Slash and Burn Agriculture in the Humid Forest Zone of Southern Cameroon: Soil Quality Dynamics, Improved Fallow Management and Farmers' Perceptions

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Dedicated to:
Carmen Godwin, Ann Godlove, Grace Jessie and Dan Emmanuel, my children

ABSTRACT

A field study was conducted on acid soils in the humid forest zone of Southern Cameroon, to characterize the traditional slash-and-burn land uses, assess the major effects of land use change on soil nutrient stocks, flows, and soil biological quality, and to explore alternatives for sustainable land management. The typical land use chronosequence in the area after forest felling includes *essep* (cucumber-based), banana, and *afup* (groundnut/cassava-based), and is interrupted by short (after banana) and long (after *afup)* fallows. Moreover, farmers have cocoa farms where many shade trees are kept. Yield declines in farmers' fields were attributed to diseases and weed infestation (56%) and soil properties (44%). Burning is practiced prior to *essep,* and prior to *afup.* It reduces the weed seed-bank, cleans the field and improves short-term soil fertility, but, together with changing land use, it strongly reduces standing biomass, carbon and nutrient stocks in the vegetation. The forest carbon stock decreased from 199 $Mg.ha^{-1}$ to 102 $Mg.ha^{-1}$ in *essep*, and to 64 $Mg.ha^{-1}$ in banana farm. Nutrient stocks showed the same trend, but *Chromolaena* short fallow, that followed banana, recovered most of the P. The cocoa plantation had 53 % of the carbon stocks of the original forest. Soil carbon stock was less affected than vegetation stocks. Burning increased P, K, Ca and Mg available stocks in *essep* and *afup*. Lowest 'system' C and N occurred in *afup*, which is followed by a long fallow to restore soil fertility. The nutrient balance at farm level was strongly negative, i.e., -72.6 kg N, -4.8 kg P and -38.2 kg K $ha^{-1}yr^{-1}$, showing its 'no external input' character, where food and wood are derived from natural stocks. Major losses were due to burning, leaching and the non-recycling of farm residues. Only the cocoa farm had a positive nutrient balance: +9.6 kg N, +1.4 kg P and +7.6 kg K $ha^{-1}.yr^{-1}$, as burning is absent, leaching modest, and deep capture by shade trees providing inputs to the productive system. Simple scenarios showed that recycling farm residues is able to redress the P and K balance, and avoiding burning could even turn the entire nutrient balance positive. Burning also negatively affected earthworm density and casting activities. Up to 95% loss in density was recorded, and casting activity was inhibited during 14 and 19 months in land use systems following *afup* and *essep* respectively. *Inga* fallow proved to favour rapid and intensive casting just as the forest ecosystem. Total cast production was: 5.9 $Mg.ha^{-1}$ in *afup*, 3.2 $Mg.ha^{-1}$ in forest and *Inga*, and 2.9 $Mg.ha^{-1}$ in *essep* after two years, but although the casts were richer in nutrients than the topsoil, the nutrients recycled from casts alone were insufficient for sustained crop production. *Inga edulis* was found to be a suitable planted fallow, providing several benefits to farmers and follow-up crops. *Inga* fallows produce more biomass (between 44.5 and 62 Mg ha^{-1}), and accumulate more C and N than natural fallow. Maize following *Inga* fallow yielded 800 to 2200 kg. ha^{-1}, against a mere 200-400 $kg.ha^{-1}$ after natural fallow. Burning *Inga* residues gave *ngon* (cucumber) production of 300 $kg.ha^{-1}$, which is similar to yields obtained in *essep* following natural forest. Mulching instead of burning, however, only gave 50 $kg.ha^{-1}$. An innovative on-farm approach was used in the development and implementation of planted fallows, ensuring high adoption. *Inga edulis* planted fallow can play a leading role among strategies to fight the gradual process of land degradation in the land use chronosequence, providing wood and fruits, and mimicking the natural forest to a considerable extent.

Key words: crop yields, earthworm cast, *Inga edulis*, land use, nutrient flows, nutrient stocks, nutrient management, slash and burn

CONTENTS

Chapter 1

GENERAL INTRODUCTION

GENERAL INTRODUCTION

The humid forest environment

The stability of the tropical humid forest relies on its large species diversity and relatively closed nutrient cycles, i.e. the dynamic equilibrium between the natural inputs and outputs of the system (Fresco and Kroonenberg, 1992; Leiros et al., 1999). An undisturbed tropical rain forest can maintain 300-500 $Mg.ha^{-1}$ of dry standing biomass (Bruijnzeel et al., 1994). In southern Cameroon about 1335 km^2 of forest is felled every year because of slash-and-burn agriculture by smallholders (Kotto-Same et al., 1997). Slash-and-burn used to be a viable ecological strategy to sustain agriculture in the tropics. Farmers maintained different plots, resulting in a mosaic of plots under cropping and fallow, allowing natural processes of soil regeneration (Bandy et al., 1993; Altieri, 2002), but human activities of non-sustainable agricultural practices disrupt this equilibrium.

Shifting cultivation

Shifting cultivation has long been considered the most adapted farming system for the humid forest zone (Bandy et al., 1993), especially in areas of low population density (Nye et Greenland, 1960). There is a nutrient flux during slash-burning: ash from burned biomass is incorporated into the soil resulting in an increase in soil fertility. Carbon and N are largely volatilised but P and cations are transferred from the biomass to ash and then into the soil. During subsequent rains, cations may be leached, but generally soils are enriched by ash after rainfall (Nye and Greenland, 1960; Giardina et al., 2000). Farmers will grow crops for a few years, until soil fertility, weed infestation and diseases (Akobundu, 1987) reduce crop yield below an acceptable level. The plot will then be left to a period of restorative fallow (Seubert et al., 1977; De Rouw, 1994).

In the shifting cultivation farming system, the soil can only fully recover if left undisturbed for many years during long fallow or in improved fallow systems (Ahn, 1979). Fallows in this way help to re-establish the equilibrium that prevailed initially in the soil before the clearing of the forest. Unfortunately, some major external driving forces have led farmers to reduce the fallow period. Increasing population density in forest regions and the subsequent increasing demand for food, fiber and shelter forced farmers to shorten fallow length, hence jeopardizing the sustainability of this farming system (Eyasu and Scoones, 1998). The practice of slash-and-burn is reported to negatively affect soil quality, thereby compromising the resilience of the system (Lal, 1997).

Soil quality and resilience

Soil quality and resilience have a profound impact on productivity and environmental quality. Soil quality refers to the soil's capacity to produce economic goods and services and to regulate the environment (Lal, 1997), to its capacity to sustain plant and animal productivity, maintain or enhance water quality and promote plant and animal health (Jeffrey, 2000). Soil quality is thus an ideal indicator of sustainable land management (Lal, 1993). Soil resilience is its ability to restore its life support processes and environmental regulatory functions after major anthropogenic perturbations, that is, its ability to absorb changes (Fresco and

Kroonenberg, 1992; Lal, 1993). Agricultural practices are among the largest sources of stress and disturbance of the environment (Brussaard, 1994).

Soil biological processes contribute to soil fertility enhancement by increasing the amount and efficiency of nutrient acquisition and recycling, the regulation of the retention and flow of water and nutrients and the maintenance of good soil physical structure (Kang et al., 1991). Soil biological processes influence ecosystem functioning through nutrient cycling, organic matter transformation, microbial oxidation and respiration, biological nitrogen fixation, mineralization, humification, decomposition and nutrient retention.

Through their feeding and nesting activities, soil macrofauna generate and maintain soil chemical, physical and biological characteristics within the ecosystem (Berry, 1994). Soil macrofauna is known to exert intense activities in the soil that affect the soil fertility (Roy-Noel, 1979; Brussaard, 1994). Earthworms can directly or indirectly modify soil properties through their feeding activities, burrowing and casting (Berry, 1994). However, their populations are checked not only by soil parameters but also by land use practices such as slashing and burning and soil tillage, as well as by climatic conditions and regional variation in vegetation and food sources (Hauser, 1993; Lavelle et al., 1998). When the ecosystem is degraded through human activities, there is an inevitable reduction of faunal density and diversity (Waid, 1999), thus affecting the ecosystem functioning.

Integrated nutrient management

Integrated nutrient management (INM) can be defined as the 'judicious manipulation of nutrient stocks and flows so as to realize satisfactory and sustainable agricultural production'. Making such an, at first sight, indeterminate definition concrete, requires

- calculation of nutrient stocks and flows
- decide on the meaning of 'judicious, satisfactory and sustainable'

In brief, we could say that 'judicious' refers to the technologies, i.e., to the type of management chosen by the farmer, the farm family or the village community. The degree of 'judiciousness' can be improved if farmers are supported by informed third parties, such as extension agents, NGOs, researchers, and the likes. 'Satisfactory' can refer to what farmers regard as the required production level to be self-supporting, or the to-be-realized farm income. Risk aversion plays a role here, and competes with profit maximization. National governments can also play a role here in setting national production targets for strategic commodities such as staple foods. 'Sustainable' can refer to the famous UNCED definition from 1992, in which future generations should be able to make use of the same production potential as we do. This may imply that nutrient stocks do not deteriorate, again implying that nutrient inflows and outflows are more of less balanced.

