{a}$ |
| Weed (% N) | 1.16$^{a}$ | 1.19$^{a}$ | 1.48$^{a}$ | 1.19$^{a}$ |
| Weed (kg N ha$^{-1}$) | 34.8$^{b}$ | 47.6$^{c}$ | 28.2$^{a}$ | 28.1$^{a}$ |
| Mucuna (kg N ha$^{-1}$) | -- | -- | 18.8$^{a}$ | 17.6$^{a}$ |
| Total (kg N ha$^{-1}$) | 34.8$^{a}$ | 47.6$^{b}$ | 47.0$^{b}$ (40.0)[2] | 45.7$^{b}$ (38.5) |

1: *Dactyladenia barteri* leaves at 2 ton ha$^{-1}$

2: percentage of total N contributed by Mucuna residues in parentheses

a, b, c: Fischer PLSD significant at 5 % within rows

The above-ground biomass recorded at 5 months after *Mucuna* seeds broadcast followed a trend similar to the data obtained at 3 months after *Mucuna* seed broadcast (Table 9-1). The mulched plots planted with *Mucuna pruriens* var. *utilis* had lesser above-ground biomass than the fallow regrowth. Over the 2 months (3 to 5 months after broadcasting), the biomass of *Mucuna pruriens* var. *utilis* in mulched and un-mulched plots, increased by 46.7 and 49.7 % respectively. In contrast, weed biomass declined by 5.2 and 14.5 % on mulched and un-mulched plots respectively. Biomass on the fallow regrowth plots had increased between 3 and 5 months, but the magnitude of increase on the fallow regrowth plots was influenced by *Dactyladenia* mulch: 7.9 % on mulched, as compared to 38.2 % on un-mulched plots. Similarly, the proportion of weeds on *Mucuna* plots was even lesser after 5 months than 3, on *Dactyladenia* mulched plots: 68.7 % on mulched plots as compared to 78.8 % without mulching.

## Amount of nitrogen in the above-ground biomass (Experiment 2)

The amount of N in the above-ground biomass is presented in Table 9-1. As expected, weeds had lower (< 1.5 %) N content than the *Mucuna* biomass (> 2.1 % N). However, due to higher amount of biomass, weeds immobilized more N (in kg $ha^{-1}$) in the biomass than *Mucuna*. Mulching tended to reduce the amount of N retained in above-ground biomass while the inclusion of *Mucuna* did not affect the immobilization of N in the above-ground biomass. On the *Mucuna* plots, about 40 % of the total N in above-ground biomass was contained in *Mucuna* residues.

## Below-ground biomass production (Experiment 2)

The below-ground biomass in the different treatments at the end of the rainy season is shown in Table 9-2. There were no significant differences between the dry weight of roots in plots under the natural fallow regrowth and *Mucuna pruriens* var. *utilis* cover. On both plots, more than 80 % of the roots were confined to the top 10 cm of the soil (Table 9-2). *Mucuna* roots constituted about 40 % of the total below-ground biomass on *Mucuna* plots.

Table 9-2. Root biomass (Mg $ha^{-1}$) under Mucuna fallow and natural fallow regrowth at the end of the rainy season (December, 1993).

| Soil depth (cm) | Mucuna fallow | | | Fallow regrowth |
|---|---|---|---|---|
| | Nodules | Mucuna | Total | |
| 0 - 10 | 0.01 (36.3)[1] | 0.61 (93.0) | 1.27 (83.6)[2] | 1.29 (80.1) |
| 10 - 20 | - | 0.05 (7.0) | 0.13 (8.55) | 0.19 (11.8) |
| 20 - 30 | - | 0.00 (0.0) | 0.07 (4.61) | 0.08 (4.97) |
| 30 - 40 | | | 0.05 (3.28) | 0.05 (3.11) |
| Total (0 - 40) | | | 1.52 | 1.61 |

[1]: percent "active" nodules in parenthesis

[2]: values in parenthesis represent % of total amount per treatment for that depth.

P = 0.88 (between fallow systems); $P < 0.01$ (between depths).

About 93 % of the *Mucuna* roots were confined to the top 10 cm of soil layer. The pattern of growth of *Mucuna* roots were such that the tap roots did not penetrate the 10-20 cm soil layer. In fact, tap roots were observed to grow vertically to a depth of about 6-8 cm and eventually curve sharply, to continue a horizontal growth (up to 5 m length was observed). *Mucuna* produced about 100 kg $ha^{-1}$ nodules, in the 0-10 cm soil layer only, about 32 % of which turned pinkish-red when sliced open.

## Spatial variability in selected soil chemical properties

There was no spatial variability in the selected soil chemical properties across the experimental field. Therefore data were pooled together according to soil depth and presented in Table 9-3. The soil was very acidic (pH 4.3), with low base cations (Ca, Mg and K) and high exchangeable acidity (Al + H). Total N, organic C and base cations content of the soil decreased, while exchangeable acidity tended to increase with depth (Table 9-3).

Table 9-3. Chemical properties of the soil at the start of the trial.

| Depth (cm) | pH | Tot. N | OC. | OM | Min. N | Bray-1 P | Ca | Mg | K | Exch. acidity | ECEC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1:1; $H_2O$) | (---------- % ---------) | | | (--- $\mu g\ g^{-1}$ ---) | | (--------- Meq 100 $g^{-1}$ ---------) | | | | |
| 0 - 10 | $4.33^a$ | $0.098^c$ | $1.29^c$ | $2.23^c$ | $3.18^c$ | $58.1^c$ | $0.02^b$ | $0.014^b$ | $0.04^c$ | $0.51^a$ | 0.58 |
| 10 - 20 | $4.36^a$ | $0.083^b$ | $1.12^b$ | $1.92^b$ | $3.12^b$ | $49.0^b$ | $0.01^a$ | $0.002^a$ | $0.02^b$ | $0.63^a$ | 0.66 |
| 20 - 30 | $4.32^a$ | $0.070^a$ | $0.86^a$ | $1.48^a$ | $4.19^a$ | $37.2^a$ | $0.01^a$ | $0.002^a$ | $0.02^a$ | $0.62^a$ | 0.65 |
| CV (%) | 2.3 | 6.30 | 19.0 | 14.1 | 17.7 | 8.8 | 5.10 | 43.7 | 17.8 | 19.1 | _ |

a, b, c: Figures differ significantly at 5 % (Fisher LSD)

## Soil mineral N content

### Experiment 1

After two months of cover crops growth, soil under *Mucuna* contained more total mineral N ( > 80 % as $NH_4^+$-N), while the fallow regrowth had lesser total mineral N concentration than the initial soil (Table 9-4). Soil under *Pueraria* or fallow regrowth had lower $NO_3^-$-N content than either *Mucuna* or the initial soil (Table 9-4).

### Experiment 2

No significant differences in soil mineral N were observed between mulched and un-mulched plots, although the latter appeared to contain slightly higher $NH_4^+$-N and lower $NO_3^-$-N. At 3 months after planting *Mucuna*, there were no significant ($P \leq 0.05$) differences between treatments. However, most (> 75 %) of the mineral N in the mulched *Mucuna* plots were in the form of $NH_4^+$-N (Table 9-4).

### Experiment 3

At the time of planting maize (April 1993), the *Mucuna* plots contained more mineral N than the fallow regrowth plots (Table 9-5). Much of the differences were due to differences in the $NO_3^-$-N content. More than 72 % of soil mineral N in *Mucuna* plots was in the $NO_3^-$-N form, as compared to 65 % in the fallow regrowth plots. At 8 weeks after planting maize, there was less mineral N in the soil in all the plots, with $NH_4^+$-N as the dominant form of mineral N (Table 9-5). However, there were no significant ($P \leq 0.05$) differences between treatments.

Table 9-4. Soil mineral N and base cations content (at 0-10 cm depth) during the experiment.

| Treatment | Min. N | $N\text{-}NH_4^+$ | $N\text{-}NO_3^-$ | Ca | Mg | K | Total cations |
|---|---|---|---|---|---|---|---|
| | (------- | $\mu g\ g^{-1}$ | ---------) | (---------- | meq $100\ g^{-1}$ | | ----------) |
| | | | | October 1992 | | | |
| | 3.18 | 1.67 | 1.52 | 0.02 | 0.01 | 0.04 | 0.07 |
| | | | | December 1992 | | | |
| Mucuna | 4.22[b] | 3.43[a] | 0.79[b] | 0.08[a] | 0.07[a] | 0.03[a] | 0.18[a] |
| Pueraria | 3.19[a] | 2.83[a] | 0.36[a] | 0.07[a] | 0.11[a] | 0.05[a] | 0.22[a] |
| Fallow regrowth | 2.15[a] | 1.76[a] | 0.39[a] | 0.07[a] | 0.10[a] | 0.03[a] | 0.19[a] |
| | | | | August 1993 | | | |
| Mulched | 4.64[a] | 3.73[a] | 0.91[a] | 0.17[a] | 0.12[a] | 0.04[a] | 0.33[a] |
| No mulch | 4.66[a] | 3.94[a] | 0.72[a] | 0.10[b] | 0.08[b] | 0.02[b] | 0.20[b] |
| | | | | October 1993 | | | |
| Fallow regrowth, no mulch | | 3.07[a] | 2.52[a] | 0.54[a] | | | |
| Fallow regrowth, mulched | | 2.93[a] | 2.43[a] | 0.50[a] | | | |
| Mucuna, no mulch | | 3.12[a] | 2.55[a] | 0.58[a] | | | |
| Mucuna, mulched | | 3.64[a] | 3.20[a] | 0.44[a] | | | |

a, b: Fisher LSD significant at 5% within same column and date.

## Base cations (Ca, Mg and K) content of soil (Experiments 1, 2 and 3)

*Pueraria* and *Mucuna* (experiment 1) had no significant ($P \leq 0.05$) effect on soil exchangeable Ca, Mg and K content (Table 9-4). Two months after mulching with *Dactyladenia barteri* leaves (experiment 2), the mulched plots contained significantly ($P = 0.05$) higher soil exchangeable Ca and Mg (Table 9-4). At the beginning of experiment 3, there were no significant ($P \geq 0.05$) differences in soil base cation content (Table 9-5). However, the *Dactyladenia* mulch plots appeared to contain more exchangeable Ca and Mg than the un-mulched fallow regrowth plots.

# Decomposition of residues

## *Pueraria phaseoloides* and *Mucuna pruriens* var. *utilis*

Residues of *Pueraria phaseoloides* and *Mucuna pruriens* var. *utilis* lost more than 20 % of their original dry weight within the first 35 days (Figure 9-3). Thereafter, decomposition was so slow that undecomposed biomass remaining at 107 days after the commencement of the experiment amounted to 30 % for *Pueraria* and more than 40 % for *Mucuna*. According to Wieder and Lang (1982), decomposition of some plant residues can be explained by the exponential model $Y_t = Y_o e^{-kt}$ or its linearized form. The exponential equation was linearized by log transformation ($\ln Y_t = \ln Y_o - kt$) and fit to data. Using the k values obtained, it was calculated that half of the residues were lost within 70 days ($r^2 = 0.91$) in the case of *Pueraria* and 93 days ($r^2 = 0.88$) in the case of *Mucuna* (Table 9-4).

Table 9-5. Residual effects of *Mucuna* cover crop and *Dactyladenia* mulch on soil mineral N and base cations.

| Treatment | $NH_4^+$-N | $NO_3^-$-N | Min. N | Ca | Mg | K | Total cations |
|---|---|---|---|---|---|---|---|
| | (--------- | $\mu g\ g^{-1}$ | ---------) | (---------- | meq 100 $g^{-1}$ | | ---------) |
| | | | At planting maize (April 1994) | | | | |
| Fallow regrowth no mulch | 2.54[a] | 4.40[a] | 6.9[a] | 0.22[a] | 0.15[a] | 0.16[b] | 0.53[a] |
| Fallow regrowth, *mulched*[1] | 3.03[a] | 5.66[ab] | 8.7[ab] | 0.33[a] | 0.24[a] | 0.16[b] | 0.73[a] |
| *Mucuna*, no mulch | 2.62[a] | 7.68[b] | 10.3[b] | 0.23[a] | 0.18[a] | 0.16[b] | 0.53[a] |
| *Mucuna*, mulched | 2.41[a] | 7.27[b] | 9.7[ab] | 0.27[a] | 0.22[a] | 0.15[b] | 0.64[a] |
| | | | Two months after planting maize (June 1994) | | | | |
| Fallow regrowth, no mulch | 1.07[a] | 2.82[a] | 3.89[a] | | | | |
| Fallow regrowth, mulched | 0.89[a] | 1.86[a] | 2.75[a] | | | | |
| *Mucuna*, no mulch | 1.36[a] | 2.48[a] | 3.84[a] | | | | |
| *Mucuna*, mulched | 1.84[a] | 2.49[a] | 4.32[a] | | | | |

[1]: 2.0 t $ha^{-1}$ of dry *Dactyladenia barteri* leaves applied in the previous season.
[a,b]: Fisher LSD significant at 5 %

Also displayed in Figure 9-3 is the biweekly rainfall over the entire period of the *Pueraria* and *Mucuna* decomposition study. The average biweekly precipitation increased from 14.6 mm in the first 60 days after placement (DAP) to 103.0 mm there-after. The period after 60 DAP marked the beginning of the wet season. During the dry season, only about 35 % of the initial residues of either species were lost, with 80 - 88 % of the losses occurring within the first 35 days. Except for a few termites, other insects found in the litterbags were dead ones. With the commencement of the rainy season, litterbag content were observed to be continuously moist and contained many insects and a few earthworms. At the same time, decomposition rates of both species increased sharply to the point that > 20 % of the original residues were lost within 20 days.

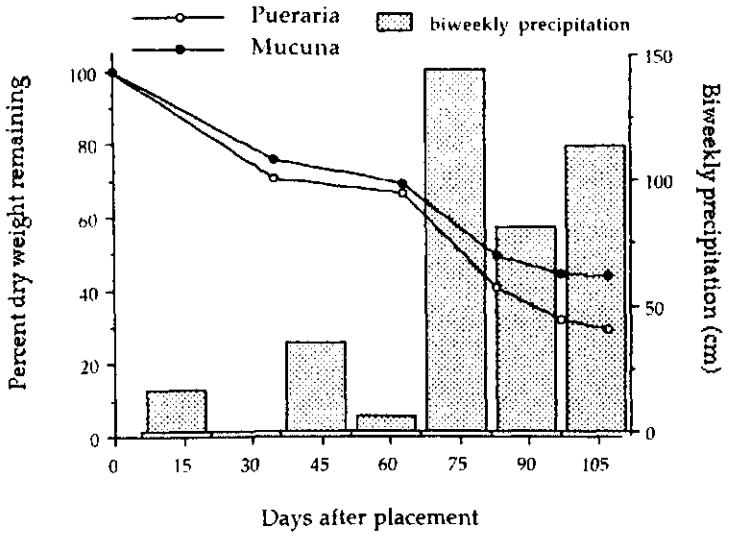


Figure 9-3. Dry weight loss of *Mucuna* and *Pueraria* through the dry season and at the beginning of the rainy season.

## Dactyladenia barteri mulch

*Dactyladenia barteri* leaves decomposed slowly (Figure 9-4). There were no apparent differences in the rates of dry weight loss between residues placed on *Mucuna* plots and those placed on the fallow regrowth plots. Decomposition was most rapid in the first 28 days after placement when 25 % of the original material disappeared. Thereafter, the rate of decomposition slowed down considerably to the point that 66 % of the initial residue remained at 56 weeks after placement. Beyond 56 days after placement, dry weight of the residues virtually remained static.

The log-transformed single exponential equation was fit to *Dactyladenia* decomposition data and the average k value obtained was $2.35 \times 10^{-1}$ $day^{-1}$. This means that about 165 days would be required for half of the *Dactyladenia* mulch to decompose.

## Performance of maize (Experiment 3)

Due to the low level soil fertility in the plots, maize planted in experiment 2 showed severe nutrient deficiencies leading to total crop failure. In experiment 3, however, there was a general improvement in the growth of maize (Figure 9-5) on all plots, including the un-mulched fallow regrowth. Mulching with *Dactyladenia barteri* in the previous season improved maize growth, but the effect was more noticeable in maize grown on the fallow regrowth plots. Growth of maize was negatively correlated ($r = -0.60$) to biomass of weeds left at the end of the previous season.

Similarly, both *Mucuna* and *Dactyladenia* mulch enhanced earleaf N content as compared to the fallow regrowth (Table 9-6). On the other hand, mulching with *Dactyladenia* leaves seemed to suppress earleaf P, while it tended to enhance earleaf Ca and Mg, the effect of which appeared to be greater on the fallow regrowth plots.

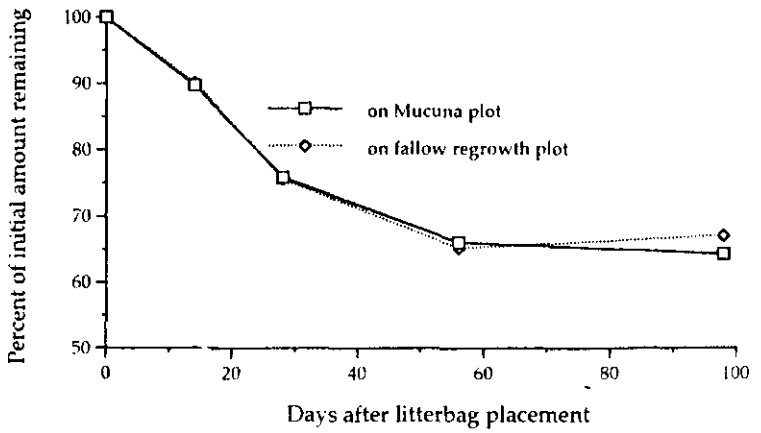


Figure 9-4. Dry weight loss of *Dactyladenia* mulch placed on *Mucuna* or fallow regrowth plots.

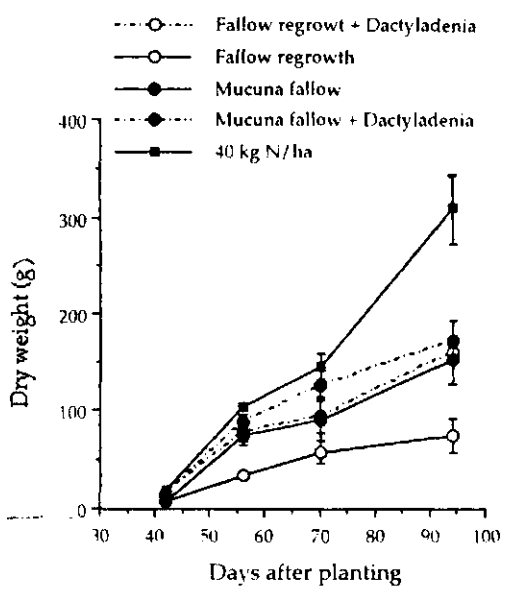


Figure 9-5. Maize growth under the different fallow management strategies.

The residual effect of *Mucuna* and *Dactyladenia* alone increased grain yield by 75.3 and 85.1 %, respectively, as compared to the fallow regrowth (Table 9-7). On the other hand, a combination of *Mucuna* cover crop with *Dactyladenia* mulch doubled the grain yield. However, the residual effects of *Mucuna* or *Dactyladenia* or even their combination was significantly ($P < 0.01$) less than urea at 40 kg N $ha^{-1}$. Grain yield was significantly (at 5 %) correlated to soil extractable $NO_3^-$-N ($r = 0.60$) and Mg ($r = 0.58$) content at the time of planting as well as earleaf N ($r = 0.69$) and Mg ($r = 0.61$).

Maize grown after *Mucuna* contained more N in the biomass than that grown after the natural fallow regrowth (Table 9-6). As compared to the un-mulched fallow regrowth plots, a five-month *Mucuna* fallow enhanced N uptake by 60.1 %. On the other hand, the residual effect of *Dactyladenia* mulch alone enhanced N uptake by 35.5 % ($P < 0.01$). A combination of *Mucuna* and *Dactyladenia* mulch, however, enhanced N uptake by 49.8 %.

# Discussion

The fact that surface broadcasted *Mucuna* seeds germinated well means that *Mucuna* can be established easily, during the rainy season, in the humid regions. The low biomass production of both *Pueraria* and *Mucuna* may be attributed to high weed infestation coupled with receding precipitation. Differences in biomass production between *Mucuna* and *Pueraria* may be due

Table 9-6. Residual effect of a 5-month *Mucuna* cover crop and *Dactyladenia* mulch on nutrient content of maize.

| | N | P | Ca | Mg | K |
|---|---|---|---|---|---|
| | | | Earleaf nutrient (%) | | |
| Fallow regrowth, no mulch | 1.68±0.1$^{a}$ | 0.17±0.0$^{a}$ | 0.17±0.0$^{a}$ | 0.22±0.0$^{a}$ | 2.48±0.1$^{b}$ |
| Fallow regrowth, mulched[1] | 1.70±0.1$^{a}$ | 0.17±0.0$^{a}$ | 0.26±0.1$^{ab}$ | 0.28±0.0$^{a}$ | 2.13±0.1$^{a}$ |
| *Mucuna*, no mulch | 1.92±0.1$^{ab}$ | 0.27±0.0$^{b}$ | 0.16±0.0$^{a}$ | 0.24±0.0$^{a}$ | 2.12±0.2$^{a}$ |
| *Mucuna*, mulched | 1.76±0.1$^{a}$ | 0.18±0.0$^{a}$ | 0.34±0.1$^{b}$ | 0.29±0.0$^{a}$ | 2.19±0.2$^{a}$ |
| Urea (40 kg N ha$^{-1}$) | 2.22±0.1$^{b}$ | 0.20±0.0$^{ab}$ | 0.29±0.0$^{ab}$ | 0.30±0.0$^{a}$ | 2.50±0.2$^{b}$ |
| | | | Nutrient content of maize (kg ha$^{-1}$) | | |
| Fallow regrowth, no mulch | 20.3±0.9$^{a}$ | 2.09±0.1$^{a}$ | 2.12±0.4$^{a}$ | 2.75±0.7$^{a}$ | 29.7±1.8$^{a}$ |
| Fallow regrowth, mulched[1] | 27.5±1.7$^{a}$ | 2.80±0.2$^{a}$ | 4.32±1.4$^{b}$ | 4.54±0.9$^{a}$ | 34.6±2.6$^{a}$ |
| *Mucuna*, no mulch | 32.5±6.9$^{a}$ | 4.49±0.7$^{a}$ | 2.72±0.7$^{a}$ | 4.24±1.2$^{a}$ | 36.3±8.5$^{a}$ |
| *Mucuna*, mulched | 30.4±4.7$^{a}$ | 3.07±0.2$^{a}$ | 5.58±0.7$^{b}$ | 5.13±1.2$^{a}$ | 38.0±6.6$^{a}$ |
| Urea (40 kg N ha$^{-1}$) | 71.6±6.0$^{b}$ | 6.67±1.0$^{b}$ | 9.82±1.5$^{c}$ | 9.92±1.6$^{b}$ | 81.5±14.0$^{b}$ |

1: 2.0 t ha of *Dactyladenia barteri* leaves applied in the previous season.

a, b: different indices indicate significative diffenrences (Fisher LSD at 5 %) between means (n = 3)

to the fact that *Mucuna* establishes faster than *Pueraria* (Hairiah and Van Noordwijk, 1986). The ability of *Mucuna* to establish itself among weeds concur with earlier reports that *Mucuna* is capable of competing with short annual grasses (Akobundu and Poku, 1984; Van Noordwijk and Guritno, 1992).

The effect of *Mucuna* on weeds was most likely due to shading of the weeds (Akobundu and Poku, 1984). On the other hand, the effect of *Dactyladenia* mulch on weeds was obvious, since mulching is known to provide an effective ground cover, that prevent the germination and growth of weeds (Russell, 1977). More than half of the *Dactyladenia* mulch was present after 5 months of application, indicating that it provided a long-lasting effect.

The more efficient weed suppression due to a combination of *Mucuna* cover crop and *Dactyladenia* mulch, however, was obviously due to the fact that both *Mucuna* and *Dactyladenia* reduced weed biomass, and at the same time, *Dactyladenia* mulch increased the biomass of *Mucuna*. The observation that total biomass (on un-mulched *Mucuna* and fallow regrowth plots) was comparable implies that, fallowing with *Mucuna* means the substitution of low N containing residues (weeds) with plant material more susceptible to provide N for crop uptake. This agrees with the observations of Starver (1989) who reported that a combination of *Inga edulis* and *Desmodium ovalifolium* cover crop enhanced the fertility of a degraded Ultisol in Peru.

Table 9-7. Residual effects of a *Mucuna* cover crop and a *Dactyladenia* mulch on the yield of maize (cv TZSR-Y).

| Treatment | Grain | Stover | Total | Harvest Index |
|---|---|---|---|---|
| | (---------- kg ha$^{-1}$ ----------) | | | (%) |
| Fallow regrowth, no mulch | 182$^{a}$ | 1027$^{a}$ | 1210$^{a}$ | 15.0$^{a}$ |
| Fallow regrowth, mulched | 337$^{ab}$ | 1286$^{a}$ | 1623$^{a}$ | 19.9$^{a}$ |
| *Mucuna*, no mulch | 319$^{ab}$ | 1356$^{a}$ | 1675$^{a}$ | 20.5$^{ab}$ |
| *Mucuna*, mulched | 379$^{b}$ | 1337$^{a}$ | 1715$^{a}$ | 21.7$^{ab}$ |
| Urea (40 kg N ha$^{-1}$) | 711$^{c}$ | 1934$^{b}$ | 2644$^{b}$ | 27.1$^{b}$ |

a, b, c: different indices indicate significative differences (Fisher LSD at 95 %) between means (n = 3) in column

The amount (and distribution) of root nodules of *Mucuna pruriens* var. *utilis* confirms the results of Hairiah and Van Noordwijk (1986), which showed that *Mucuna* formed root nodules in the 0-10 cm soil layer. That no roots of *Mucuna* were observed below 20 cm is, however, in contrast to the report of Hairiah and Van Noordwijk (1986) who observed that *Mucuna* roots penetrated to 30 cm depth. Our observation was probably because the sub-soil, in our field, contained lower Ca, Mg and organic C than the 0-10 cm soil layer (Hairiah *et al.*, 1991). From the rooting pattern observed in this trial, it may be concluded that *Mucuna* may not play any significant role in recycling leached nutrients at the experimental site. However, *Mucuna* developed a thick network of roots, which may influence soil nutrient dynamics by immobilizing, in the biomass, nutrients that would otherwise be leached.

In spite of *Mucuna*'s low biomass (373 kg ha$^{-1}$) production (experiment 1), soil under it contained about twice the $NH_4^+$-N content of soil under the fallow regrowth suggesting that *Mucuna* might have nodulated and actively fixed N to enhance the $NH_4^+$-N status of soil. Apart from the release of $NH_4^+$ into the soil during $N_2$-fixation and the decomposition of dead nodules, the presence of active $N_2$-fixing nodules has been reported to enhance the mineralization of soil organic N (Giller and Wilson, 1991). The lesser $NO_3^-$-N content of soils under *Pueraria* or fallow regrowth may be due to either uptake of $NO_3^-$-N by vegetation (predominantly grasses),

leaching, or both. On the *Mucuna* plots, weeds (mostly grasses) growing may have gained from the elevated soil $NH_4^+$-N level since legumes can improve N supply to grasses growing along with them (Mulongoy and Akobundu, 1992).

The slightly higher $NH_4^+$-N on the mulched *Mucuna* plots (experiment 2) could likely be due to higher $N_2$-fixation activity, as a result of increased *Mucuna* biomass (Giller and Wilson, 1991), while the decline in the mineral N status of soil was probably due to losses of especially $NO_3^-$-N from the soil. Apart from crop removal, there is a high rate of leaching of $NO_3^-$-N in the humid tropics (Van der Heide and Hairiah, 1989). *Dactyladenia* mulch possess the potential to enhance soil exchangeable Ca and Mg content, while its lack of effect on soil mineral N was apparently due low N (1.68 %) content (Tian *et al.*, 1992).

The enhanced performance of maize due to *Mucuna* cover crop or *Dactyladenia* mulch, or even their combination suggests that the system could be beneficial. The effect of *Mucuna pruriens* var. *utilis* on maize agrees with the report of Milton (1989). The significant correlation between soil extractable $NO_3^-$-N and grain yield confirms the importance of N management, and the need to include $N_2$-fixing species in fallows, on the highly leached Ultisol in the humid tropics.

The slow of decomposition of *Pueraria phaseoloides* and *Mucuna pruriens* var. *utilis* residues over the dry season conforms to the fact that decomposition is slow during the dry season and increases at the onset of the rains (Swift, 1986). During the rainy season, rainfall modifies the micro-climate around the decomposing residues in favor of decomposer organisms (Richards, 1987), thereby resulting in a higher decomposition rate. The abundance of soil fauna in litterbags during the rainy season could suggest that they played a role in the decomposition processes (Henrot and Brussaard, 1996). Slow decomposition of *Mucuna* residues during the dry season implies that, *Mucuna* plants constituted an organic input for the next cropping season. On the other hand, the slow decomposition of *Dactyladenia barteri* (during the rainy season) is well known, and attributable to high lignin (47.2 %) and low N (1.68 %) content (Van der Kruijs et al., 1989).

Considering the rapid establishment, ability to control weeds and effect on soil N, the annual *Mucuna pruriens* var. *utilis* may be more suitable as a relay cover crop, in the humid tropics, than the perennial species (such as *Pueraria phaseoloides*) especially in mulched systems. Including fast growing herbaceous legumes into *Dactyladenia* mulched systems may be a useful soil management practice for the highly degraded Ultisols. At the Onne site, e.g., *Dactyladenia* performs very well as a hedgerow species in alley cropping but an annual rotation of fallow with cropping is necessary for sustained production. Broadcasting *Mucuna* in the alleys towards the end of the rainy season or planting *Mucuna* during the fallow phase, therefore, would most likely improve crop yield. However, considering the acidity (pH 4.3) of the soils at the site, only acid tolerant herbaceous legume cultivars may show a similar effect.

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# 10. RESIDUAL EFFECTS OF A PREVIOUS *MUCUNA PRURIENS* CROP ON THE PERFORMANCE OF MAIZE

E. Ile, M. Hamadina, J. Henrot and N.M. Tariah

## Abstract

The need to grow more food in the humid tropics to be able feed the ever growing population has resulted in a drastic shortening of the fallow period necessary to maintain soil fertility. This urges the need to develop improved fallow systems, e.g. by using herbaceous legumes as relay cover crops. Herbaceous legumes improve the yield of food crop through weed suppression, $N_2$-fixation, and production of fast decomposing residues that release nutrients to the subsequent crop. In this chapter the results of a field trial are presented in which the residual effects of the herbaceous legume *Mucuna pruriens* used as a fallow crop on the performance of a subsequent maize crop are studied.
Maize grain yields obtained from *Mucuna* plots were about twice as high as those on the control plots, they were about 320 and 180 kg $ha^{-1}$, respectively. It should be noted that much higher yields could be obtained after the application of 40 kg N $ha^{-1}$ as urea. Grain yield then amounted to about 700 kg $ha^{-1}$. The low maize yields obtained were probably due to the low inherent soil fertility.