INM technologies can be grouped into those that:

- SAVE nutrients from being lost from the system
- ADD new nutrients to the system
- CASH IN on natural soil fertility
- ROUTE nutrients into a direction where OUT 1/kg nutrient is highest

(OUT 1 is the quantity of nutrients N, P, K exported in crop products sold. For further details on the methodology of quantifying OUT 1 and all relevant stocks and flows, see Figure 1 in Chapter 4).

SAVE nutrients from being lost from the system
This refers mainly to low-external input systems, which focus much on good use of 'Internal Flows', such as the links between crop residue removal and application of manure. More specifically, it relates to the removal of residues from Primary Production Units (PPUs) to the paddock where Secondary Production Units (SPU) feed on them. Part of the residues is turned into body mass and perhaps milk and meat, but an approximate 80% is turned into manure, which has become part of the paddock, which is a Redistribution Unit. From there, it may be taken back to other PPUs in the farm. Similarly, erosion control measures fall under 'SAVE'. Stone rows and contour ridges are meant to stop movements of soil and water so that nutrients are not leaving the system through (erosion) OUT 5. Examples: Sahelian, millet-based systems without inputs, that rely on composting, manuring and harmattan dust.

ADD new nutrients to the system
New nutrients to the system are supplied by mineral fertilizers (IN 1), and by amendments such as rock phosphates, lime and dolomite (although the latter are primarily meant to resolve acidity problems). Organic inputs from outside the farm (manure from animals that roam outside the farm, concentrates and other animal feeds, compost from town, non-farm food waste, etc.; IN 2) can be important, and so is the fixation of atmospheric nitrogen by rhizobia in leguminous species, non-symbiotic N-fixers, and by algae and *Azolla* in wetland systems (IN 4). In downstream wetland systems and irrigated systems, nutrients are also added from outside as they receive water that contains sediments and dissolved nutrients. Examples: Asian irrigated rice-based systems, often involving two to three crops per year.

CASH IN on natural soil fertility
Soil fertility in humid forest zones is low due to old age of the landscape. Both Central Africa and the Amazon region are on geologically inactive old surface that are billions of years of age, and have low pH, leached soils made up of low-activity clays. Still, the natural vegetation is lush and rich. In that sense, the soils may be poor but the total above-ground and below-ground system has a lot to offer. Hence, farmers in forest margins tend to cash in on nutrient reserves through slash and burn. In areas that are sparsely populated, this system may be perfectly sustainable, but with increasing population pressure, lands are opened up and cultivated semi-frequently. Short-term advantages derived from burning (pH increase, readily available nutrients, weed suppression) are believed to be offset by longer-term deterioration of the soils, which, without their majestic vegetation cover, have little to offer, once carbon and nutrients have been lost by burning, other gaseous loss processes, leaching and crop uptake. Examples: Forest margins, where total (above- and below-ground) system nutrient stocks are high.

ROUTE nutrients for highest agronomic efficiency
Routing refers to the concept of factor productivity. It can refer to both 'adding' and 'saving'. 'Cashing in' is always unsustainable, with the exception of traditional shifting cultivation societies. A proper understanding of (1) nutrient stocks, and balances between nutrients that are part of the stock, (2) yields that can be realized, and (3) additional inputs needed to get there, will help achieving high agronomic efficiency (high yield or high dry matter per kg nutrient). Proper routing gives high Yield or dry matter/OUT 1 ratios as well as high Yield or dry matter/IN 1 ratios.

INM is a way of farming in which Saving, Adding, and Routing are addressed at the same time through the management of the Inputs, Outputs and Internal Flows. The ideal situation arises where farmers make the most efficient use of the production factors capital, labour and land, i.e., realizing high output/input, both in agronomic as well as in monetary units.

RATIONALE OF THE STUDY

Global climate change
At the global scale, land use dynamics are related to climate changes (Bruijnzeel et al., 1994). Changes in soil capacity to produce and consume atmospheric gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) can influence atmospheric quality. The present threat of global climate changes and ozone depletion through elevated levels of greenhouse gases is partly associated with the decline of the forest ecosystem (Smaling et al., 1999; FAO, 2002). Methane, carbon dioxide, and nitrous oxide are the most important greenhouse gases and the agricultural sector is believed to substantially contribute to their emission through the high use of fertilizers, slash-and-burn agriculture and intensive agriculture (Smaling et al., 1999).

Strategies to improve the resilience of tropical soils
There is an urgent need for the development of highly productive, yet sustainable land use systems that can support the growing population without degrading the natural resource base (Muschler and Bonnemann, 1997) in the humid forest zone. Integrated nutrient management including agroforestry is envisaged as a potential means to increase the resilience of farmland and redress the negative nutrient balance. The methodological approach needs to start by the characterisation of the initial resource base, investigation of the impact of the actual management on the natural resource base and the identification and development of alternative management options, with the potential to revert the current trend. The urgent need to combat rural poverty and conserve and regenerate the deteriorated resource base of small farms requires an active search for new kinds of agricultural research and resource management strategies. These strategies must be based on a more innovative approach for technology development and dissemination (Altieri, 2002).

Inherent soil fertility
The soils in Southern Cameroon are generally Oxisols and Ultisols (US taxonomy), equivalent to Ferralsols and Acrisols (FAO taxonomy). These are strongly weathered and acidic soils dominated by low activity clays (kaolinite, hematite, goethite and gibbsite) and a low base saturation. Ferralsols have very poor chemical

properties; they have low nutrient levels in the soil solution, aggravated by Al and Mn toxicity (Kang et al.1991) and strong inactivation of P because of a high content of sesquioxides. In such soils, K, Ca and Mg are bound in low amounts, and concentrations in the soil solution are low. Replenishment from other sources is crucial for proper plant/crop growth. They however have good physical properties to great depth, high permeability and stable macrostructure. The old shifting cultivation systems in the humid forest zones are under pressure, the soils are old and poor but the system as a whole is rich thanks to the nutrients in the forest. The challenge is to develop sustainable land uses system, taking into account the biophysical, socio-economic and environmental constraints in natural resource management.

Objectives of the thesis

The objectives of this study are to

- Quantify the effects of major perturbations due to land use changes along the slash-and-burn chronosequence on soil nutrient stocks and fluxes and soil biological quality at different spatial scales.
- Explore alternative land and nutrient management strategies that may redress the nutrient balance and reverse the trend of soil quality degradation.
- Develop a methodological approach to implement alternative management strategies at farmer level, to ensure high adoption rates.

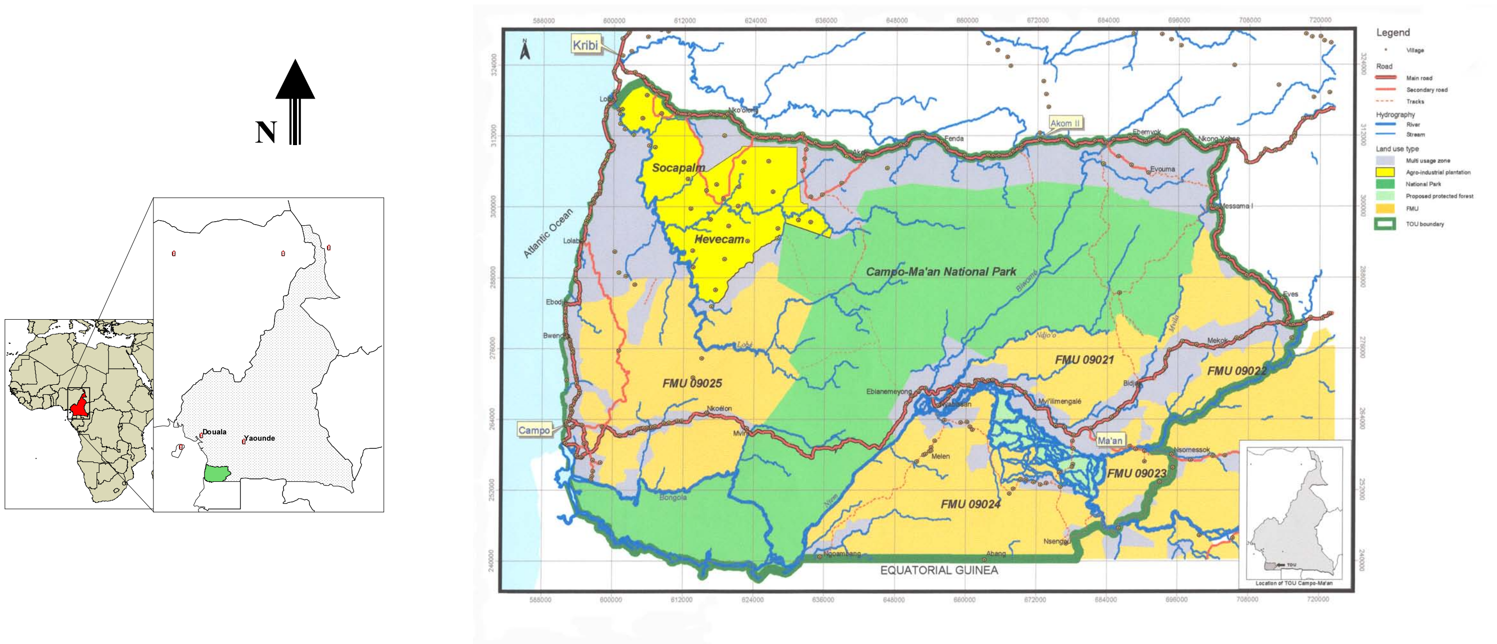
GENERAL METHODOLOGY

Site description

The study described in this thesis has been conducted in small-holder farms in the buffer zone of the Technical and Operational management Unit (UTO) Campo Ma'an located between 2^o 10' -2^{o}52' N, and 9^{o}50' – 10^{o}54' E (Figure 1). The UTO covers a land area of about 771,000 ha out of which 203,000 ha (26%) are devoted to agriculture, in the "Océan" and "Vallée du Ntem" Divisions of Southern Cameroon. The climate of the site is sub-equatorial, with a bimodal rainfall distribution, and four distinct seasons: two humid seasons, September – November (heaviest rainfall) and April - May, and two dry seasons December - March and June – August. The annual rainfall is 3000 mm on the coastal plain and decreases to 1800 mm in the eastern part of the site. The mean annual temperature is 25^{o}C. Generally, the climate gradually changes with increasing distance from the coast and with elevation. Inland the annual rainfall and temperature tend to decrease.

The topography varies from west to east. The coastal plain has an elevation ranging from the sea level to 100 m altitude, then the "Massif des Mamelles" culminating at 1050 m and then the eastern plateau between 300 and 600 m altitude. The south-east and south are dominated by the flood plain of the Ntem river. The vegetation of the site forms part of the humid evergreen forest. The coastal region is dominated by the dense Atlantic Biafran forest, with *Ceasalpiniaceae* and *Socoglottis gabonensis*, at an altitude between 20 and 200 m asl. Mixed evergreen Atlantic forests are restricted to the mountainous region at an altitude above 500 m asl. The eastern zone is covered by primary and secondary lowland forest, swamp forest in the Ntem valley and recently abandoned fields and plantations (Van Gemerden and Hazeu, 1999; Dijk, 1999).

Figure 1. Localisation map of the UTO Campo Ma'an



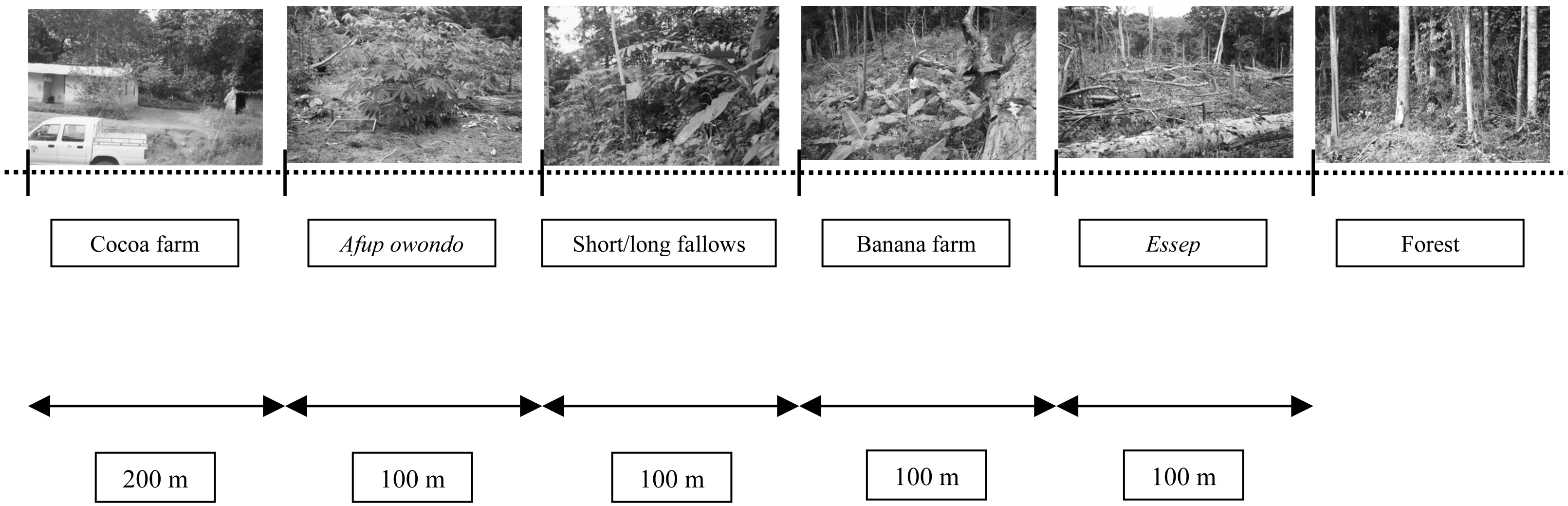
The population density of the site is low, 3.5 inhabitants.km^{-2}. The major ethnic groups are *Ntoumou*, *Mvae* and *Bulu*. Agriculture is the main activity of 84% of the population while hunting and fishing is practiced by 15%. The household size is 5 to 7. The major land uses in the traditional farming system of the study sites are the *essep*, banana farm, *afup owondo*, and cocoa plantation, as described below.

In Southern Cameroon, the conversion of the forest to agriculture starts with the selective cutting and incomplete burning of the forest vegetation preserving useful trees, upon which cucumber and banana (plantain) are planted. This first land use is locally referred to as *essep* or forest farm. In year 2, cucumber is harvested, the field is managed for intensive banana production for 2 to 3 years, and called banana farm. After banana, the plot is left fallow for a few years, then slashed and burned again and planted to food crop; the field is called *afup owondo*. The slash-and-burn chronosequence considered in this study was: the secondary forest, the *essep*, the banana plantation, the short fallow, the *afup owondo* and the long fallow. Two additional land uses were also considered for comparison, the *Inga edulis* planted fallow, and the cocoa plantation. The different land uses are summarized in Figure 2.

Outline of the thesis

Chapter 2 of this thesis investigates farmers' indigenous knowledge in soil resource management. Chapter 3 estimates the natural resource base, and how it is affected along the slash-and-burn chronosequence. Chapter 4 is the quantitative assessment of nutrient transfers through the different farming activities, to assess which activities are the most depletive. Chapter 5 evaluates the effects of land use changes, on density and casting activity of earthworms, and on nutrient recycling potentials of the system. Chapter 6 investigates the potentials of *Inga edulis* planted fallow to redress the current trend in land degradation, and Chapter 7 evaluates the timing for successful introduction of *Inga edulis* in the traditional farming system. Chapter 8 is a methodological approach for effective introduction of planted fallows in the traditional farming, and for ensuring farmers' involvement. Chapter 9 puts together the major findings of the thesis, and makes recommendations for replenishing soil fertility and restoring the nutrient balance in traditional farming systems in the humid forest zone of southern Cameroon.

Figure 2. A transect showing a toposequence of the different traditional land uses in the Campo Ma'an area, southern Cameroon.



Chapter 2

LAND DEGRADATION UNDER SLASH-AND-BURN AGRICULTURE IN THE HUMID FOREST ZONE: FARMERS' PERCEPTIONS AND THEIR MANAGEMENT STRATEGIES

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ABSTRACT

A field study was initiated in the buffer zone around the Campo Ma'an national park, in southern Cameroon, to assess farmers' indigenous knowledge of soil fertility, and their management strategies of natural resources. Farmers mentioned the infestation with weeds, occurrence of diseases, low soil moisture retention, soil colour and soil density or compaction as indicators of soil quality. In *essep*, soil compaction and diseases limit *ngon* production; in banana, compact soil, diseases and weeds; in *afup owondo*, weed infestation, compact soil, and diseases; and in cocoa farm, diseases and weeds were most frequently mentioned. Diseases and weed infestation accounted for 56% and soil- related factors for 44% of factors mentioned by farmers. Farmers consider soil fertility problems as part of a wide complex of interacting constraints and perceive yield decline as resulting from these interactions. *Essep* is first in the chronosequence, as *ngon* requires weed- and disease-free plots. After the *essep*, logs progressively rot and release nutrients for the next crop (banana). *Afup* is established on *Chromolaena odorata* fallows after complete burning. Burning reduces the weed seed bank, cleans the field and improves soil fertility. At harvest groundnut stems are used as mulch for crops remaining in the field. In cocoa plantations farmers rely on shade trees for fertility maintenance. Tree densities were 24, 12, 25 and 145 trees ha^{-1} in *essep*, banana, *afup* and cocoa, respectively. Through shade management farmers regulate light, temperature, and humidity, which affect the incidence of pests and diseases. A total of 104 tree species were identified; 99 occurred in cocoa plantation, 14 in *essep*, 8 in banana and 15 in *afup*. Farmers valued fruit trees (27 species) and medicinal trees (53 species) most. Farmers preserve and protect forest resources and biodiversity in cocoa compared to other land uses. Farmers planted many fruit trees in cocoa and *afup.* Fruit trees highly contributed to household revenues. The domestication of the most valuable tree species, especially food-related or income-generating species, offers considerable scope for enhancing the food and economic security of subsistence farmers, thus allowing farmers to invest in tree-based systems.

Key words: humid forest, indigenous knowledge, integrated nutrient management, land degradation, soil fertility indicators.