**Keywords:** humid tropics, *Mucuna pruriens*, *Zea mays*, fallow, soil fertility, cover crops

## Introduction

Crop performance depends largely on the fertility of the soil (Prinz, 1986). In the humid tropical regions, soil fertility is usually maintained by abandoning a briefly cultivated land for a longer period of rest in a system of production otherwise called bush fallow (Reijntjes *et al.*, 1992). The need to grow more food to feed the growing population, however, has resulted in a drastic shortening of the fallow period necessary to maintain soil fertility (Kang and Wilson, 1987). In addition, the soils of the humid tropics are characterised by low inherent fertility (Kang *et al.*, 1984). Although soil fertility can be improved through the usage of chemical fertilizers, peasant farmers in the tropics cannot afford the high cost of such fertilizers (Kang *et al.*, 1984). This led to the development of improved fallow systems such as the use of herbaceous legumes as relay cover crops (Prinz, 1986). Herbaceous legumes improve the yield of food crop through weed suppression, $N_2$-fixation, and production of fast decomposing residues that release nutrients to crops among others (Prinz, 1986). As much as 30-60 kg N $ha^{-1}$ $yr^{-1}$ is reported to be added to the soil by legumes (Reijntjes *et al.*, 1992).

In a relay system that involve the planting of herbaceous legumes, the legumes are planted about two months after maize and left to take over the land after harvest. At the beginning of the next rains, the legumes are slashed and food crop is again planted. For instance *Mucuna pruriens* var. *utilis* is used as a relay cover crop (after maize) by many farmers in humid tropical regions in Northern Honduras (Milton, 1989). In some parts of South-east Nigeria, some farmers grow *Mucuna pruriens* var. *utilis* to smother weeds and minimise soil erosion as well as prevent waterlogging (Anonymous, 1993). Due to the fact that *Mucuna pruriens* var. *utilis* is an annual crop, it usually dies during the dry season which minimizes the cost of land preparation (Milton,

1989). In this chapter the residual effects of a previous *Mucuna pruriens* var. *utilis* crop on the performance of maize are evaluated.

# Materials and methods

## The experimental site

This trial was conducted at the High Rainfall station of the International Institute of Tropical Agriculture (IITA) at Onne, 4° 51'N; 7° 03'E, in the South-Eastern part of Nigeria. The rainfall pattern of the area is monomodal lasting from March to December. The station experiences a mean annual rainfall of 2400 mm and relative humidity ranging from 78 % to 89 %, while annual minimum and maximum temperatures are 25 °C and 27 °C, respectively. The soils of the area is a typical Ultisol classified as loamy siliceous isohyperthermic Typic Paleudult (Hullugale *et al.*, 1990), derived from coastal sediments and high in available phosphorus (IITA, 1993).

The experimental field has been cropped by IITA since 1978 (about 16 years ago), without fertilization except on the 2nd and 6th year of cropping when 200 kg $ha^{-1}$ NPK were applied. Hydrated lime was also applied at 750 kg $ha^{-1}$ in the sixth year of cropping. No other chemical input was applied. The field was continuously cropped except for a short fallow of: *Mucuna pruriens* var. *utilis*, for 18 months, 7 years ago, *Pueraria phaseoloides*, for a year, 4 years ago and natural fallow (for one year) 2 years ago.

Prior to the establishment of plots for this experiment, the field was mowed and later slashed in October 1992. Then plots (8 x 36 m) were established for a trial whose treatments included:- *Pueraria phaseoloides*, *Mucuna pruriens* var. *utilis* and a fallow re-growth, in three block replicates. The cover crops were planted at the rate of 78 and 12 kg seeds $ha^{-1}$ for *Mucuna* and *Pueraria* respectively. That trial continued into the subsequent rainy season, May, 1993: the plots were planted with maize at a density of 20,000 plants $ha^{-1}$. Due to the low soil fertility level of the plots, maize performed poorly and barely tasselled but did not yield any grain. On August 2nd, 1993, *Mucuna* was planted, at 78 kg seeds $ha^{-1}$, on the respective plots and left to cover the land after maize.

## Experimental methods

At the beginning of the rainy season (April, 1994) plots for this trial were established. Three plots (8 x 9 m each) were laid in a Randomized Complete Block design with three replications. Treatments included plots that were planted with *Mucuna pruriens* var. *utilis* in the previous year, left to re-grow as grass fallow and an 18-month grass fallow + Urea (40 kg N $ha^{-1}$). Prior to planting maize, plots were manually slashed and later weeded. Then maize (TZSR-Y), treated with Apron-Plus, were planted on April 19th, 1994. Planting was done at a spacing of 100 x 50 cm (2 later thinned to 1 plant $hill^{-1}$) giving a density of 20,000 plants $ha^{-1}$. Fertilizer were applied in two split doses: at planting and 4 weeks thereafter. At planting, 20 kg N $ha^{-1}$ were broadcasted and later incorporated into the soil, while the rest were banded at a distance of about 15 cm from each maize row, at 4 weeks after planting.

## Sampling methods

Soil sampling: at the beginning of this trial, surface soil (0-10 cm) was sampled from each plot. Each sample was a composite of 15 auger samples kneaded in a polythene bag after sampling. Samples were analyzed for pH, total and mineral N, organic C and matter, exchangeable Ca, Mg and K as well as available P. At the end of the experiment, soil was again sampled to the

same depth and analysed for total N and available P. Mineral N and exchangeable Ca, Mg and K, were extracted from fresh soil samples while other parameters were extracted on air-dried samples sieved to 2 or 0.5 mm.

Maize plants: starting from 4 weeks after planting (WAP), the height and leaf area of maize plants were estimated on three pre-labelled plants, at fortnightly interval. The plant height, length (L) and width (W) of each leaf were measured using a flexible measuring tape. From such measurements, leaf area (LA) was then calculated based on the equation: LA = 0.75 (L x W) as suggested by Wahua (1985). On each date height and LA measurements were done, five plants were randomly sampled for dry matter estimation. Sampling was done by cutting the plants at ground level using a sharp knife. Plant samples were separated into leaf blades (leaves) and stalks, put in labelled paper bags and oven-dried at 60 °C.

At the silking stage, 15 earleaves were randomly sampled from different plants. At 13 WAP, maize were harvested for grain and stover yields. Cobs from each plots were weighed and the fresh weight (a) noted. Samples of about 15 cobs were taken then its fresh weight (b) noted. These samples were dried in a room equiped with an automatic electric heater which maintained a constant temperature of about about 50 °C. After drying to a moisture content of about 10 % cobs were shelled to obtain grains. The weight of grains (c) were then noted. The yield of grains $ha^{-1}$ was obtained from the following relationship: {(a÷b) x c} x (10,000÷72), where 72 = plot size in $m^2$ and 1 ha = 10,000 $m^2$.

## Analytical methods

Soil analyses: (Tables 10-1 and 10-2) soil pH was determined on a 1: 1 soil: $H_2O$ solution with a glass electrode pH Meter; organic carbon was determined using the procedures outlined by Tel and Rao (1982). Organic matter content was obtained by multiplying organic carbon values by a factor of 1.724 (Rao and Tel, 1982).

Table 10-1. Chemical soil characteristics of the experimental field.

| Parameter | Value |
|---|---|
| pH (1:1, $H_2O$) | 4.3 |
| Total Nitrogen (%) | 0.098 |
| Organic Carbon (%) | 1.29 |
| Organic Matter (%) | 2.23 |
| Bray-1 P (µg $g^{-1}$) | 58.9 |
| Exchangeable acidity (meq 100 $g^{-1}$) | 0.49 |
| ECEC (meq 100 $g^{-1}$) | 0.58 |
| Base saturation (%) | 15.5 |

Total N was determined with a Technicon Auto Analyzer (Technicon AAII), after digesting samples with a mixture of concentrated orthophosphoric and sulfuric acid, in a Tecator Digestor. For soil mineral N, fresh soil samples were mixed with 1N KCl at 20: 50 soil:extractant ratio and shaken in a tightly covered plastic cup. Extracts were then filtered through a 0.2 µm pore-size membrane filter and NH-N and NO-N were determined using a Technicon autoanalyser AAII. Available P in soil was determined, using the Bray-1 method, with a Technicon AAII. Complete details of all the procedures have been outlined by Tel and Rao (1982).

Table 10-2. Chemical properties of the soil at the time of planting of maize (April 1992).

| | $NH_4^+$-N | $NO_3^-$-N | Min N | Ca | Mg | K | Total cations |
|---|---|---|---|---|---|---|---|
| | (---------- | $\mu g\ g^{-1}$ | ----------) | (---------- | meq $100^{-1}$ g | ----------) | |
| Fallow regrowth (Control) | 2.54 | 3.57 | 6.03 | 0.22 | 0.24 | 0.12 | 0.57 |
| *Mucuna* fallow | 2.64 | 7.68 | 10.3 | 0.20 | 0.21 | 0.11 | 0.52 |
| Urea (40 kg N $ha^{-1}$) | 2.46 | 3.49 | 4.73 | 0.21 | 0.17 | 0.12 | 0.50 |
| CV (%) | 38.9 | 27.6 | 26.2 | 35.9 | 41.3 | 21.3 | 46.0 |
| $LSD_{(0.05)}$ | 1.2 | 3.8 | 4.9 | 0.2 | 0.2 | 0.2 | 0.3 |

The exchangeable Ca, Mg and K were extracted with 1N $NH_4OAc$ + 0.01*M* EDTA, at the same ratio as mineral N using the same procedure but, separate apparatus to avoid contamination. The concentrations of Ca Mg and K in the extracts were measured according to the procedures contained in the report of Tel and Rao (1982).

The exchangeable acidity (Al + H) and the effective cation exchange capacity (ECEC) were determined using the method described by Tel and Rao (1982).

Plant analyses: total N content was determined after samples with a mixture of concentrated $H_2SO_4$ and $H_2O_2$ (30.0 %) in the presence of one Kjeldahl catalyst tablet (1 g $Na_2SO_4$ + 0.05 g Selenium) in a Tecator Digestor System (Tel and Rao, 1982).

The content of plant samples were determined after digesting samples first with a mixture or perchloric acid ($HClO_4$) then with 6N HCl (Tel and Rao, 1982).

# Results and discussion

## Growth of maize

The height of maize at various dates after planting are displayed in Figure 10-1. At 4 weeks after planting (WAP), there were no significant difference between treatments, except for that between the Control and Urea. On Urea or *Mucuna* plots, maize height increased sharply until 8 wks after planting when maize started tasselling. On the other hand, the rate of growth on the Control (especially beyond 6 WAP) was relatively slow, which delayed tasselling by about one week.

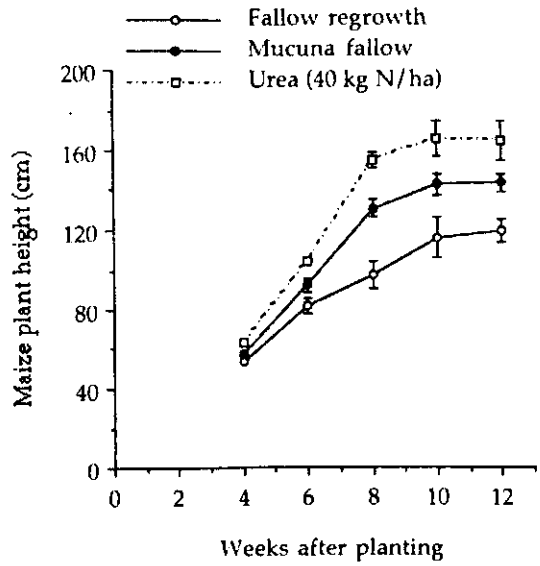


Figure 10-1. The effect of soil management strategy on the growth of maize (TZSR-Y).

At 8 WAP, maize on Urea as well as *Mucuna* plots attained 95.7 and 91.1 % of their maximum heights recorded at harvest, respectively, as compared to 82.8 % on the Control plots. The effect of a previous *Mucuna* crop on the growth of maize may, therefore, be speculated to be that of N supply from decomposing *Mucuna* residue. A decomposition study conducted on the experimental field showed that about 50 % of *Mucuna* residues remain undecomposed by the second week of April of the next season (Hamadina *et al.*, 1996).

## Leaf area of maize

Leaf development was faster in maize planted on Urea, as compared to *Mucuna* or Control plots (Figure 10-2). Initially (at 4 weeks after planting), only the effects of Urea and Control treatments differed significantly. By the 6th WAP, however, the area of photosynthetic leaves had increased remarkably and there were significant differences between treatments in the order: Urea > *Mucuna* > Control. On the Control plot, leaf area (LA) development was so slow that at 8 WAP, the values of LA on Urea or *Mucuna* plot was twice that of Control.

This observation was probably because leaves of maize on the Control plots were shorter and thinner, as compared to *Mucuna* or urea treatment. While maize on *Mucuna* or Urea plot did not show any sign of N deficiency in the first 6 WAP, they were obviously N deficient on the Control plots with many necrotic leaves. Throughout the sampling period, there were more green leaves on maize fertilized with 40 kg N $ha^{-1}$ or planted after *Mucuna* as compared to those on the Control plots.

There was a positive correlation ($r = 0.93$) between LA and height of maize. As shown in Figure 10-3, the relationship between LA and height was best defined by the equation: $y = 4.40x^{0.425}$ ($r^2 = 0.874$). This observation can be explained from the fact that as maize plants grow taller, they tend to produce more leaves (Kling, 1991), therefore, maize plants more likely to have greater leaf surface area with increased plant height.

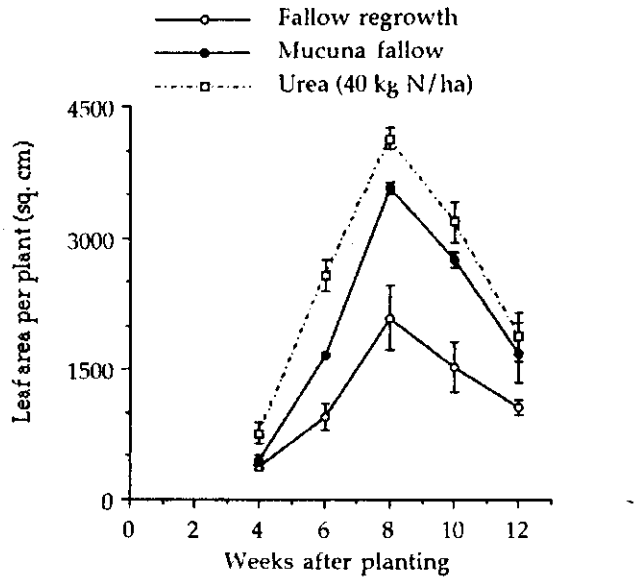


Figure 10-2. The effect of soil management strategy on leaf area of maize.

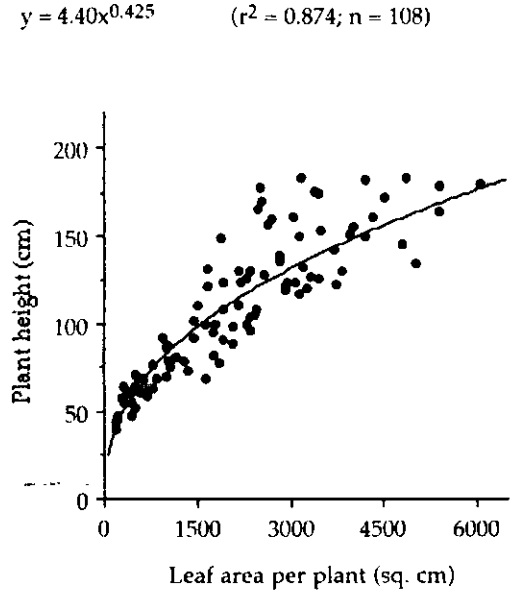


Figure 10-3. The relationship between leaf area and height of maize plants during the initial 8 weeks of growth.

## Dry matter production

The dry matter yield of maize at different times during the growing period is shown in Figure 10-4. During the initial 6 weeks of maize growth, total dry matter production was initially slow (Figure 10-4), with leaves constituting most of the dry matter (Figure 10-4). However, the effect of 40 kg N $ha^{-1}$, applied as urea, was significantly higher than either *Mucuna* or Control. Thereafter, the dry matter of maize increased significantly (at 5 % level of significance) in the order: Urea > *Mucuna* > Control. Most of the increase in total dry matter was due to increase in the weight of stalk (Figure 10-4). There was a positive correlation between the stalk and leaf dry matter (r = 0.97) as well as stalk dry weight and total dry matter (r = 0.99). The relationships between leaves and stalk, and the total plant dry matter are displayed in Figure 10-5.

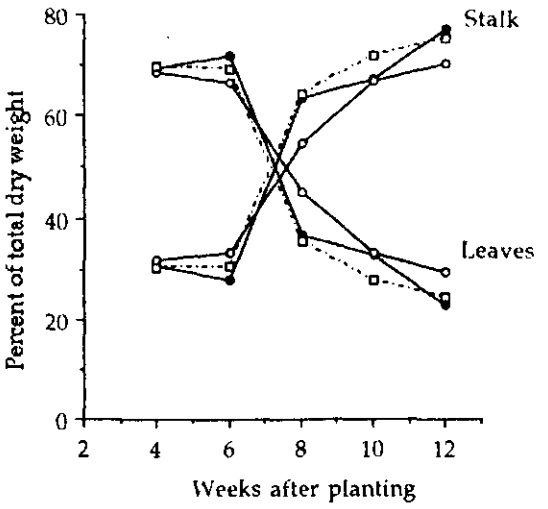


Figure 10-4. The distribution of dry matter between leaves and stalks in maize grown under the different management practices.

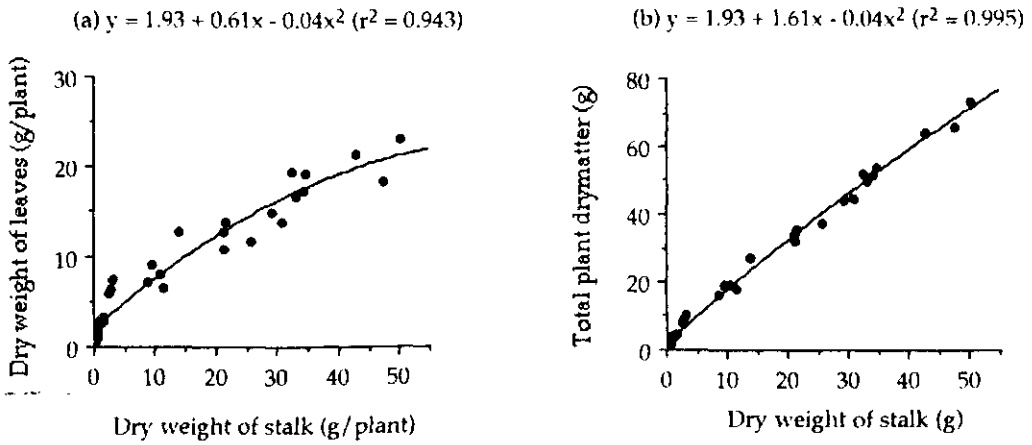


Figure 10-5. The relationship between leaf-, stalk- and total dry matter yield of maize (n = 45).

The pattern of distribution of dry matter seemed to have occurred in 3 phases (Figure 10-4). The first 6 weeks of growth represent the first phase, during which leaves constituted about 70 % of the plant's total dry matter. This was followed by a 2nd phase (6 - 8) during which there was a sharp increase in the weight of stalks, which constituted > 60 % of total maize dry matter on *Mucuna* and Urea, and only 55 % on Control plots. The period beyond 8 WAP, marked the third phase when the stalk generally constituted about 70 % of maize total dry matter.

This observation is quite in agreement with that of Hanway (1962). According to Hanway (1962), stalks of maize plants begin to constitute the bulk of dry matter from 6 weeks after planting, mainly due to the transfer of photosynthates into the stalk. This implies that, the period between 6 and 8 weeks after planting is very critical for optimum maize performance.

## Yield of maize

Maize grain and stover yields obtained from *Mucuna* plots were about twice as high as those of the control (Table 10-3). At harvest, grains weighed about 319 kg $ha^{-1}$ on *Mucuna*, as compared to 182 kg $ha^{-1}$ on the control plots. On the other hand, grain yield on the urea fertilized (40 kg N $ha^{-1}$) plots was as much as 711 kg $ha^{-1}$. I should be noted that the yield of maize was low, which was probably due to the low inherent soil fertility. Grain yield constituted as much as 27.2 % of total dry matter yield of maize on urea plots, as compared to 19.9 and 15.0 % on *Mucuna* and control plots, respectively.

Table 10-3. The effect of Mucuna fallow and Urea on the yield of maize (TZSR-Y).

| | Grain | Stover | Total dry matter | Harvest index |
|---|---|---|---|---|
| | (---------- | kg $ha^{-1}$ | ----------) | (%) |
| Fallow regrowth (Control) | 182 | 1027 | 1210 | 15.0 |
| *Mucuna* fallow | 319 | 1356 | 1675 | 19.9 |
| Urea (40 kg N $ha^{-1}$) | 711 | 1933 | 2644 | 27.2 |
| CV (%) | 19.9 | 24.3 | 20.5 | 21.3 |
| $LSD_{(0.05)}$ | 161 | 670 | 754 | 8.78 |

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# 11. POTENTIAL OF SOME INDIGENOUS PLANT SPECIES FOR ENHANCING SOIL FERTILITY IN SHORT FALLOW SYSTEMS OF THE HUMID TROPICS

J. Kanmegne, B. Duguma, J. Henrot and N.O. Isirimah

## Abstract

*Alchornea cordifolia, Calliandra calothyrsus, Pennisetum purpureum,* and *Chromolaena odorata* were evaluated for their potentials for enhancing fertility of acid Ultisols. They were evaluated for quality and quantity of biomass, root distribution, interaction with mycorrhizae and earthworm activity in a two years fallow.

*Pennisetum* and *Alchornea* produced more biomass (66.6 and 54.2 Mg $ha^{-1}$, respectively) than *Calliandra* (15.4) and *Chromolaena* (9.9). The highest root mass occurred under *Pennisetum*. They all produced enough biomass to maintain soil organic matter. A high proportion of *Pennisetum* roots (92 %) was found in the 20 cm top soil, compared to *Chromolaena* (76 %), *Alchornea* (74 %) and *Calliandra* (57 %). *Calliandra* thus is a good option for intercropping. *Alchornea* and *Calliandra* had deeper roots and has therefore a good potential to recover leached nutrients. *Alchornea* residue was rich in N and Ca, and *Pennisetum* in N and K; most of the nutrients in *Calliandra* and *Alchornea* occurred in the wood. Earthworm casting activity was slightly higher under *Pennisetum* fallow, and mycorrhizae infested mostly *Alchornea* roots. Also *Pennisetum* enriched the top soil in P and K, and *Alchornea* in P. *Pennisetum* and *Alchornea* were therefore the most promising fallow species.

**Keywords**: humid tropics, fallow, *Calliandra, Alchornea, Pennisetum, Chromolaena*

## Introduction

The ever increasing population pressure and the subsequent decline in per capita land holding, has forced resource poor farmers of the humid tropics to shorten fallow length from 10 to less than 3 years without additional input. This has resulted in the gradual decline in quality and quantity of the vegetation in natural fallows, as well as in agricultural output, and an accelerated environmental degradation (Sanchez, 1976; Lal *et al.*, 1978). The need is therefore urgent to develop an efficient fallow management technique compatible with short fallow system, that can accelerate the process of soil fertility restoration. The strategy is to enrich bush fallow with selected plant species which would enhance the efficiency of nutrient recycling, thus ameliorating the soil fertility in a shorter period than the traditional bush fallow system (Prinz, 1986; Lal *et al.*, 1978; Swift, 1986).

Many exotic legume species already tested can hardly survive high soil acidity (IRA/ICRAF, 1992), and little or no information is available on the potentials of indigenous species. This study is initiated in order to investigate the potentials of dominant short fallow species in order to identify the most suitable ones for fallow systems in the humid topics of West and Central Af-

rica. *Chromolaena odorata, Alchornea cordifolia, Pennisetum purpureum* were selected from a survey in short fallows of Central Cameroon (Table 11-1). *Calliandra calothyrsus*, reported to have good potentials for soil fertility improvement (Duguma and Tonye, 1994) was also retained for evaluation. Specific criteria were chosen for the evaluation of selected species in fallows of two years of age : (1) standing biomass, (2) nutrient concentration in the biomass, (3) root distribution, (4) colonization of root by mycorrhizae, (5) effect of the fallow species on earthworm casting activity and (6) soil properties.

*Table 11-1. Fallow species found in 31 farmers fields in Central Cameroon.*

| Location | Fallow age (years) | Dominant species | Species-2 | Species-3 | Species-4 |
|---|---|---|---|---|---|
| Mbedoumou | 1 | Chromolaena | Setaria | Stachytarpheta | Picnatus |
| | 2 | Pennisetum | Panicum | - | - |
| | 2 | Chromolaena | Alstonia | Picnatus | Alchornea |
| | 2 | Chromolaena | Trema | Alchornea | Albizia |
| | 2 | Chromolaena | Alchornea | Albizia | Ricinodendron |
| | 4 | Alchornea | Myrianthus | Triumfetta | - |
| Ponso | 1 | Paspalum | Erigeron | Alchornea | - |
| | 1 | Erigeron | Chromolaena | - | - |
| | 1 | Paspalum | Chromolaena | Brachiaria | - |
| | 2 | Chromolaena | Erigeron | Alchornea | Melitia |
| | 3 | Chromolaena | Afromomum | Setaria | Cola |
| | 3 | Chromolaena | Trema | Alchornea | - |
| | 3 | Chromolaena | Alchornea | Trema | - |
| Abondo | 1 | Sida | - | - | - |
| | 1 | Sida | Chromolaena | Triumfetta | Alchornea |
| | 2 | Sida | - | - | -- |
| | 2 | Chromolaena | Alchornea | Albizia | Triumfetta |
| | 2 | Chromolaena | Ricinodendron | Albizia | Musanga |
| | 2 | Chromolaena | Triumfetta | Alchornea | - |
| | 2 | Chromolaena | Panicum | Triumfetta | - |
| | 2 | Chromolaena | Triumfetta | Alchornea | Albizia |
| | 2 | Chromolaena | Alchornea | Triumfetta | Vernonia |
| | 3 | Chromolaena | Albizia | Ceiba | Combretum |
| Nkolfep | 1 | Chromolaena | - | - | - |
| | 1 | Erigeron | Chromolaena | Sida | Alchornea |
| | 2 | Chromolaena | - | - | - |
| | 2 | Chromolaena | - | - | - |
| | 2 | Panicum | Ficus | Cassia | - |
| | 3 | Panicum | Sorghum | Andropogon | - |
| | 3 | Panicum | Chromolaena | Pennisetum | - |
| | 3 | Chromolaena | Pennisetum | Sida | - |

The restoration of soil organic matter is repeatedly emphasized as an important function the natural fallow but little is known about how quickly and to what extend this is achieved. Also, little or no information is available on the potential contribution of individual fallow species to soil fertility restoration, the type and quantity of plant nutrients stored in the tissues and recycled during the fallow phase. In the humid tropics where intense leaching occurs, rooting depth

of fallow species is of primary importance to N-use efficiency. For highly mobile elements deep root system is required, while for low mobility elements, a high root density is a preferred attribute (Van Noordwijk and De Willigen, 1991). During the fallow period, trees and shrubs use their extensive root system to absorb substantial quantities of nutrients from lower soil horizons. They enrich the top soil through litter fall or after slash and burn, thus acting as a net to trap nutrients which otherwise would be leached down the soil profile (Dyani *et al.*, 1990). The ability of a fallow species to function as nutrient pump during the fallow period can be improved by its association with mycorrhyzae. The fungal hyphae act as an extension of the root system thus enhancing water and nutrient uptake, especially P (Russel, 1977). Also. mycorrhizae infected roots may decompose faster than non infected ones (Wright and Milner, 1994). Also soil fauna especially earthworm through their feeding activities affect soil fertility restoration (Lavelle, 1988). Their activity is however affected by the fallow species (Hauser, 1993).

# Materials and methods

## Study sites

The study was conducted in four villages of the humid lowlands of central Cameroon: Minkoameyos, Nkolfep, Mbedoumou and Abondo, located between 2° to 4°N and 11° to 12° E. The climate is Equatorial (Guinean type) with 1530 mm mean annual rainfall, 23.9 °C mean temperature, 640 m mean elevation and bimodal rainfall pattern. The soils are mostly Oxisols or ferralsols derived from low activity clays. Low pH, Al and Mg toxicities, and P deficiency are some of the major constraints to crop production. (Sanchez, 1989; Kang *et al.*, 1990). The general soil characteristics are given in Table 11-2.

Table 11-2. Some characteristics of two years fallow soil in the humid forest zone of Cameroon.

| | Soil layers (cm) | | | |
|---|---|---|---|---|
| Soil properties | 0-5 | 0-15 | 15-30 | LSD |
| pH (water) | 6.3 | 6.2 | 5.7 | 0.9 |
| pH ($BaCl_2$) | 5.6 | 5.6 | 5.1 | ns |
| Ca (meq/100g) | 9.60 | 7.05 | 3.63 | 5.70 |
| Total N (%) | 0.228 | 0.179 | 0.131 | 0.065 |
| Avail. P (mg/kg) | 11.23 | 5.58 | 4.11 | ns |
| K (meq/100 g) | 0.248 | 0.152 | 0.092 | 0.102 |
| Org. C (%) | 3.37 | 2.14 | 1.43 | 0.89 |
| Mg (meq/100g) | 2.63 | 1.76 | 1.08 | 1.21 |

For each fallow species a representative plot was selected per village, and on each plot 4 average plants (of *Calliandra* and *Alchornea*) or quadrats of 1 m by 1 m (of *Pennisetum* and *Chromolaena*) were identified. The four plants or quadrats were sampled and the four observations bulked to a mean value before analysis. All measurements were performed on the same plants and quadrats with the rationale to have comparable above and below ground characteristics of each species. *Calliandra* fallows were not available in Mbedoumou.