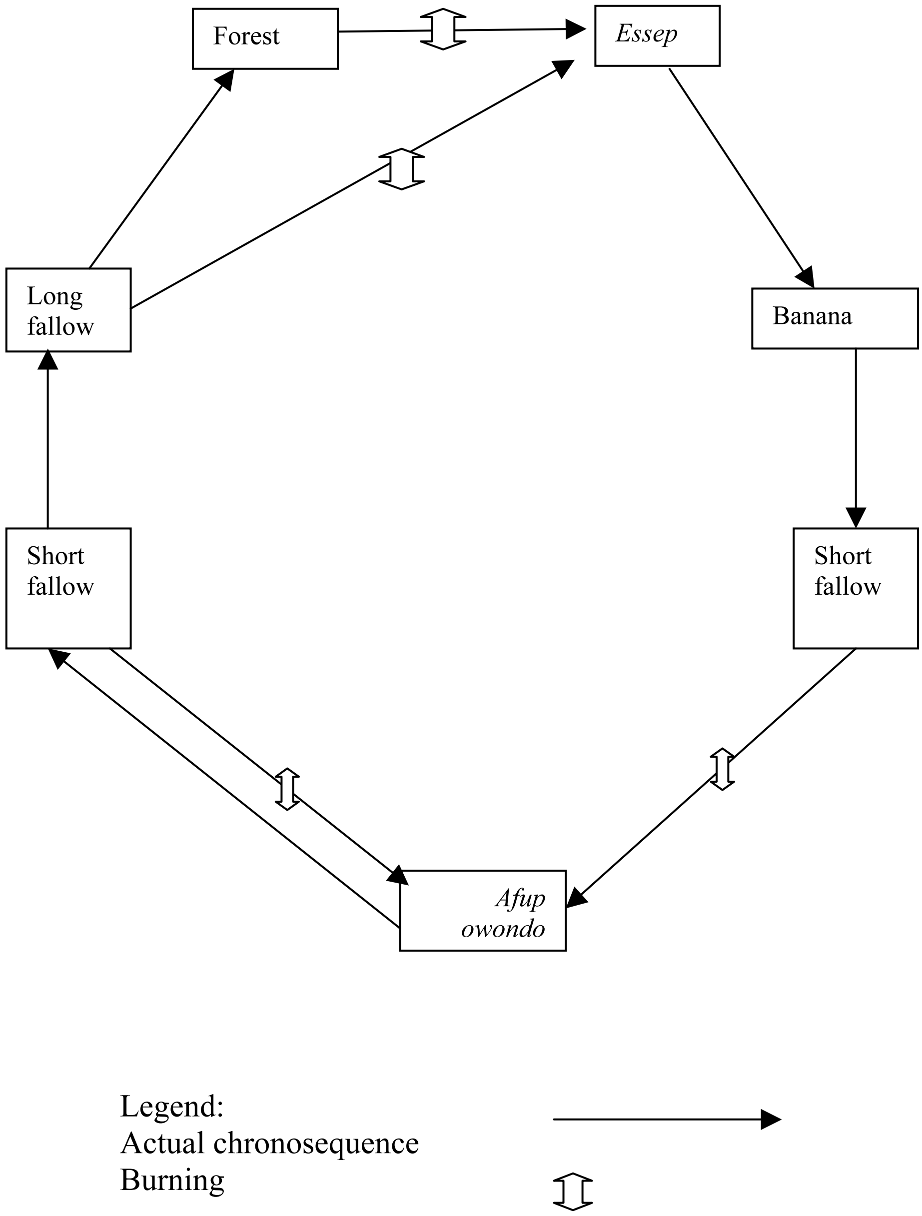
INTRODUCTION

Shifting cultivation is generally described as a sustainable farming system in sparsely populated areas, as farmers can allow long restorative fallow periods. It has been practiced over decades throughout the forest zone of southern Cameroon, with less than 10 inhabitants per km^2. Rural household income was generated usually from cocoa plantations. Significant changes in land uses are noticeable all over the humid forest zone. (1) During the late 1980s, the drastic fall in world prices of cocoa, the fluctuating cocoa prices at farmer level, and the cessation of state subsidies on farm inputs, forced farmers to abandon cocoa and look for other income-generating opportunities, mostly food crop production. (2) Many state employees who lost their jobs or faced salary cuts increased their activity in food crop production to compensate for the lost income. This led to a very significant increase in forest clearing with its attendant profound negative environmental consequences (Duguma et al., 2001). Kotto-Same et al. (1997) estimated that about 1335 km^2 of forest is lost every year in southern Cameroon because of shifting cultivation. More specifically for the Campo Ma'an area in southern Cameroon, (3) farmers abandoned cocoa farms and turned to intensive hunting in the adjacent forest reserve. The foundation of the reserve in the Campo Ma'an national park, with restricted access to the natural resources of the park, forced farmers to intensify food crop production in the buffer zone. Also (4) the development of trans-border markets with Gabon and Equatorial Guinea and the creation of large settlement zones around agro-industrial complexes (HEVECAM and SOCAPALM) increased the demand for food crops and, thus, agricultural intensification.

The sequence of land use of smallholders in the forest zone is summarized in Figure 1. Farmers select a forest plot, based on the presence of fertile soil indicator species (Year 0), then convert it to *essep* (year 1). The following years come banana (year 2), a short fallow (year 3 and 4), *afup owondo* (year 5) and cassava (Year 6). Then the plot is left for a long fallow (6 to 15 –20 years). The long fallow can be reconverted to *essep*. *Essep* is actually the main source of income for farmers in the zone, since the collapse of the cocoa market. Every year, every household creates about 1.2 ha of *essep*, either from the forest or from long fallows. After the *essep*, the same plot can be reconverted to *essep* after a minimum of 15-20 years.

The driving forces mentioned above resulted in intensification of food cropping and induced changes in land use systems, especially shorter fallows, which led to declining soil fertility and land degradation, resulting in increasing constraints on local people's livelihoods. Information about farmers' perception of soil fertility and the importance they attach to it may be useful when searching for technologies to overcome nutrient deficiencies (Buttner and Hauser, 2003). Hence, this paper attempts to identify indicators that are consistent with farmers' perceptions of soil fertility, then assess farmers' strategies in response to these changes, and make a link between their strategies and soil fertility restoration.

Figure 1. Land use changes of the slash-and-burn chronosequence in the humid forest zone



Methodology

The study site

The study was conducted in the agroforestry zone that constitutes the buffer zone around the Campo Ma'an national park, in southern Cameroon. The park is located between 2° 10' -2°52' N, and 9°50' – 10°54' E. The climate of the site is sub-equatorial, with a bimodal rainfall distribution. The humid seasons are September – November (heaviest rainfall) and April - May, and the dryer seasons December - March and June – August. The annual rainfall is 3000 mm on the coastal plain and decreases to 1800 mm in the eastern part of the site. The mean annual temperature is 25°C. The climate gradually changes with increasing distance from the coast and with elevation. Inland the annual rainfall and temperature tend to decrease. The soils are Oxisols/Ultisols. The vegetation of the study site is a humid tropical forest. The population density less than 10 inhabitants.km^{-2}. The active population of the Campo Ma'an region is mostly involved in fishing on the coast, then agriculture and hunting in the inland.

Description of the questionnaire

The research methodology was based on interviews and field observations. The sample unit was the farm household with the head of the household as the respondent. A questionnaire was offered to a random sample of 154 households in 4 different zones of the Campo Ma'an national park. The main focus was farmers' perception of land degradation and their soil fertility management strategies, and the role of trees in land use management. Questions were asked on land use change, factors governing such changes, management of crop residues, household waste, animal dejections and availability of chemical fertilizers (Annex 1).

Out of these 154 households, 30 were chosen for ethno-botanical and field surveys on the basis of the importance of agriculture in the household enterprises. After obtaining permission to survey the different fields (cocoa farm, *essep*, banana farm, and *afup owondo*) existing in the farm, we used the assistance of the owner to identify the species, density and uses of the different trees occurring in a 40 x 40 m quadrate demarcated in each land use.

Results

Trees in traditional land uses

From the field survey, 104 tree species were identified in the different land uses. Farmers identified the tree species by local names, and from the literature and with assistance from the National Herbarium in Cameroon, 83 species, belonging to 38 families, were taxonomically identified (genus, species, family), see Annex 2. The most valuable trees for farmers were fruit- and food-related tree species, providing spices, insect larvae and essential oils. A total of 27 species were registered in this group; the most frequently used fruit trees were *Persea americama*, *Dacryodes edulis*, *Citrus spp* and *Irvingia gabonensis* (Table 1). Farmers also valued 53 tree species with medicinal uses. Farmers use leaves, roots or bark of the different trees, but the list of diseases cured was not consistent among the different households. The most frequently used trees in the farms were *Alstonia boonei*, *Anthocleista schweinfurththii*, and *Funtumia elastica*.

Most of the tree species occurred in cocoa plantation, where 99 different species were found compared to 14 in *essep*, 8 in banana and 15 in *afup*. In cocoa farms, farmers preserved and protected forest resources and biodiversity more than in other land uses in the slash-and-burn chronosequence. The primary use for trees in cocoa plantations was to provide shade.