## Standing biomass

The biomass was measured by harvesting and weighing four plants of *Calliandra* and *Alchornea* and four quadrats of *Chromolaena* and *Pennisetum* per site. The material was subsampled and oven-dried at 65 °C for 48 hours to determine the dry weight. The standing biomass was expressed in Mg $ha^{-1}$ for *Pennisetum* and *Chromolaena*, and on tree basis then converted to Mg $ha^{-1}$ considering the plant population of density of 10 000 trees $ha^{-1}$ as conventionally obtained in hedgerow intercropping arrangement (4 m x 0.25 m) for *Calliandra*, and the natural population of *Calliandra* on the plot. Soil litter was collected on a 1m x 1m quadrat under the four fallow species at the time of sampling. The collected material was oven dried at 65 °C for 48 hours weighed and corrected for ash content.

## Rooting pattern and below-ground biomass

For *Alchornea* and *Calliandra*, the rooting pattern was examined up to 80 cm depth and 80 cm away from the trunk, using the block monolith sampling method. (Anderson and Ingram, 1993).

The sampling depths were 0-20 cm, 20-50 cm, and 50-80 cm. For *Chromolaena* and *Pennisetum*, soil monoliths were taken at same depth interval but on a 50 x 50 cm surface. The blocks were later given gentle washing over a 0.5 mm mesh sieve to remove the roots. The collected roots were separated into fine roots (below 2 mm diameter), woody, and coarse roots (above 2 mm), then oven dried at 65 °C for 48 hours and weighed. The percent distribution of the roots, the root standing mass (Mg $ha^{-1}$), and the proportion of coarse roots in the different soil horizons were determined.

The data was arranged to suit a randomized complete block design (RCB), with factorial arrangement of 4 species and 3 sampling depths (4x3) in 4 replications. In blocks without *Calliandra* treatments, the missing observations were considered as missing values. The ANOVA was performed, then the LSD (0.05) used to separate the different means whenever significant differences occurred.

## Nutrient content of the biomass

At the time of biomass harvest, plant samples 300 g each of leaf and/or woody component, were collected from each quadrat and tree, and oven dried at 65 °C for 48 hours, ground to pass through 0.15 mm mesh sieve. Portion of the different samples were analyzed for N, K, Ca, lignin and cellulose. Total N was determined by micro Kjeldahl digestion, followed by distillation and titration. K was measured by flame photometry, and Ca measured using atomic absorption spectrophotometry (IITA, 1984), lignin and cellulose by the acid detergent fibber method (Anderson and Ingram, 1993).

## Earthworm activity

Earthworm activity was monitored weekly by collecting and weighing surface casts produced in a 50 by 50 cm frame. Four frames were placed on each plot, under the selected fallow species during the first rainy season 1994.

## Association of roots with mycorrhizae

Mycorrhizal infection was studied using fine root from the top 20 cm of the profiles. A root sample of 0.6 g was collected in 4 replicates per species, and stained following the Phillips and Hayman method as described by Anderson and Ingram (1993). Then the grid intersect method (Tennant, 1975) was used to quantify the infection and the results expressed as a percentage of the root length occupied by fungus.

## Site characterization

A systematic or grid sampling method was used for soil sampling to guarantee complete coverage of each plot. Twenty sampling points were located on each experimental unit and a soil auger used to collect the soil samples. Surface plants and litter material were removed, then augering was done at 0-15 and 15-30 cm, and close to each augering site a soil sample was collected in the top 0-5 cm.

The 20 soil samples collected on each layer were thoroughly mixed to form a composite sample, then subsampled and analyzed for organic carbon, N, P, K, Ca, and pH. The soil pH was measured in water in a 1:5 ratio (pH1), and in 0.002 M $BaCl_2$ solution (pH2). The basic cations were extracted in a 0.1M $BaCl_2/NH_4Cl$ solution, 1:10 ratio and reported as milli equivalent per 100 g soil. Organic carbon was determined using the Walkley Black method and reported as a percentage. Total nitrogen was determined using the Kjeldahl method and reported as a percentage. Available P was measured using the Bray-1 method and reported as micro grams per gram P.

# Results and discussion

## Standing biomass

Figure 11-1 represents the standing biomass of the four fallow species under investigation. The above-ground biomass the root mass and the litter showed significant ($P < 0.05$) differences between the fallow species. *Alchornea* and *Pennisetum* produced the highest above-ground mass of 66.6 and 54.2 Mg $ha^{-1}$ respectively. *Calliandra* produced statistically low biomass and *Chromolaena* the lowest. The highest quantity of decomposable material was produced by *Pennisetum*, and the lowest by *Calliandra*.

*Pennisetum* produced up to 19.4 Mg $ha^{-1}$ of root material, more than 17 Mg $ha^{-1}$ of which was in the top 20 cm. It was statistically higher than *Alchornea* with 7.9 Mg $ha^{-1}$. *Chromolaena* and *Calliandra* had less than 3 Mg $ha^{-1}$ of root in the 0-80 cm soil layer.

Soil litter was mainly collected under *Pennisetum*, while other species had similar litter fall. Thus *Pennisetum* produced up to 100 Mg $ha^{-1}$ of total standing biomass, followed by *Alchornea*, *Calliandra* and *Chromolaena* with 65, 20 and 16 Mg $ha^{-1}$ of dry matter respectively. Young (1987) estimated that 8 Mg $ha^{-1}$ dry matter of above ground biomass, or 4 Mg $ha^{-1}$ of tree leaf biomass is enough to maintain organic matter at level acceptable for soil fertility in the humid tropics. The four fallow species can thus be recommended provided the residue quality and management are adequate. *Chromolaena* is the most abundant fallow species in the study sites, it produces low root mass. It may therefore contribute poorly to the below-ground organic residue especially under slash and burn practice. *Alchornea* and *Pennisetum* can be a serious option for increasing the biomass production in short fallows under acid soil conditions.

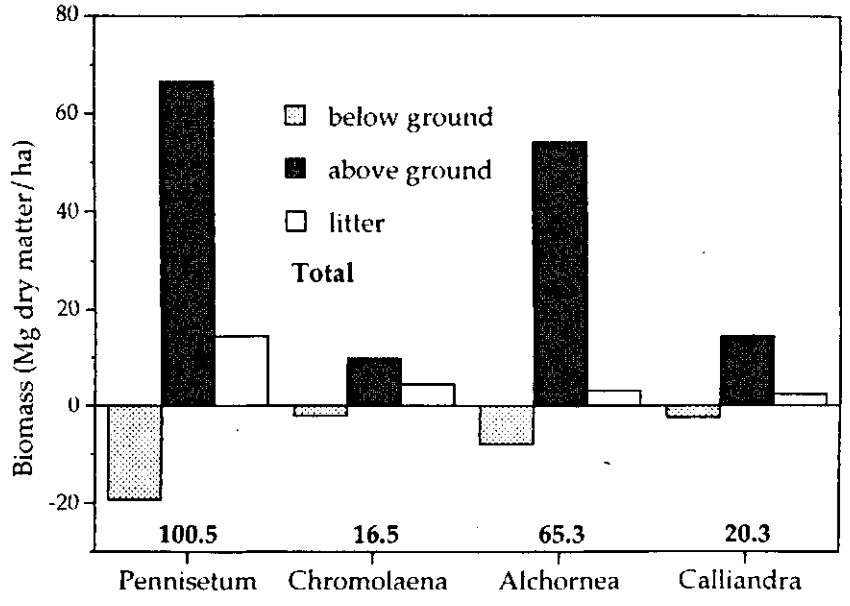


Figure 11-1. Standing biomass of four fallow species.

The biomass of *Calliandra* and *Alchornea* were significantly correlated to easily measurable parameters such as plant height, stem diameter and stem basal area, but not to the number of branches (Table 11-2). All species conformed to the root:shoot ratio of between 1:3 and 1:7. Maximum above-ground dry weight coincided with maximum root production in *Pennisetum*.

## Root distribution

There was a highly significant ($P < 0.01$) difference in root distribution at the different soil depths, irrespective of the fallow species. Most of the roots were found in top 20 cm. Significant ($P < 0.05$) differences occurred between the four fallow. *Pennisetum* had the highest root concentration in the upper 20 cm soil layer, where 92 % of its roots are found. *Chromolaena* and *Calliandra* had the lowest proportion of their root in this soil layer. In the 20-50 cm layer of the soil profile *Calliandra* concentrated more root than others. *Chromolaena* had up to 10 % of its roots in the 50-80 cm soil depth, compared to 7, 6, and 2 % of *Calliandra*, *Alchornea*, and *Pennisetum* respectively (Figure 11-2). The highest proportion of coarse roots was observed under *Pennisetum* with 66 %, followed by *Alchornea* and *Calliandra*, with 59 and 55 % respectively. *Chromolaena* had only 25 % of coarse roots.

*Calliandra* had few roots in the top soil, indicating the ability to recover leached nutrients, a reduced competition with food crops and potentials for intercropping systems. *Alchornea* had 74 % of it roots in the top soil, indicating high competition in intercropping system, and also tillage difficulties. Heavy pruning during the cropping phase is thus necessary. The species also has an important root mass below 50 cm (0.47 Mg $ha^{-1}$) and can therefore be used to recover leached nutrients. Ruhigwa *et al.* (1992) observed similar root distribution of *Alchornea* in the acid soils of South Eastern Nigeria. *Pennisetum* fallows may be difficult to slash and weed, because of the high concentration of roots in the top soil. However it has the potential of picking nutrients from decomposing soil litter during the fallow phase, and to recover leached nutrients from deep soil, with 0.39 Mg $ha^{-1}$ of root in the 50-80 cm soil layer.

The concentration of 10% of *Chromolaena* roots between 50-80 cm was equivalent to 0.27 Mg $ha^{-1}$, compared to 0.15 for *Calliandra*. However, the ability of the different species to take up nutrients cannot be over-emphasized, as it is more related to the root length than root weight (Newman, 1966; Anderson and Ingram 1993).

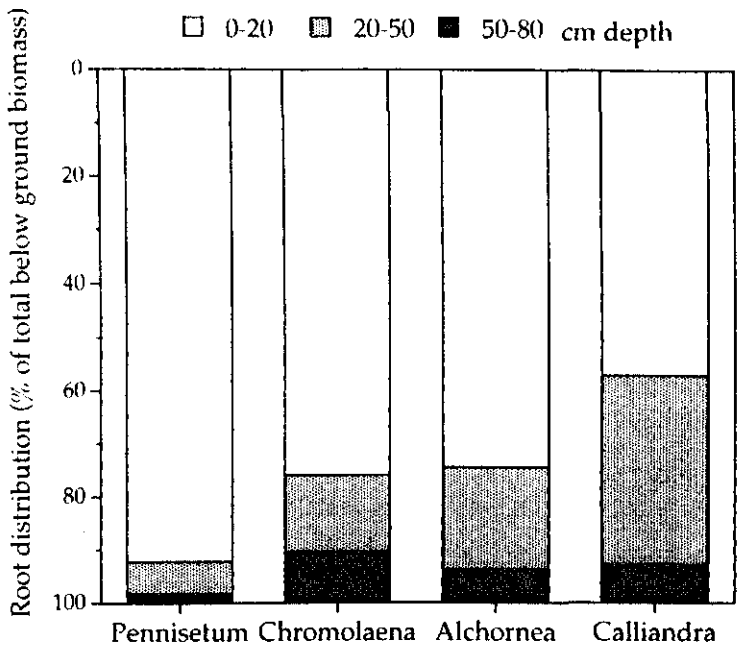


Figure 11-2. Root distribution with depth of four fallow species.

## Nutrient status in the standing biomass

The concentration of N, K, and Ca in the leaves and/or wood of the four fallow species and the equivalent nutrient content of the standing biomass are given in Tables 11-3 and 11-4. Leaves of *Calliandra* had the highest concentration of nitrogen, followed by *Alchornea* and *Chromolaena*. *Pennisetum* had the lowest. However owing to the high biomass production, *Pennisetum* fallow produced more N than *Calliandra*. The highest N quantity was produced in *Alchornea* fallow with 722 kg $ha^{-1}$, most of it occurring in the wood.

Table 11-3. Chemical composition of residues of four fallow species in the humid forest zone.

| Residue type | N % | K % | Ca % | lignin % | Cellulose % |
|---|---|---|---|---|---|
| Call. leaves | 3.23 | 0.16 | 0.73 | 12.51 | 17.09 |
| Call. wood | 0.71 | 0.54 | 0.71 | 20.73 | 47.23 |
| Alch. leaves | 2.68 | 0.81 | 1.08 | 23.75 | 17.41 |
| Alch. wood | 0.99 | 0.95 | 1.90 | 17.39 | 39.12 |
| Chromolaena | 1.37 | 1.19 | 0.84 | 18.34 | 39.28 |
| Pennisetum | 0.87 | 2.0 | 0.29 | 12.06 | 41.38 |
| LSD | 0.71 | 0.59 | 2.28 | 6.06 | 9.72 |

Potassium was mostly concentrated in *Pennisetum* and *Chromolaena*, compared to *Calliandra* and *Alchornea*. The highest potassium yield was observed in *Pennisetum* fallow with 1332 Mg $ha^{-1}$, and *Alchornea* with 496.9 Mg $ha^{-1}$. *Calliandra* fallow produced the lowest 66.7 Mg $ha^{-1}$. Calcium was mostly concentrated in *Alchornea*, and its fallow produced up to 912.4 kg $ha^{-1}$ of Ca, compared to only 83.5 kg $ha^{-1}$ in *Chromolaena* (Figure 11-3).

Table 11-4. Nutrient equivalent in the biomass of the four fallow species in two-year-old fallow of the humid lowlands of Cameroon.

| Species | Biomass t/ha | N kg/ha | K kg/ha | Ca kg/ha |
|---|---|---|---|---|
| Alch. leaves | 14.36 | 327.4 | 117.46 | 155.52 |
| Alch. wood | 39.86 | 394.6 | 379.4 | 756.9 |
| Call. leaves | 4.31 | 139.2 | 6.98 | 31.38 |
| Call. wood | 11.13 | 79.0 | 59.77 | 78.47 |
| Chromolaena | 9.90 | 135.6 | 117.71 | 83.56 |
| Pennisetum | 66.6 | 579.4 | 1332.67 | 191.14 |
| Alch. fallow | 54.22 | 722.0 | 496.93 | 912.46 |
| Call. fallow | 15.44 | 218.2 | 66.75 | 109.85 |

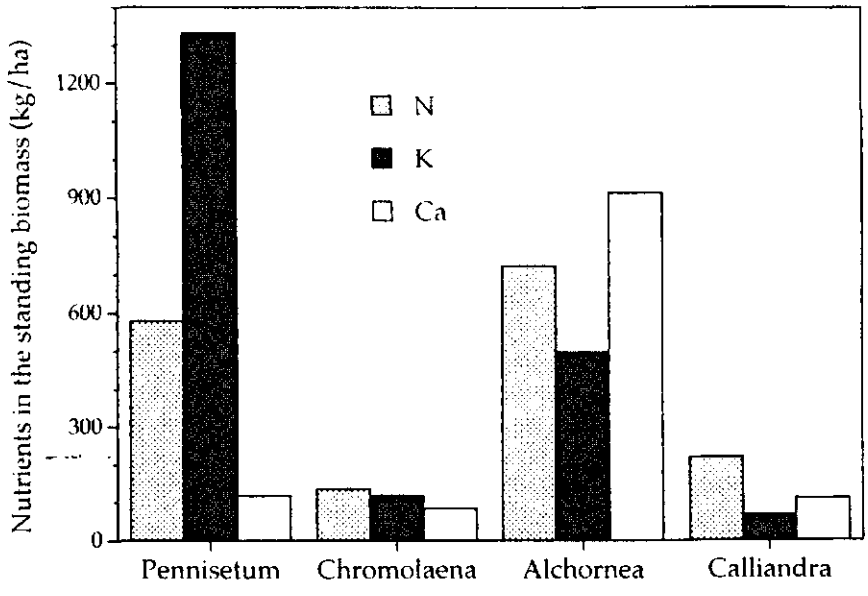


Figure 11-3. Nutrients in the standing biomass of four fallow species.