Table 1. Tree species planted by farmers in land uses of southern Cameroon

Scientific name	Family	Main Use	Where planted
Alstonia boonei	Apocynaceae	Medicinal	*Essep*
Baillonella toxisperma	Sapotaceae	Fruits/timber	*Essep*
Ceiba pentandra	Bombacaceae	Timber /shade	*Afup owondo*
Citrus spp.	Rutaceae	Fruits	Cocoa plantation
Dacryodes edulis	Burseraceae	Fruits	Cocoa plantation
Dacryodes macrophylla	Burseraceae	Fruits	Cocoa plantation
Garcinia Kola	Clusiaceae	Fruits	Banana farm
Irvingia gabonensis	Irvingiaceae	Fruits	Cocoa plantation
Lophira alata	Ochnaceae	Timber	*Essep*
Mangifera indica	Anacardiaceae	Fruits	Cocoa plantation
Cola acuminata	Sterculiaceae	Fruits	Cocoa plantation
Mansonia altissima	Sterculiaceae	Timber	*Essep*
Milicia excelsa	Moraceae	Timber	*Afup owondo*
Persea americana	Lauraceae	Fruits	Cocoa plantation
Pycnanthus angolensis	Myristicaceae	Timber	Banana farm
Terminalia superba	Combretaceae	Timber	*Essep*
Trichoscypha acuminata	Anacardiaceae	Fruits	Cocoa plantation

Tree density

During the initial forest clearing for *essep*, farmers allow only 24 trees ha^{-1}. The trees left are indigenous trees with food-related uses (*Baillonella toxisperma*, *Irvingia gabonensis*, *Ricinodendron heudelotii*), high value timber tree species (*Disthemonanthus benthamianus*, *Lovoa thrichiloides*) or simply those which they are unable to fell with their simple tools. In banana only 12 trees ha^{-1} were found, some of the trees left after forest clearing died after burning. *Afup owondo* has more trees, 25 trees ha^{-1}, most of which are fruit trees planted by farmers. Crop species in *essep*, banana and *afup* are not shade-tolerant, and allowing more trees would increase shade and result in crop failure. In the cocoa plantation, 146 trees ha^{-1} were counted. Trees found in the farms were purposely protected or planted by farmers for specific uses.

Indicators of soil fertility

For farmers, it was difficult to separate soil fertility and crop yield, so we rather investigated the major factors limiting or reducing crop yield in the different land uses. Farmers mentioned the infestation with weeds, occurrence of diseases, low soil moisture retention, soil colour and soil density or compaction as the most important factors. The different factors combined at different rates to affect crop yield in the different land uses (Table 2). In *essep*, soil density and diseases were the most limiting factors to *ngon* production. In banana, the dominant factors were soil density, diseases and weeds. In *afup owondo*, farmers mentioned weed infestation, soil density, and diseases as major constraints to food crop production. In cocoa farm, diseases and weeds were the factors most frequently mentioned.

Table 2. Factors limiting crop yield in the different land uses, mentioned by 30 farmers of southern Cameroon

Indicators	Land use				Total score	Frequency (%)
	Cocoa	*Essep*	Banana	Food crop		
Soil moisture	7	4	2	3	16	9.2
Soil density	9	11	8	16	44	25.1
Weed	16	7	7	18	48	27.4
Diseases	19	11	8	12	50	28.6
Soil colour	4	3	3	7	17	9.7
Total score	55	36	28	56	175	

Farmers preferred black soils, soils with low density, and soils with high moisture retention. Soils with high density are hard to till and do not allow crop roots and tubers to develop. In *afup* it reduces groundnut grain yield and cassava tuber size. In banana farm it allows only superficial rooting of plantain, therefore it increases vulnerability to wind. Soils with high moisture content are important in cocoa plantation, to allow cocoa to survive the long dry season. On low moisture retention soil, cocoa dries out completely during some dry seasons in spite of the shade trees. Farmers considered black soils more fertile than red soils, particularly in *afup owondo*. However, in this land use, other factors such as weed infestation, diseases and soil density were considered more important.

Diseases and weed infestation accounted for 56% of the factors mentioned by farmers, and soil-related factors 44%. Soil-related factors were mainly physical (density and moisture). Soil colour, which is related to soil organic matter content, was rated lower than weed infestation and diseases. Farmers consider soil fertility problems as part of a wide complex of interacting constraints and perceive yield decline as resulting from these interactions. When the weed infestation or the disease incidence is high on a plot, farmers usually abandon it to bush fallow.

Strategies in soil fertility management

Essep is established after slashing and burning a forest or a long-fallow plot. Farmers considered forests and long fallows to be weed- and disease-free, and used burning to improve soil fertility. *Ngon* is a high value, disease- and fertility-sensitive crop (*essep*). The sales of *ngon* and plantain generally compensate for the hired labour for tree-felling. *Ngon* grows fast and uses nutrients from the burning of the forest residues. As a climber, the vines grow around the unburned logs, increase the humidity and thereby accelerate wood decomposition. Nutrients from the decomposing logs will maintain plantain production for 1 to 2 years before the plot is left to fallow.

Food crops (*afup owondo*) are established on short fallows, usually *Chromolaena odorata* fallows. Groundnut requires a clean field, therefore clearing and complete burning of the residue. The residues remaining after burning are piled up and burned again, resulting in accumulation of wood ash in some areas of the field. Farmers also recognize spots of high fertility resulting from high burning intensity and decomposing logs. They usually plant special crops such as onions, tomatoes and fruit vegetables on such areas. When burning is not possible because of early rains, farmers remove all the slashed vegetation before planting of groundnut. Burning reduces the *Chromolaena* seed bank, thus delaying weeding operations, and improves soil fertility. On *afup owondo* farmers grow a diversity of crops, with different harvesting sequence; fast-growing crops such as groundnut, maize and vegetables, rapidly use nutrients from the ash. Slow-growing crops such as cassava, cocoyam, yam and sugar cane stay longer in the field and make use of nutrients remaining in the soil. During groundnut harvest, the stems are accumulated under crops remaining in the field, usually cassava and cocoyam, to improve tuber yield.

Cocoa plantations used to be amended with chemical fertilizers, but since the removal of state subsidies, farmers cannot afford them any longer. Farmers consider some tree species as indicators of fertile soils; during clearing for the establishment of cocoa farms, such trees are preserved for the purpose of soil fertility maintenance in the cocoa agroforest. In the investigated cropping systems, farmers identified 17 tree species as indicators of good soils. *Ceiba pentandra*, *Terminalia superba* and *Alstonia boonei* were the most frequent species (Table 3). Farmers generally attribute the soil fertility maintenance or improvement to the quality of litterfall, including leaves and fruits, and to shade, especially in cocoa farms. In cocoa farms farmers planted some of these trees when cocoa is dying back. According to them, such trees have direct effects on cocoa through litterfall, and indirect effects through shade and regulation of humidity and wind speed. Through shade management farmers are able to reduce light intensity, regulate temperature, air movement and humidity, which affect the incidence of pests and diseases.

Table 3. Tree species indicating fertile soils in the traditional land uses of southern Cameroon, and referred to as good trees. (The frequency is the percentage of farmers who mentioned the species).

Local name	Scientific name	Family	Frequency
Doum	*Ceiba pentandra*	Bombacaceae	90.3
Akom	*Treminalia superba*	Combretaceae	84
Etoto'o			45.2
Ekouk	*Alstonia bonei*	Apocynaceae	42
Eteng	*Pycnanthus angolensis*	Myristicaceae	32.3
Ayous	*Triplochyton scleroxylon*	Sterculiaceae	29
Ebaye	*Pentaclethra macrophylla*	Mimosaceae	25.8
Evovone	*Spathodea campanulata*	Bignoniaceae	25.8
Akak	*Duboscia macrocarpa*	Tiliaceae	19.3
Abang	*Milicia excelsa*	Moraceae	13

Farmers also identified some tree species as indicators of poor soils, because of their shallow root system, the slow decomposition rate of their leaves, or because they hosted insects. The most frequently mentioned are presented in Table 4. Still they were present on- farm, because they serve other purposes such as providing medicines, construction poles or timber. The most frequently mentioned were *Erythrophleum ivorense*, *Disthemonanthus benthamianus* and *Lophira alata*.

Table 4. Tree species indicating poor soils in the traditional land uses of southern Cameroon, and referred to as bad trees.

Local name	Scientific name	Family	Frequency
Elon	*Erythropleum ivorense*	Cesalpiniaceae	94.7
Eyen	*Disthemonanthus benthamianus*	Cesalpiniaceae	71
Okoa	*Lophira alata*	Ochnaceae	48.4
Ebaen			42
Engo	*Cetlis tessmannii*	Ulmaceae	29
Engokom	*Myrianthus arboreus*	Cercropiaceae	29
Nka	*Araliopsis sauyauxii*	Rutaceae	29
Ngon	*Klainedoxa gabonensis*	Irvingiaceae	25.8
Assas	*Macaranga spp.*	Euphorbiaceae	22.6
Entendamba	*Funtumia elastica*	Apocynaceae	19.3

Potential for tree-based systems

A considerable array of tree species are planted or protected by farmers. Trees are mostly planted in cocoa plantations (Table 1). Farmers preferred fruit trees, especially those with high cash and home-consumption value. In the study area, the different households commercialized 17 indigenous fruit species. The most valuable ones were *Irvingia gabonensis*, *Dacryodes edulis* and *Aleis guineensis*. Exotic species such as *Persea americana* and *Citrus spp*. are also actively planted and commercialized in the area. *Irvingia gabonensis*, *Dacryodes edulis* and *Aleis guineensis* generated 34% of the total household annual revenue (Table 5). Although medicinal plants are not marketed in the study area, they play an important role in reducing household expenses for health.

Table 5. Contribution of tree products to household revenues (in FCFA*) in the Campo Ma'an area, southern Cameroon.