*Alchornea* had a good ability to absorb and store N, although being unable to fix $N_2$. It indicate the risk of N competition with food crops in intercropping systems, and also its potential as green manure. *Pennisetum* produced a deal of biomass and accumulated K faster than other species as also observed by Printz (1986). *Chromolaena* also had high content of K, and therefore can contribute to soil K and improved groundnut yield after *Chromolaena* fallow as believed by farmers. Nutrients in *Calliandra* and *Alchornea* were mostly stored in the wood material, especially Ca and K. Burning after slashing may therefore be recommended.

## Casting activity

The weight of air dry casts produced during the experimental period (April to August 1994) was 9.2 Mg $ha^{-1}$ under *Pennisetum*, 6.5 Mg $ha^{-1}$ under *Chromolaena*, 6.1 Mg $ha^{-1}$ under *Alchornea* and 4.4 Mg $ha^{-1}$ under *Calliandra* fallows. However the difference between fallow species was not statistically significant, although there was a tendency of better casting under *Pennisetum* (Figure 11-4).

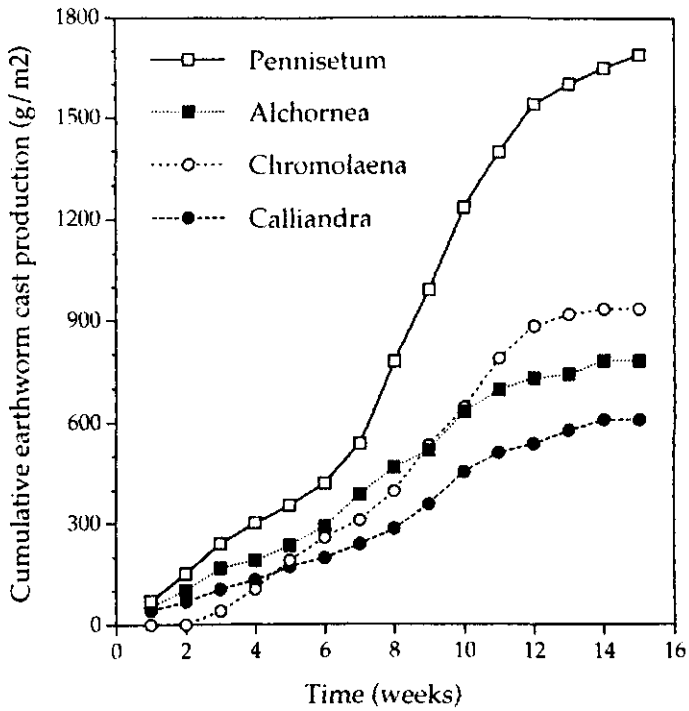


Figure 11-4. Cumulative earthworm cast production under four fallow species, from April to August 1994.

## Association with mycorrhizae

The percentage of root length infested with mycorrhizae ranged from 10 to 18.25 % and was significantly ($P < 0.05$) higher in *Alchornea* in roots while other species had similar levels of colonization. Root architecture seemed to have affected the colonization by mycorrhizae. *Alchornea* with the highest proportion of coarse roots also had the highest level of mycorrhizal infection. *Pennisetum* roots were less colonized, as it concentrates most of its fine roots in the top soil. Wright and Milner (1994) also observed that coarseness of root is loosely associated with mycorrhizal dependence, and plant species with highly developed root hairs are often nonmycorrhizal. Hairiah and Van Noordwijk (1986) observed 28 % infection for *Alchornea*. The relatively low rate in the present work may be related to the dry season sampling often associated with a high rate of root decay (Wright and Milner, 1994).

## Soil characteristics

Some soil chemical properties were significantly affected by the different fallow species. In the top 0-5 cm, higher level of K and available P were observed under *Pennisetum* and more organic carbon under *Alchornea*. *Pennisetum* also induced higher level of available P in the 0-15 cm and Ca in the 15-30 cm soil layer, compared to other species. *Chromolaena* fallow enriched the soil in N, Ca, P and K. The lowest soil nutrients were observed under *Calliandra* (Tables 11-5, 11-6 and 11-7).

Table 11-5. Effects of two years fallow of selected fallow species on some soil properties in the soil layer 0-5 cm.

| Properties | Call. | Alch. | Penn. | Chromol. | LSD |
|---|---|---|---|---|---|
| pH (water) | 6.0 | 6.3 | 6.6 | 6.3 | ns |
| pH (BaCl2) | 5.5 | 5.8 | 5.7 | 5.6 | ns |
| Ca (meq/100g) | 3.33 | 3.84 | 4.36 | 3.42 | ns |
| Total N (%) | 0.23 | 0.23 | 0.24 | 0.21 | ns |
| Avail. P (mg/kg) | 4.66 | 9.16 | 17.96 | 8.71 | 8.52 |
| K (meq/100 g) | 0.219 | 0.219 | 0.340 | 0.211 | 0.11 |
| Org. C (%) | 2.90 | 6.79 | 3.78 | 4.44 | 0.88 |
| Mg (meq/100g) | 2.65 | 1.97 | 3.13 | 2.77 | ns |

Table 11-6. Effects of two years fallow of selected fallow species on some soil properties in the soil layer 0-15 cm.

| Properties | Call. | Alch. | Penn. | Chromol. | LSD |
|---|---|---|---|---|---|
| pH (water) | 6.0 | 6.3 | 6.4 | 6.3 | ns |
| pH (BaCl2) | 5.2 | 5.7 | 5.7 | 5.7 | ns |
| Ca (meq/100g) | 4.51 | 8.53 | 7.56 | 7.61 | ns |
| Total N (%) | 0.15 | 0.17 | 0.18 | 0.19 | ns |
| Avail. P (mg/kg) | 2.65 | 7.78 | 25.46 | 6.79 | 8.52 |
| K (meq/100 g) | 0.080 | 0.209 | 0.191 | 0.152 | 0.11 |
| Org. C (%) | 2.06 | 2.50 | 2.17 | 2.21 | ns |
| Mg (meq/100g) | 1.59 | 1.81 | 2.01 | 1.77 | ns |

Table 11-7. Effects of two years fallow of selected fallow species on some soil properties in the soil layer 15-30 cm.

| Soil properties | Call. | Alch. | Penn. | Chromol. | LSD |
|---|---|---|---|---|---|
| pH (water) | 5.8 | 5.8 | 6.1 | 5.8 | ns |
| pH (BaCl2) | 5.0 | 5.1 | 5.3 | 5.0 | ns |
| Ca (meq/100g) | 6.12 | 10.01 | 13.9 | 8.36 | 5.69 |
| Total N (%) | 0.13 | 0.15 | 0.12 | 0.11 | ns |
| Avail. P (mg/kg) | 1.69 | 4.56 | 4.29 | 3.45 | ns |
| K (meq/100 g) | 0.052 | 0.008 | 0.097 | 0.083 | ns |
| Org. C (%) | 1.58 | 1.38 | 1.46 | 1.46 | ns |
| Mg (meq/100g) | 1.03 | 1.06 | 1.23 | 1.10 | ns |

# Conclusions

The four fallow species differed in terms of quality and quantity of biomass produced, root distribution and their effect on soil properties. *Alchornea* fallow produced a high above ground biomass, mostly made of wood material with high Ca and N concentration. Although it is a deep rooted species, most of its coarse and woody roots are found in the top 20 cm soil. *Pennisetum* had a high biomass production and good nutrient build up. It favors the activity of soil organisms, and improves some key properties of soil during the fallow period. *Chromolaena* fallows produce low quality and quantity of biomass during the fallow period. They need to be associated with deep rooted, high biomass producing such as *Alchornea* in the short fallows in order to improve the nutrient use efficiency of the system. Nutrients were mostly stored in the woody component of *Calliandra* and *Alchornea*. Adequate residues management will be required. The species differently improved the soil chemical properties, *Pennisetum* and *Alchornea* enriched the top soil more than *Calliandra* and *Chromolaena*. The potential contribution of the four fallow species to soil fertility management is assessed. More in situ studies are necessary to evaluate their actual contribution to crop sustainability after the fallow period.

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# 12. SOIL MANAGEMENT AND BASE CATION LEACHING IN AN ULTISOL OF THE HUMID TROPICS

J. Henrot

## Abstract

Since acid soils in the humid tropics usually have a low CEC and they experience a high rainfall, there is a risk of leaching of base cations. Unlike for N, which can be fixed biologically from the air, there is no natural mechanism that can balance the losses of base cations. External inputs of base cations are therefore required for sustainable crop production on these soils.
In this study two hypotheses were tested: 1. Base cations applied to the soil in combination with mulch as nitrogen input are less rapidly subjected to leaching than when they are applied with inorganic N fertilizer and 2. Mulches of contrasting qualities (N and lignin content) have different effects on base cation leaching. The research was conducted in lysimeters.
The type of green manure applied on the soil (and probably even its presence) affected little the base cation and N output of the soil column at 1.3 m depth. Application of inorganic N fertilizer, in contrast, resulted in substantial losses of K, Ca, and Mg. Losses in base cation increase soil acidity. It is concluded that base cation conservation is better achieved with mulch than mineral N fertilizer. Because leaching of Ca + Mg is proportional to that of nitrate, the management of base cations in the soil is intimately tied to the management of nitrogen.

**Keywords:** humid tropics, base cations, leaching, mulch, nitrogen fertilizer

## Introduction

Acid soils of the humid tropics (Ultisols and Oxisols) are poor in base cations ($Ca^{2+}$, $Mg^{2+}$, $K^{+}$). Since they have a low CEC and they experience a high rainfall, there is a high risk of leaching of base cations present. Furthermore, base cations are exported from the field in the harvest products of crops. Unlike for N, which can be fixed biologically from the air, there is no natural mechanism that can balance the losses of base cations. In consequence, in the long-term, external inputs of base cations are necessary for a sustainable crop production on these soils.

Base cations added to the soil as mineral salts can be subject to rapid leaching under high rainfall conditions. Therefore, in order to minimize the cost of the fertilizer input for the smallholder farmer and to maximize the plant uptake efficiency, soil management practices which retard base cation losses should be developed.

In this study, we tested the following hypotheses: 1. base cations added to the soil in combination with mulch as nitrogen input leach less rapidly than when added with inorganic N fertilizer and 2. mulches of contrasting qualities (N and lignin content) have different effects on base cation leaching.

The first hypothesis is based on the assumption that base cations can be substantially immobilized by microorganisms developing on the decomposing plant material in the early phase of

decomposition. As decomposition proceeds and the microbial populations decrease, the immobilized base cations are slowly released. In the case where the mulch and base cations are applied at the time of planting, this would result in a better synchrony with crop demand.

The second hypothesis is based on the assumption that the development of microbial populations capable of immobilizing the added base cations is dependent on the quality of the mulch. Mulches higher in N content and decomposing more rapidly would be less effective in immobilizing base cations.

Monolith lysimeters cut from a Typic Paleudult received either a mineral N addition, or pruning of *Dactyladenia barteri* (1.6 % N), or pruning of *Flemingia congesta* (2.7 % N) or a mixture of the two, then, two weeks later, a dressing of Ca, Mg, and K (60 kg ha-1 each). The concentrations of base cations and mineral N in the top 10 cm of the soil and the amount of base cations and mineral N leaching at the lysimeter bottoms (1.35 m depth) were recorded for a period of one year.

# Materials and methods

## Experimental site, soil, lysimeters, and rhizons

The experiment was conducted at the High Rainfall Station of the Institute for Tropical Agriculture, in Onne (4° 51'N; 7° 03'E), near Port Harcourt, in the humid forest zone of S. E. Nigeria. Rainfall at the site is monomodal with a rainy season lasting from March to December and a mean annual rainfall of 2.4 m. Relative humidity remains high throughout the year (78 to 89 %) and mean annual temperature is 25 °C.

The treatments were applied to 12 undisturbed monolith lysimeters (1.35 m long and 80 cm Ø,described in Wong *et al.*,1987) cut from a coarse textured Ulitisol (Typic Paleudult) derived from Pleistocene coastel sand. Selected soil parameters of the soil column are given in Table 12-1. The ceramic suction candles embedded in silica sand at the bottom of the lysimetrs were maintained, by a vacuum pump, under a suction of 0.1 bar to ensure adequate drainage.

The lysimeters had been cut several years prior this experiment and left unattended (except for drainage removal), they were covered by a thick layer of grasses which were clipped at their base (roots not pulled) 3 months before applying the treatments. The grass blades were removed from the site.

Leachate water was collected after 25 L of drainage or every 3 days (whichever came first) and weighed. A subsample was taken and kept frozen until analysis. There was no difference in drainage volume between the 12 lysimeters and the drainage volume corresponded closely to the amount of water input (Figure 12-1).

To collect surface soil water (0-10 cm depth) without destructive sampling (which would create holes in the lysimeters and disturb the water flow pattern), 4 Rhizon Soil Moisture Samplers (Eijkelkamp Agrisearch Equipment, called "rhizons" in this text) were installed vertically into each lysimeter. The rhizons are tubes of 2.5 mm ø and 10 cm long, made out of an inert hydrophilic porous polymer connected to a PVC tubing. Soil water was collected weekly by applying suction in the rhizons with a syringe. The water collected from the 4 rhizons located in the same lysimeter was pooled and the samples were kept frozen until analysis.

## Treatments

On 9 July 1992, mulch (pruning of hedgerow trees from an alley-cropping trial) was applied on 9 of the 12 lysimeters: 3 lysimeters received 4.1 Mg $ha^{-1}$ dry matter of *Flemingia* congesta pruning, another 3 received 3.6 Mg $ha^{-1}$ of *Dactyladenia* barteri pruning, and the last 3 a mixture of *Dactyladenia* (1.8 Mg $ha^{-1}$) and *Flemingia* (2.1 Mg $ha^{-1}$). Twelve days later, basic cations were applied to all lysimeters: 60 kg $ha^{-1}$ K as $K_2SO_4$, 60 kg $ha^{-1}$ Ca as $CaCO_3$ and 60 kg $ha^{-1}$ Mg as $MgCO_3$. The 3 lysimeters without mulch received a dressing of mineral N (120 kg $ha^{-1}$ N as $(NH_4)_2SO_4$) along with the basic cations.

No crop was planted in the lysimeters but rhizons were inserted vertically in the top 10 cm of the soil (for soil water collection) in what would be the zone of high rooting density if a crop had been planted. The surface of the lysimeters was kept free of weeds and maintained under shade by a green mesh screen.
*Flemingia* and *Dactyladenia* pruning consisted of leaves and small twigs (less than 2 cm ø). Their composition was: 2.7 % N, 0.7 % K, 0.6 % Ca, 0.2 % Mg, and 22 % lignin for *Flemingia* and 1.6 % N, 0.4 % K, 0.8 % Ca, 0.2 % Mg, and 38 % lignin for *Dactyladenia*. A decomposition trial in nearby plots, using 2 mm-size steel mesh litterbags, and which started on the same date as the mulch addition to the lysimeters yielded decomposition K constants of 0.039 $week^{-1}$ for *Flemingia* and 0.022 for *Dactyladenia* (Henrot and Brussaard, 1996). The amounts of nutrients released by the mulch which were used to calculate the nutrient budgets (Tables 12-2, 12-3, 12-4, 12-5) were obtained by subtracting from the mulch input the amounts of nutrients present in the mulch remaining at the end of the experiment.