Products	Revenue per household
Irvingia gabonensis	10,000
Dacryodes edulis	50,000
Palm wine	45,000
Persea americana	12,435
Coula edulis	3,970
Garcinia cola	1,000
Cola acuminata	1,100
Ricinodendron heudelotii	1,000
Trichoscyphas acumunata	1,260
Canarium schweinfurthii	6,560
Ofumbi	4,635
Pachypodanthium staudtii	1,340
Total income from tree products	138,290
Income from crop products	162,290
Contribution of tree products (%)	46

*650 CFA=1Euro

Discussion and conclusions

Farmers attach more importance to soil physical than chemical properties. Soil moisture is moderately valued in cocoa plantations and farmers manage it through shade trees. Through high litterfall, trees maintain the soil cover during dry periods. Among the chemical properties, soil organic matter is of fundamental importance in chemical, physical and biological aspects of soil fertility (Nandwa, 2001).

Weeds and diseases are more critical than chemical properties in the farmer's perception. In cocoa systems, yield loss due to pests and diseases ranges from 50 to 80% (Duguma et al., 2001). Akobundu (1987) attributed the subsistence nature of tropical farming to a combination of weeds and diseases, which has direct effects on crop yield, and forces farmers to shift. In our study, 44% of the factors that force farmers to shift were rather related to soil factors. Fallow is usually a way to get rid of weeds and diseases.

Farmers preferred *Chromolaena* fallow for *afup*; *Chromolaena* fallows are reported to reduce the labour required for land preparation and weeding, and the species has a high combustibility even when green compared to other weed species (Goodall and Erasmus, 1996). The use of fire is an important tool for land preparation and supplies nutrients in the form of ash for subsequent crops, but on the other hand nutrients are lost during and after burning (Mackensen et al., 1996; Giardina et al., 2000). The indigenous knowledge of farmers for composting, collection and redistribution of animal dejections, and kitchen residues was very low. They relied mostly on burning and fallowing for soil regeneration. In areas with high population density and intensive agriculture, composting and recycling of household residues are more rooted (Ceccolini, 2002).

After clearing a forest plot for an *essep*, farmers come back for another *essep* after 15-20 years, and every year each household will continue to convert 1.6 ha of forest to *essep*. Planted fallows are reported to accumulate high biomass, and regenerate soil properties in a shorter time than natural fallows. It is expected that, if planted fallows can be converted to *essep*, more forest will be saved.

Agroforests that mimic local ecosystem processes can be used to provide for farmers' well-being while protecting and preserving forest resources and biodiversity (Clerck and Negreros-Castillo, 2000). Farmers derive income from tree products with high market value. *Irvingia gabonensis*, *Dacryodes edulis* and *Ricinodendron heudetotii* are commercialised at regional and even international levels, therefore have a high potential as income-generating products on trans-border markets. Palm wine is consumed locally. Farmers generally collect other tree products primarily for home consumption. The domestication of the most valuable species, especially food-related or income-generating species, offers considerable scope for enhancing the nutritional and economic security of subsistence farmers (Duguma et al., 2001; Anegbeh et al., 2003; Kwesiga et al., 2003). Market opportunities should be developed for food-related species and medicinal plants which can significantly contribute to the household revenue, thus allowing farmers to invest in tree-based systems.

Farmers use a diversity of techniques, many of which fit well in local conditions, and can lead to conservation and regeneration of the natural resource base, but not all are effective. Therefore, modifications and adaptations are necessary (Altieri, 2002). Such modifications should take into consideration farmers' rationale and knowledge (Buttner and Hauser, 2003; Altierie, 2002). This should be based on a thorough knowledge on how farmers use household and field characteristics to make adoption decisions (Bannister and Nair, 2003).

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Annex 1. Questionnaire used for household interviews

THEME : Soil fertility management and the role of trees in traditional agroforestry systems of the Campo Ma'an area

Name of the village
Farm number and code
Principal facilitator

Household head	
Name	
Sex (male/female)	
Date of birth or age	
Level of education	
Active as head of household since	

SECTION 1. HOUSEHOLD AND FARM CHARACTERISTICS

Basic elements of the farm
Size of the household
Children
Men
Women
Active household members
Children
Men
Women
Agricultural equipment

Sources of household income

agriculture…………, animal production,………… hunting, ………..
fishing,…………… handicraft………….., commercial……………
salary……………,

Monthly household income

1. Less than 1000 FCFA : …………………..
2. Between 1000 and 10 000 FCFA : ……………………
3. Between 10,000 and 50,000 F : ……………..……..
4. More than 50,000 FCFA : …………………….

Surface area under different land uses

Land uses	*Number of plots*	*Total area*
1. *Essep*		
2. Banana		
3.A*fup owondo*		
4. Cocoa		
5. Others		

Use of fertilizers on crops in fields

	Cocoa	*Essep*	Banana	*Afup*	Other fields
Type of fertilizers					
Source of fertilizers					
Estimated quantity					

Use of organic inputs including crop residues and kitchen refuse

Type of inputs
Sources
Estimated quantity

Use of animal manure on farm

Animal groups
Quantity of manure collected
Where used

Soil fertility management in the different land uses

- Current practices
- Reasons for current practices
- Knowledge gap

SECTION 2. ROLE OF TREES IN PRODUCTION SYSTEMS

1. Which trees do you maintain on farm, and for which purpose
For each tree in the farm, indicate the uses

No.	Species	Shade	Medicinal	Fertility	Fruit	Other foods	Timber	Fuel wood	Poles	Others
1										
2										
3										
4										
5										

2. Trees indicating or improving soil fertility
Which trees indicate fertile soil, and how do they affect the soil?

	Species	Leaves	Root	Shade	Bark	Fruits	Exudates	Adapted crop species
1								
2								
3								
4								
5								

3. Trees indicating poor soil fertility

Which trees indicate poor soil, and how do they affect the soil?

	Species	Leaves	Root	Shade	Bark	Fruits	Crop species most affected
1							
2							
3							
4							
5							

4. Tree species generating income

No.	Species	Products	Quantity sold/yr	Revenus/yr
1				
2				
3				
4				
5				

III. Farmer preferences for tree planting

1. **Which tree species would you like to plant, and in which land use?**

Land uses	**Tree species**	**Purpose**
Essep		
Banana		
Afup Owondo		
Cocoa		

2- **Have you already planted/protected some of these trees** ?
Give the species, and whether planted or protected
How many trees do you allow on farm?

IV. Farmer perception of land degradation

1. On which basis do you select a forest or a fallow plot for crop field
2. On which indicators do you decide to abandon a plot fallow
3. In the different land uses, what are the main causes of low yields

Indicate by crossing in boxes, the determinant of crop yields in the different land uses

	Forest	*Essep*	Banana	Food crop
Soil moisture				
Soil compaction				
Weeds				
Deseases				
Soil colour				
Others				

Annex 2. Synthesis table of different tree species and tree uses found in traditional land uses of the Campo Ma'an area

Local name	**Scientific name**	**Family**	**Land use system where found**				**Main uses**
			Cocoa	***Essep***	**Banana**	***Afup***	
Abang/Iroko	Milicia exelsa (Welv.) C.C. Berg.	Moraceae	X			X	Medicinal
Abel/otou/aiele	*Canarium schweinfurthii* Engl.	Burseraceae	X				Fruit, medicinal, fuel, timbers
Abeu	*Cola acuminata* (P. Beaauv) Schott et Endl.	Sterculiaceae	X				Fruits, medicinal, fuel
Abing/essia	*Petersianthus macrocarpus* (P.Beauv.) Liben	Lecythidaceae	X	X		X	Medicinal, shade, fertility, fuel timber
Adjap/azae/azang	Manilkara obovata (Sabine and G.Don) J.H. Hemsley	Sapotaceae	X	X			Shade, medicinal, fertility, fuel
Adjap/moabi	*Baillonella toxisperma* Pierre	Sapotaceae	X	X			Fruits, timber, medicinal, oil
Adoum/edum/okan	*Cylicodiscus gabunensis* Harms	Mimosaceae	X				Medicinal,
Afio	*Persea americana* Miller	Lauraceae	X			X	Fruits, medicinal, shade, fuel
Akak	*Duboscia macrocarpa* Bocq	Tiliaceae	X			X	Fertility
Akee	Blighia welwishii (Hiern) Radlk.	Sapindaceae	X				
Akeng	Morinda lucida Benth	Rubiaceae	X				Medicinal
Ako	Antiaris africana	Moraceae	X				Kitchen tools
Akom/frake	*Terminalia superba* Engl. and Diels	Combretaceae	X	X		X	Fruits, fertility
Alep	Irvingia oblonga	Irvingiaceae	X		X		Medicinal
Alloma/akondok	*Naulea diderrichii* (Dewild. et D. Durand) Merrill	Rubiaceae	X				Timber, medicinal, fertility
Amvut	*Trichoscypha acuminata* Engl.	Anacardiaceae	X				Fruit, medicinal
Angongui/ozabili	*Antrocaryon klaineanum* Pierre	Anacardiaceae	X				Fruit, timber, shade, fertility, medicinal
Andok	*Irvingia gabonensis* (Aubry-Lecomte) Baill.	Irvingiaceae	X				Food, fuel, medicinal
Angok	Didelotia letouzeyi Pellegr.	Cesalpiniaceae	X				Shade, fishing poison
Angossa	Markhamia lutea (Benth.) K. Shum.	Bignoniaceae	X				Farm tools
Asae/safoutier	*Dacryodes edulis* (G. Don) Lam H.J.	Burseraceae	X				Fruits, fuel
Asie/Sapelli	Entandrophragma cylindricum (Sprague)	Meliaceae			X		Timber, poles
Assam	*Uapaca paludosa* Aubr. et Leandri	Euphorbiaceae	X	X			Fishing poison
Assas onone	*Macaranga sp* Thouars	Euphorbiaceae	X				Fuel, medicinal
Asseng	*Musanga cecropioides* R. Br. Ex Tedlie	Cecropiaceae	X				Shade, fuel, medicinal, timber

Local name	Scientific name	Family	Land use system where found				Main uses
			Cocoa	*Essep*	Banana	*Afup*	
Assila	Maranthes glabra (Oliv.) Prance	Chrisobalanaceae	X				Fruit
Ekekam	*Ficus natalensis* Hochst.	Moraceae	X				Medicinal, fuel
Eko/Ekaba	Tetraberlinia bifoliolata (Harms) Hauman	Cesalpiniaceae	X				None
Ekouk/Emien	*Alstonia boonei* De Wild	Apocynaceae	X	X	X		Fertility, medicinal, timber
Elolom	*Anthocleista schweinfurthii* Gilg.	Loganiaceae	X				Fertility, medicinal,
Elon/Tali/ Tom	Erythrophleum ivorense A. Chev.	Cesalpiniaceae	X				Medicinal, timber
Engo/Diana	Celtis tessmannii Rendle	Ulmaceae	X				Shade
Engokom/Angom	*Myrianthus arboreus* P. Beauv.	Cecropiaceae	X			X	Fertility, medicinal
Ekwan	Musa sp	Musaceae	X				Fuel
Esak	*Albizia glaberrima* (Schum. and Thonn.) Benth.	Mimosaceae	X				Shade, medicinal, fruit, fuel insects
Essabem	Berlinia bracteosa Benth.	Cesalpiniaceae	X				Fuel
Essang	Maesobotrys sp	Euphorbiaceae	X				None
Essok	*Garcinia lucida* Vesque	Clusiaceae	X				Medicinal
Essoula	Gilbertiodendron preussii	Cesalpiniaceae	X				None
Etendamba/Mutondo	*Funtumia elastica* (Preuss) Stapf.	Apocynaceae		X			Medicinal, fuel
Eteng//illomba	*Pycnanthus angolensis* (Welw.) Excell	Myristicaceae	X	X			Fertility, timbers, poles, fuel, medicinal, shade
Evovone	*Spathodea campanulata* P. B	Bignoniaceae	X				Medicanal, shade
Ewome	*Coula edulis* Baillon.	Olacaceae	X				Poles, food
Eyen/Movingui	*Disthemonanthus benthamianus* Baillon	Cesalpiniaceae	X	X			Timber, shade, medicinal
Ezang	*Ricinodendron heudelotii* Mull. Arg.	Euphorbiaceae	X				Spices, timber, medicinal
Faro	Daniella oblonga Oliv.	Cesalpiniaceae	X				Poles
Mandarine	*Citrus paradisi* Mac. F.	Rutaceae	X			X	Fruits
Mango	*Mangifera indica* Linn	Anacardiaceae	X			X	Fruits, medicinal
Mmbe	*Pterocarpus soyauxii* Taub.	Fabaceae	X		X	X	Medicinal, timbers
Mebemengone	Omphalocarpum procerum P. Beau V.	Sapotaceae	X				Shade
Mfol, Eve'e	Enantia clorantha	Annonaceae	X				Medicinal
Minsii , Miama	Calpocalyx heitzii Pellegr.	Mimosaceae	X		X		None
Mvee	Nauclea sp	Rubiaceae	X				Shade, medicinal, fertility, fw,
Mvinekwe	*Lonchocarpus sericeus* (Poir.) H. B. et K.	Fabaceae	X				Fuel
Ndzong	*Eribroma oblonga* (Mast.) Bod.	Sterculiaceae	X			X	Medicinal
Ngane	Carapa procera D.C.	Meliaceae	X				None

Local name	**Scientific name**	**Family**	**Land use system where found**				**Main uses**
			Cocoa	***Essep***	**Banana**	***Afup***	
Ngon	*Klainedoxa gabonensis* Pierre	Irvingiaceae	X				Medicinal, timbers
Nka	Araliopsis soyauxii	Rutaceae	X				Timbers, poles
Nkangla	*Maesopsis eminii* Engl.	Rhamnaceae	X				Shade
Nnom afane	*Panda oleosa* Pierre	Pandaceae	X				None
Ntom	Pachypodanthium staudtii Engl. And Diels	Annonaceae	X				Fruits
Obatoan	Dacryodes klaineana (Pierre) Lam.	Burseraceae	X				Shade, medicinal, fuel, fruits
Okoa, Azobe	*Lophira alata* Banks ex Gaerth. F.	Ochnaceae	X				Shade, timber, food, medicinal
Olong	*Zanthoxylum macrophylla* L.	Rutaceae	X				Shade, medicinal, fuel
Onie	*Garcinia kola* Heckel	Clusiaceae	X		X		Medicinal, fruit
Ophos	Pseudospondias microcarpa	Rutaceae	X			X	Fruits, shade, fuel, medicinal
Oranger	*Citrus sinensis* L. Osbeck	Rutaceae	X	X		X	Fruits
Pamplemoussier	Citrus grandis	Rutaceae	X	X		X	Fruits
Quinqueliba	Picralima nitida (Ttpf) T. Durand and H. Durand	Apocynaceae				X	Fruits
Sayeme	*Albizia adianthifolia* (Schm.) W.F. Wright	Mimosaceae	X				Shade, fuel, medicinal
Zamenguila, Ngollon	Khaya ivorensis A. Chev.	Meliaceae	X		X		Shade, fuel, medicinal
Abangak			X				Medicinal, shade
Akodom			X				Shade, fertility, medicinal
Apwere			X				None
Azalla			X				Shade, medicinal
Dili			X				Medicinal
Ebaen			X				None
Echeme			X				Medicinal, hunting tools
Edjefok			X				None
Ekoko			X				Fertility
Essi			X				Medicinal, shade
Essope			X				Aphrodisiac
Etoto'o			X				Fertility, medicinal
Evindifam			X				Farm tools
Mbafolo'o			X				Shade
Okevikezong			X				Poles
Ongoavua			X				Fruits

Local name	**Scientific name**	**Family**	**Land use system where found**				**Main uses**
			Cocoa	***Essep***	**Banana**	***Afup***	
Opwenle			X				None
Otouang, Atuing			X				Shade, fuel
Owe			X				Hunting tools, shade, farm tools
Oyang			X				Medicinal, poles

Chapter 3

EFFECTS OF LAND-USE CHANGES ON BIOMASS, CARBON AND NUTRIENT STOCKS IN THE HUMID FOREST ZONE OF SOUTHERN CAMEROON

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ABSTRACT

The major causes of C loss in tropical forest system and CO_2 accumulation in the atmosphere are generally considered to be slash-and-burn and subsequent land uses. We investigated changes in vegetation biomass, carbon and nutrient stocks, and soil nutrient stocks in the different traditional land uses of the slash-and-burn chronosequence in southern Cameroon. Seven land-uses: natural forest, *essep*, banana farm, short fallow, *afup owondo*, long fallow, and cocoa plantation were investigated on an Ultisol. Vegetation parameters included biomass of standing trees, understorey vegetation, unburned logs, soil litter, and roots. Soil data were collected at 0-5, 5-10, 10-20 and 20-50 cm depth. Standing biomass, carbon and nutrient stocks in the vegetation fractions were heavily affected by land use changes, and decreased sharply upon conversion of the forest to cropland. From the original 443 $Mg.ha^{-1}$ of standing biomass in the forest**,** 48% was lost after slash and burn, and another 20% the following year. The forest carbon stock decreased from 199 $Mg.ha^{-1}$ to 102 $Mg.ha^{-1}$ in *essep*, and to 64.1 $Mg.ha^{-1}$ in banana farm. Nutrient stocks in the vegetation followed the same trend, but the short *Chromolaena* fallow efficiently recovered most of the P and significantly increased the P stock in the vegetation. The cocoa plantation maintained moderate carbon and nutrient stocks in the vegetation, compared to other land uses. Soil carbon stock was not heavily affected by land use change; burning increased P, K, Ca and Mg available stocks in *essep* and *afup*, but thereafter the P and K fell to extremely low levels suggesting important nutrient export through crop harvest, and/or excessive leaching. The maintenance and/or inclusion of trees in the cropping system potentially maintains a high nutrient and carbon base in the system, and should be targeted when developing alternative land uses to slash and burn agriculture.

Key words: Acid soils, carbon stock, land use change, nutrient stocks, slash-and-burn chronosequence, standing biomass.

INTRODUCTION

Drastic land-use changes are going on in many areas of the world forest margins. Mature forest vegetation is being cleared at a rate of 154 000 km^2 yr^{-1}, with more than 0.32 Gt C loss to the atmosphere from land-uses in Africa, most of which results from slash-and-burn agriculture (Kotto-Same et al. 1997). In southern Cameroon, farmers have shifted towards food crops such as plantain, *ngon*, maize and cassava, resulting in more forest clearing in times of low cocoa prices (Duguma et al., 2001).