## Data collected and analytical methods

Lysimeter leachates were collected for 12 months, from June 92 to July 93, and analyzed for Ca, Mg, K, mineral N, pH, and total acidity. Top soil surface water was collected for 5 months only, from July to November 92, and analyzed for the same elements.

Concentrations of base cations and mineral N in the soil water and the leachates were determined with an atomic absorption spectrophotometer (Perkin-Elmer 703) for Ca and Mg, a flame photometer (Gallenkamp) for K, and an autoanalyzer (Technicon AAII) for ammonium and nitrate.

Nutrient and fiber contents in the pruning and in the plant material remaining at the end of the experiment were determined after Kjeldahl digestion for N, acid digestion ($HCLO_4$ + $HNO_3$ (1:2) then 6 N HCl) for K, Ca, and Mg, and by the van Soest procedure for lignin.

Table 12-1. Soil properties at the lysimeter cutting site; from Wong et al (1987) and Wong et al. (1992).

| Depth | Horizon | pH | CEC | organic C | total N | Bulk density | Exchangeable cations $cmol_c\ kg^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|---|
| cm | | 1:1water | $cmol_c\ kg^{-1}$ | % | % | $g\ cm^{-3}$ | Ca | Mg | K |
| 0-20 | A1 | 4.3 | 23.5 | 1.46 | 0.178 | 1.4 | 0.28 | 0.055 | 0.060 |
| 20-32 | A3 | 4.5 | 25.0 | 0.56 | 0.085 | 1.31 | 0.24 | 0.040 | 0.045 |
| 32-45/50 | IIA1 | 4.4 | 23.1 | 1.08 | 0.134 | 1.30 | 0.19 | 0.037 | 0.037 |
| 45/50-67/74 | IIA3 | 4.5 | 26.3 | 0.78 | 0.053 | 1.27 | 0.17 | 0.040 | 0.040 |
| 67/74-130 | IIB | 4.5 | 22.4 | 0.50 | 0.063 | 1.28 | 0.13 | 0.030 | 0.032 |
| 0-130† | | | 399 | | | | 30.3 | 6.4 | 6.7 |

† Amounts in $cmol_c\ ha^{-1}$ in the 0-130 cm layer

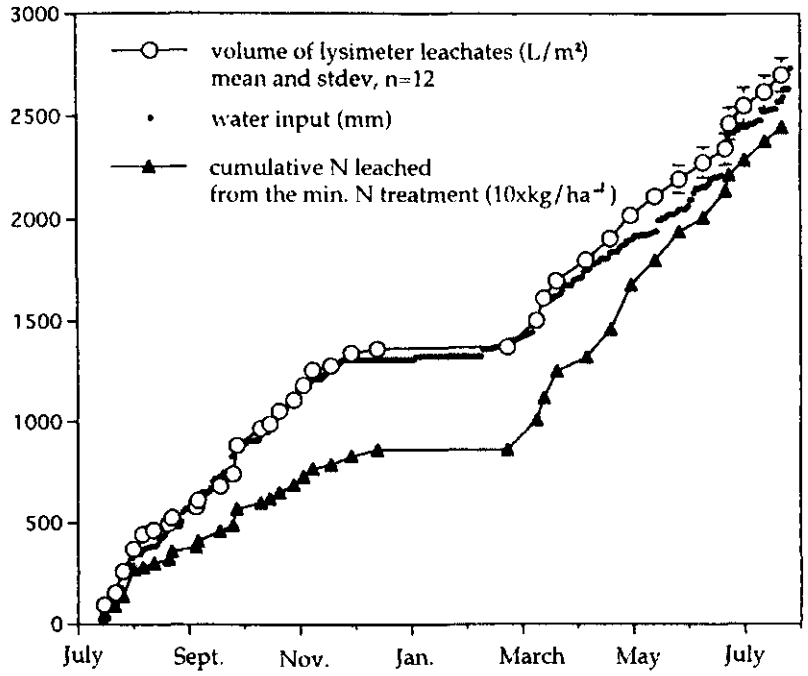


Figure 12-1. Water input and output and mineral N leached from the lysimeters.

# Results

## Base cations and mineral N in soil water of the lysimeter top 10 cm

Differences between treatments (Figures 12-2, 12-4, 12-6 and 12-8) were in general small and not statistically significant. When they existed, they were most remarkable in the first 40 days of the experiment. During this period, the general trend was that Ca and Mg were higher in the soil water of the lysimeters treated with mineral N and *Flemingia* leaves (Figure 12-2 and Figure 12-3), K was lower in the lysimeter treated with mineral N (Figure 12-6), and mineral N was larger in the lysimeter treated with mineral N (Figure 12-8); the differences were, however, not statistically significant throughout the 40 first days.

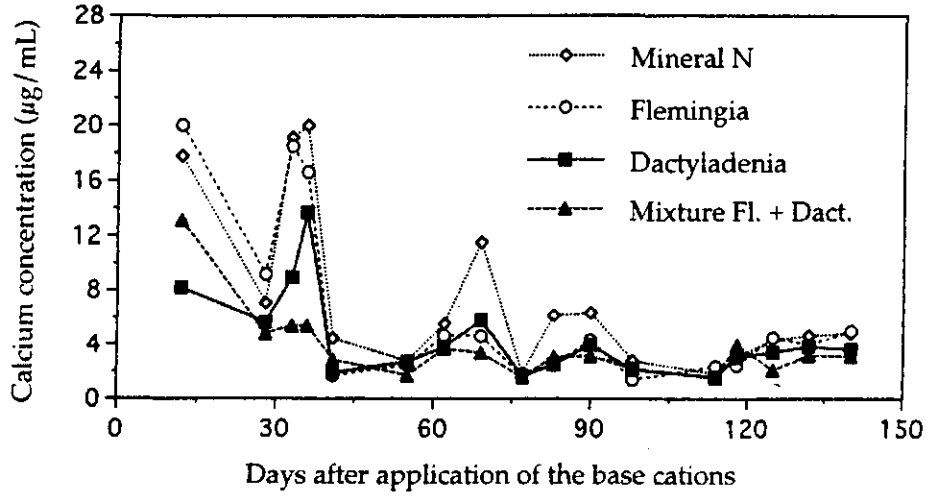


Figure 12-2. Calcium concentration in the soil water of the lysimeter top 10 cm.

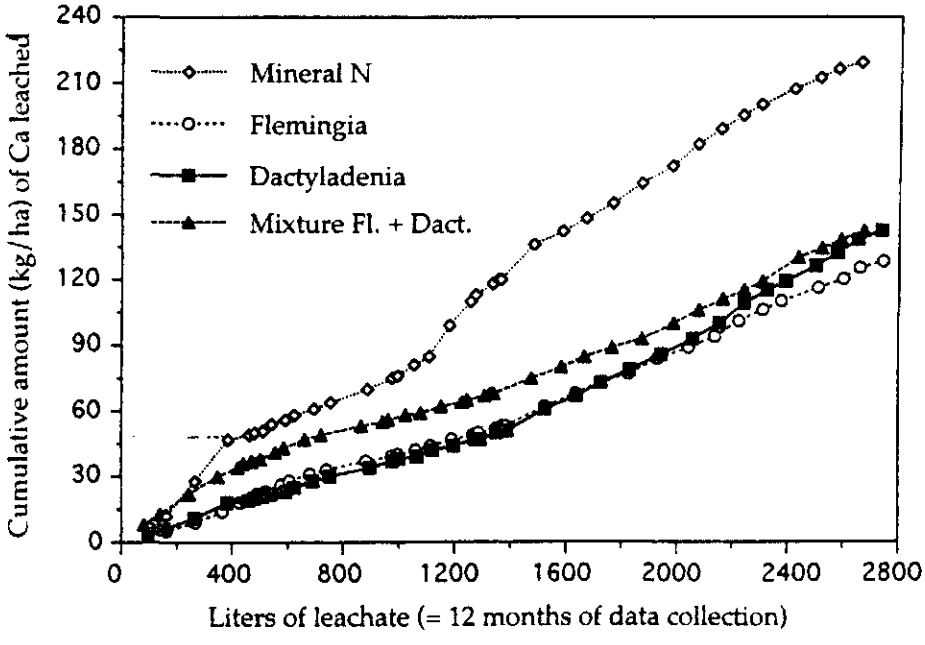


Figure 12-3. Cumulative amounts of Ca leached from the lysimeters.

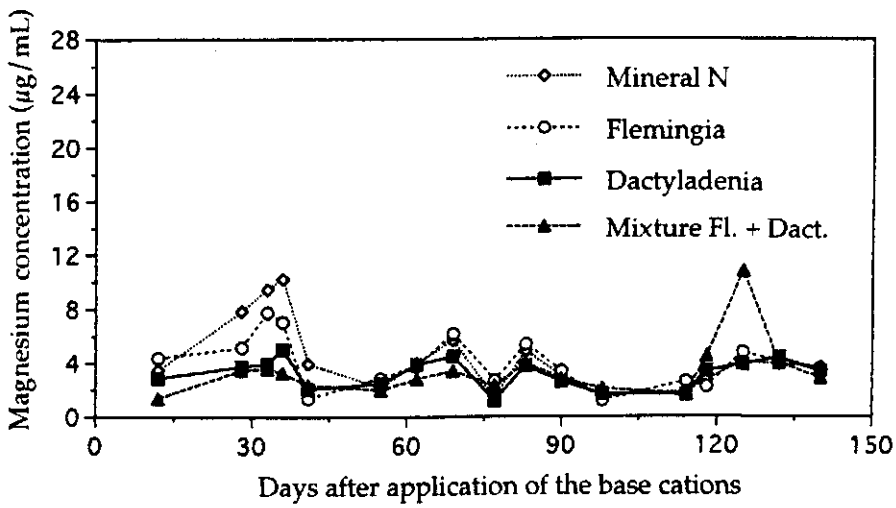


Figure 12-4. Magnesium concentration in the soil water of the lysimeter top 10 cm.

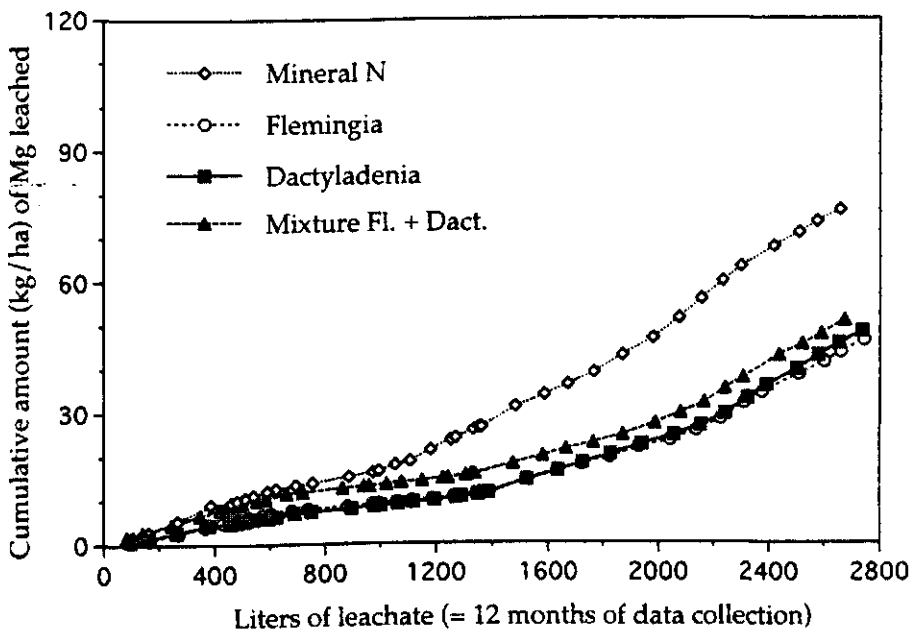


Figure 12-5. Cumulative amounts of Mg leached from the lysimeters.

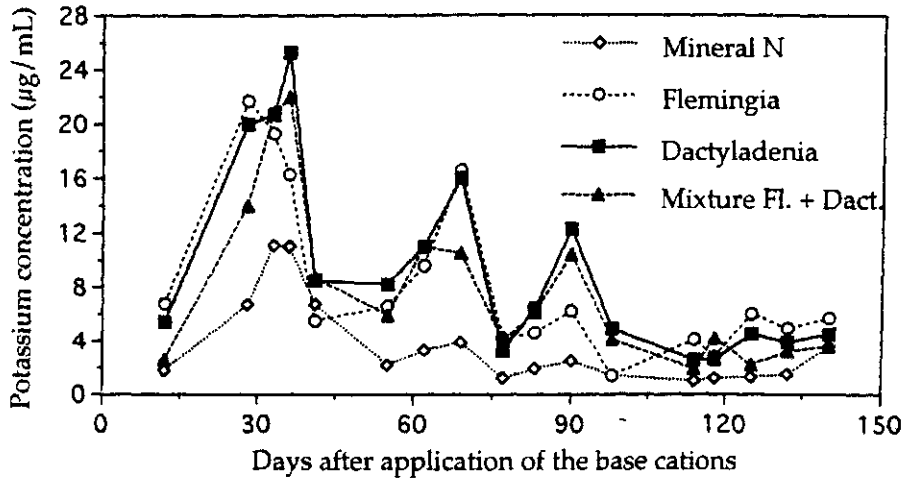


Figure 12-6. Potassium concentration in the soil water of the lysimeter top 10 cm.

## Base cations and mineral N leached from the lysimeters

The amounts of Ca and Mg leached from the lysimeters did not differ between mulched lysimeters but were significantly higher from the lysimeters treated with mineral N (Figures 12-3 and 12-5). After one year, 50 % more Ca and 60 % more Mg had leached from the lysimeters treated with mineral N (Tables 12-2 and 12-3).

The amounts of Ca leached exceeded, largely and in all treatment, the Ca input (Table 12-2). In the case of Mg, it was only the case for the mineral N treatment (130 % of input); the lysimeters mulched had lost about 75 % of the Mg input within 1 year (Table 12-3).

Table 12-2. Calcium budget (values in kg $ha^{-1}$).

| | | Mineral N | Dactyladenia | Flemingia | Mixture |
|---|---|---|---|---|---|
| INPUT | | | | | |
| Fertilizer | | 60 | 60 | 60 | 60 |
| Mulch | Added | | 30 | 24 | 27 |
| | Remaining | | 7 | 5 | 5 |
| | Released | | 23 | 19 | 22 |
| Total added | | 60 | 83 | 79 | 82 |
| OUTPUT (leachate) | | | | | |
| after 6 months | Amount | 81 ± 2 | 38 ± 12 | 42 ± 9 | 58 ± 27 |
| | % of added | 135 | 46 | 53 | 71 |
| after 12 months | Amount | 219± 26 | 142 ± 45 | 128 ± 26 | 142 ± 36 |
| | % of added | 365 | 171 | 162 | 173 |

Table 12-3. Magnesium budget (values in kg $ha^{-1}$).

| | | Mineral N | Dactyladenia | Flemingia | Mixture |
|---|---|---|---|---|---|
| INPUT | | | | | |
| Fertilizer | | 60 | 60 | 60 | 60 |
| Mulch | Added | | 7 | 8 | 7.5 |
| | Remaining | | 2 | 1 | 1 |
| | Released | | 5 | 7 | 6 |
| Total added | | 60 | 65 | 67 | 66 |
| OUTPUT (leachate) | | | | | |
| after 6 months | Amount | 18 ± 5 | 9 ± 3 | 9 ± 1 | 13 ± 3 |
| | % of added | 30 | 14 | 13 | 20 |
| after 12 months | Amount | 76 ± 18 | 48 ± 7 | 46 ± 4 | 51 ± 19 |
| | % of added | 127 | 74 | 69 | 77 |

The amounts of K leached over a 1 year period decreased in the order mulch mixture > *Flemingia* = mineral N > *Dactyladenia* mulch (Figure 12- 7, Table 12-4). The amount of K leached exceeded the input in the mineral N and mixed mulch treatment (Table 12-4).

Table 12-4. Potassium budget (values in kg $ha^{-1}$).

| | | Mineral N | Dactyladenia | Flemingia | Mixture |
|---|---|---|---|---|---|
| INPUT | | | | | |
| Fertilizer | | 60 | 60 | 60 | 60 |
| Mulch | Added | | 15 | 32 | 23 |
| | Remaining | | 0 | 0 | 0 |
| | Released | | 15 | 32 | 23 |
| Total added | | 60 | 75 | 92 | 83 |
| OUTPUT (leachate) | | | | | |
| after 6 months | Amount | 12 ± 5 | 7 ± 0 | 16 ± 7 | 23 ± 2 |
| | % of added | 20 | 9 | 17 | 28 |
| after 12 months | Amount | 63 ± 14 | 43 ± 4 | 69 ± 30 | 107 ± 6 |
| | % of added | 105 | 57 | 75 | 129 |

Leaching of base cations was in the order Ca > Mg >> K (Figures 12-3, 12-5 and 12-7).
The amount of mineral N leached did not differ between treatments for the first 3.5 months of the experiment (Figure 12-9). This period of time corresponds to 1100 L of water passing through the lysimeter or most of the duration of the heavy rains (Figure 12-1). After this period of heavy rains, there remained no difference in N leached between mulched treatments but the mineral N treatments leached substantially more N than the others (Figure 12-9). This trend suggests a retarded leaching of the N applied as ammonium sulfate, i.e., that the nitrate leached during the first 3.5 months originated mainly from soil N mineralization and that the N applied only began to leach substantially from the lysimeters at the beginning of the next rainy season (Figure 12-1).

One year after the start of the experiment, 3 to 5 times the N input had leached from the lysimeters (Table 12-5). From the nitrogen budget table, soil N mineralization rate can be estimated at about 200-300 kg N $ha^{-1}$ $year^{-1}$ (amount of min. N leached - N input). Soil N mineralization rate calculated this way was higher for the mineral N treatment (294 kg N $ha^{-1}$ $year^{-1}$ ) compared to the much treatments (190-200 kg N $ha^{-1}$ $year^{-1}$ ).

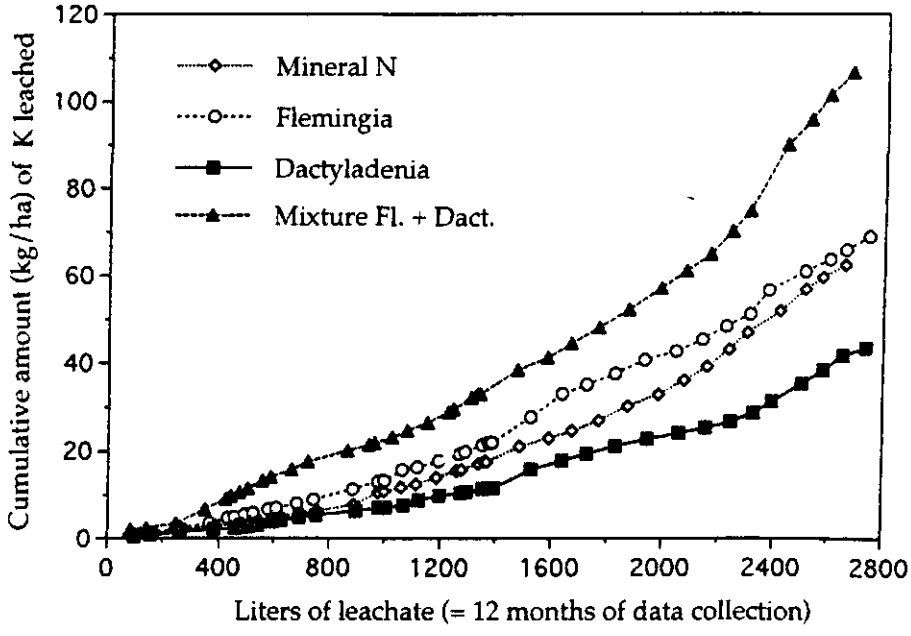


Figure 12-7. Cumulative amounts of K leached from the lysimeters.

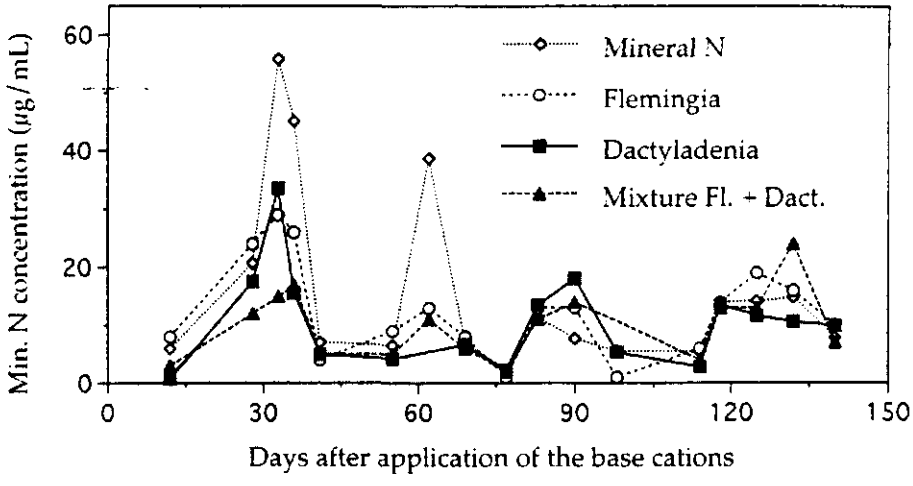


Figure 12-8. Nitrogen concentration in the soil water of the lysimeter top 10 cm.

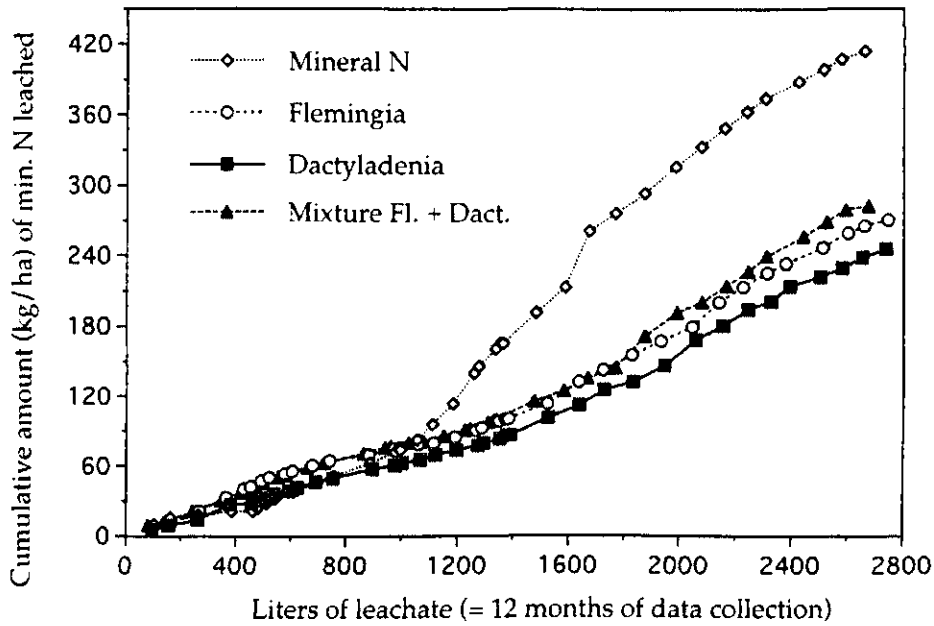


Figure 12-9. Cumulative amounts of N leached from the lysimeters.

Mineral N was nearly entirely (> 95 %) leached as nitrate and the cumulative mineral N leached was positively correlated ($R^2 = 0.95$) to the sum of Ca and Mg leached (Figure 12-10).

Table 12-5. Nitrogen budget (values in kg $ha^{-1}$).

| | | Mineral N | Dactyladenia | Flemingia | Mixture |
|---|---|---|---|---|---|
| INPUT | | | | | |
| Fertilizer | | 120 | | | |
| Mulch | Added | | 58 | 109 | 84 |
| | Remaining | | 10 | 15 | 15 |
| | Released | | 48 | 94 | 69 |
| Total added | | 120 | 48 | 94 | 69 |
| OUTPUT | (leachate $NO_3^-$ and $NH_4^+$ only) | | | | |
| after 6 months | Amount | 82 ± 7 | 62 ± 8 | 78 ± 4 | 79 ± 10 |
| | % of added | 68 | 129 | 83 | 114 |
| after 12 months | Amount | 414 ± 103 | 245 ± 38 | 270 ± 5 | 282 ± 78 |
| | % of added | 345 | 510 | 287 | 409 |

# Discussion

Leaching of Ca and Mg added as inorganic fertilizer to the soil in combination with mulch as nitrogen input was indeed less rapid than when Ca and Mg were added with inorganic N fertilizer (hypothesis 1), however, there was little effect of mulch quality on the amounts of Ca, Mg, and N leached (hypothesis 2). This suggests that the ability of the mulch to immobilize base cations was limited and that the leaching pattern observed in the mulch treatments is likely similar to what would have been observed in a no mulch and no mineral N treatment.

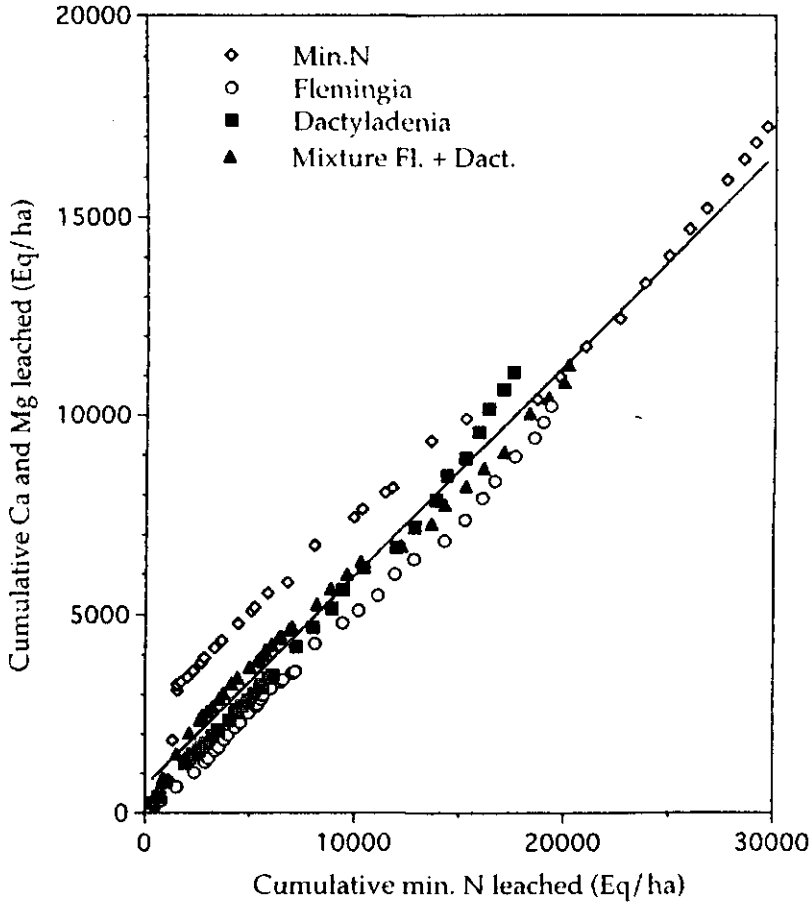


Figure 12-10. Relationship between the leaching of divalent base cations (Ca + Mg) and mineral N.

Divalent base cations (Ca and Mg) moved down the soil profile with mineral N (Fig. 10; mineral N is > 96 % $NO_3^-$), as previously observed by Raney (1960), Poss and Saragoni (1992) and Wong *et al.* (1992). Even tough *Flemingia* mulch had a substantially higher N content than *Dactyladenia* (2.7 vs. 1.6 %) and released in one year twice the amount of N that *Dactyladenia* did (94 kg N $ha^{-1}$ vs. 48), the amount of mineral N leached in the *Flemingia* treatment was only slightly higher and the amount of base cation leached was the same in the two treatments. This could have two explana-tions: (1) the N produced from the mineralization of the mulch was small compared to the N mineralized by the soil (calculated as about 200-300 kg $ha^{-1}$ $year^{-1}$) and (2) some of the N released by the mulch might be under organic rather than mineral form and therefore affect differently the movement of base cations.

Calcium losses from the lysimeters were greater than that of Mg and K and largely exceeded the Ca inputs in all treatments: losses were 170 (mulch treatment) or 360 (min. N treatment) % of the input and represented 140 or 220 $ha^{-1}$ $year^{-1}$. A very similar trend was observed in an oil palm plantation in Central-Southern Nigeria: losses of Ca exceeded those of Mg and K and native nutrients contributed substantially to the total loss (Omoti *et al.*, 1983). Calculated losses of native nutrients were 165 kg $ha^{-1}$ $year^{-1}$ for Ca, 32 kg for Mg, and 3 kg for K. Since there were no plants growing on the lysimeters in his study, losses exceed the ones that would normally occur by the amount that the vegetation would have taken up.
The study of Omoti *et al.* (1983) was conducted over a period of 4 months (June to November) and no difference was found between the amounts of cations leached, at 1.5 m depth, from the fertilized (with ammonium sulfate and base cations) and the non-fertilized lysimeters. The observation was interpreted as a good nutrient utilization by the oil palms. In this study, which

started in early July, there was no difference in the base cations leached from the mulch or mineral N treatments until November; differences started to appear only at the beginning of the next rainy season. This suggests that applied mineral N can reside in the soil for several months before being leached and that the lack of difference in cations leached between fertilized and non-fertilized lysimeters found by Omoti *et al.* may be due to the short duration of the observations.

The long residence of applied N in the soil column may be caused by a slow nitrification of the applied ammonium sulfate (nitrification proceeds more slowly at low pH: De Willigen (1985)) and/or a retarded leaching of nitrate due to small amounts of anion exchange capacity in the soil (Arora and Juo, 1982; Wong *et al.*, 1987; Melgar *et al.*, 1992).

The lesser quantity of K leached compared to the divalent cations has been explained by the strong affinity of the soil for K when its degree of saturation on the exchange complex is small (Pleysier *et al.*, 1979) and was also observed by Wong *et al.* (1992) and Omoti *et al.* (1983).

Differences between treatments in N and base cation concentrations in the lysimeter top soil water were unexpectedly small, this may be related to the severity of the rainfall during the first month of the experiment (577 mm in July 92).

# Conclusions

The type of green manure applied on the soil (and probably even its presence) affected little the base cation and N output of the soil column at 1.3 m depth. Application of inorganic N fertilizer, in contrast, resulted in substantial losses of K, Ca, and Mg. Losses in base cation increase soil acidity. In the humid tropics where soils are inherently poor in base cations and have a low CEC, base cation conservation is of primary importance and is better achieved with mulch than mineral N fertilizer. Because leaching of Ca + Mg is proportional to that of nitrate, the management of base cations in the soil is intimately tied to the management of nitrogen.

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