The effects of human disturbance and land use change on soil carbon and nutrient storage are of great interest in the context of international policy on greenhouse emission mitigations (Lal, 1997; Kato et al. 1999; Chen and Li, 2003). Forested soils in the tropics contain a large carbon pool that may contribute to global environmental change such as climate warming (Powers and Schlesinger, 2002). Converting natural forests to farmlands, clear-cutting, repeated burning and nutrient export in crops and crop residues cause changes in the hydrology, microclimate and chemical and biotic environments (Mac Alister et al., 1998), which may considerably affect the soil capacity to sustain biological productivity and to maintain environmental quality. The present study was initiated to quantify the effects of land-use changes on biomass, carbon and nutrient stocks in the system compartments soil and vegetation, as affected by the slash-and-burn agriculture in the humid forest zone. We compared nutrient stocks in soil and vegetation of the natural forest and six subsequent land uses, involving total carbon and nitrogen total stocks, and the labile or available stocks of P and cations K, Ca and Mg. We also intended to identify major factors contributing to the rapid soil fertility depletion and land degradation in the humid tropics.

MATERIALS AND METHODS

The study site

The study was conducted in the buffer zone of the Campo Ma'an National park in the humid forest zone of southern Cameroon, located between 2 ^{o}-3^o N and 10^{o}10' and 10^{o}70'E. The study site is characterized by a sub-equatorial climatic type. The rainfall regime is bimodal with four seasons; two rainy seasons: major (September – November) and minor (March – June), and two dry seasons: major (November – February) and minor (July to August). Mean annual rainfall is 1882 mm while mean annual temperature for the last ten years is 25.4^{o}C. The soils are Oxisols/Ultisols, with excellent physical properties (adequate water and oxygen supply), but they are nutrient-deficient and have low cation exchange capacity (Menzies and Gillman, 1997).

The slash-and-burn chronosequence

A mature secondary forest or a long fallow plot is generally selected by farmers, then slashed and burned, and planted with *ngon* (*Cucumeropsis manii*) and plantain banana (*Musa* sp.). Such a field is locally called *essep ngon*, or forest farm. Plantain/*ngon* based fields are the largest source of household revenues after the cocoa farm. The following year, the *ngon* is harvested and the plot is managed as an intensive plantain farm for one to two years, and then left for a short grass fallow of one to two years. It is later slashed and burned again for a mixed food-crop field with groundnut (*Arachis hypogeae*) and cassava (*Manihot esculenta* Crantz), called *afup owondo*. *Afup owondo* largely guarantees household food security, and in areas with market access, generates marketable surpluses. *Afup owondo* are managed in a rotational 3-5 years fallow, followed by one year cropping until the crop yields fall below acceptable levels; the plot will then be left for a long fallow of 10-20 years. Another important land use is the cocoa (*Theobroma cacao*) plantations. Most households own cocoa plantations because they are the main source of income. Cocoa farms are agroforests with an array of fruit, medicinal and timber trees providing shade to cocoa and other basic needs for farmer's livelihood.

In the study we selected six land uses of the slash-and-burn chronosequence: (1) a mature secondary forest (hereafter referred to as initial forest), (2) an *essep*, (3) a plantain farm (referred to as banana farm), (4) a 2-3 years *Chromolaena* short fallow (5) an *afup owondo*, and (6) a long fallow (8-10 years fallow). A mature cocoa farm was included in the study (7) and considered as a control system with little or no disturbance. A false time-serial sampling was used; therefore, the soil properties and land-use effects were confounded.

Parameters measured

The phytomass of standing trees, necromass of felled but unburned logs, understorey vegetation, surface litter, and root biomass were estimated in the different land uses based on methodologies developed by Anderson and Ingram (1993), Kotto-Same et al. (1997), and Woomer and Palm (1998). For each land use, 8 farmer fields were selected, and a 40 x 40 m plot was demarcated in each field.

Phytomass of standing trees

In each plot, a subplot of 5 m x 20 m was randomly selected; the diameter (D) at breast height was recorded for all trees with diameter greater than 2.5 cm falling within the 100-m^2 subplots, using a diameter tape or a caliper. Only trees with more than 50% of their diameter falling within the quadrates were recorded. The phytomass (B in kg/tree) was estimated from the following allometric equation involving the tree diameter (D), and the estimated total height (H) of trees developed for the moist tropical forest with rainfall between 1500 – 4000 mm (Anderson and Ingram 1993).

$$B\ (kg) = \exp(-3.1141 + 0.9719 \ln (D^2 H))$$

With $$H\ (m) = \exp(1.0710 + 0.5677 \ln D)$$

Necromass of unburned logs

The necromass of logs was determined from the length (L), the mid point diameter (D) of large logs (>10 cm diameter) and the volume/density relationships according to the equation developed by Woomer and Palm (1998):

$$\text{Log biomass (g)} = d \times \Sigma (0.25\ \pi\ L\ D^2)$$

The tree density d = 0.58 for tropical Africa was used.

Estimation of the understorey vegetation and surface litter
In each subplot, understorey biomass was collected from two 1 x 1 m quadrates assigned at random in the subplot. The vegetation was clipped at ground-level, sorted, dried and weighed. Surface litter was collected from the central 50 x 50 cm of each quadrate (Woomer and Palm, 1998).

Estimation of root biomass
Soil monoliths were collected manually from two points in each subplot. The soil and roots were excavated from a 50 x 50 cm area at 0-10 cm, 10-20 cm and 20-50 cm. The samples were washed over a 0.5 mm mesh sieve, and roots collected. Roots were manually separated from debris, then oven-dried and weighed (Anderson and Ingram, 1993).

Soil sampling
Soil samples were collected with an auger at 8 spots along each of the diagonals of each of the 40 x 40 m plots, making 16 sampling points per plot. Sampling was done at four depths (0-5, 5-10, 10-20, and 20- 50 cm). For each plot, soil samples of the same depth were thoroughly mixed and a composite sample retained and sent to the laboratory for chemical analysis (Anderson and Ingram, 1993).

Plant and soil analyses and determination of nutrient accumulation
Samples of roots, soil litter, unburned logs and understorey vegetation from each land-use were analyzed for major nutrients N, P, K, Ca and Mg in triplicate. Standing trees in the forest and in subsequent land uses were difficult to sample; we used data of nutrient concentration in trees from primary forest stands in eastern Amazonia (Johnson et al., 2001).

Soil samples were analyzed for pH, organic C, N, exchangeable Ca, Mg, K, and extractable P. Soil samples were air-dried and ground to pass a 2 mm mesh. Cations (Ca, Mg, K) were extracted by the Mehlich-3 procedure (Mehlich, 1984); cations were determined by adsorption spectrophotometry. Phosphorus was extracted with the Bray II method and analyzed by the malachite green colorimetric procedure (Motomizu et al., 1983). Soil pH was determined in water at a 2:5 soil: liquid ratio. Organic carbon was determined by chromic acid digestion and spectrophotometry (Heanes, 1984). Total N was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremmer and Tabatabai, 1972; Nelson and Sommers, 1972). For plant samples, all fresh biomass samples were oven-dried at $65^{o}C$, then ground to pass a mesh of 0.5 mm, and digested according to Novozamsky et al. (1983). Total N was determined with an ammonium-sensitive electrode (Powers et al., 1981). Ca, Mg and K were analyzed by atomic absorption spectrophotometry. Total P was determined by the malachite green colorimetric procedure (Motomizu et al., 1983). Nutrient accumulation in the different fractions of plant biomass was calculated by multiplying the dry mass per hectare with the nutrient content of the samples.

Soil physical analysis
Soil was sampled for bulk density at three depths (0-10, 10-20 and 20-50cm). Samples were taken by driving a thin-walled metal cylinder of known volume (V) and weight (W_1) into the vertical face of an excavation made in each plot during soil

monolith collection, with a wooden mallet. Excess soil from the cylinder ends was trimmed with a knife and corked thoroughly and stored in a case. Samples were dried at 105^{o}C for 48 hours. The dry weight (W_2) was then measured. The bulk density (D) was calculated (Anderson and Ingram, 1993) as:

$$D = (W_2 - W_1) \times V^{-1}$$

Carbon and nutrient stocks

The biomass of all fractions was multiplied by a factor of 0.45 for carbon stock determination (Woomer and Palm, 1998). The nutrient stocks were calculated by multiplying dry mass of the different fractions with their nutrient concentrations. Stocks of extractable P, K, Ca, Mg, and total N and organic C in the soil of each land-use type were calculated by multiplying the soil concentrations with bulk density and the thickness of each soil horizon, then summing the quantities in each layer. The stocks of each layer were summed up to give an overall soil stock in the 0-50 cm layer.

Statistical analysis

The experiment followed a completely randomized design with seven treatments (land-use) and eight replicates (plots). Biomass and nutrient stocks in the different fractions: roots, litter, understorey, standing trees and logs, and nutrient concentration and nutrient stocks at different soil depths, were used as the dependent variables. The analysis of variance was made at 5% probability using the SAS package (SAS, 1996). The standard error of difference of the mean (s.e.d.) was used to separate the means when significant differences were observed.

RESULTS

Standing biomass

The biomass of the different fractions was significantly ($p < 0.05$) affected by land uses (Table 1). High biomass in standing trees (376 Mg.ha^{-1}) occurred in the forest, out of which 88% was felled during conversion of forest to *essep*. *Essep* had more trees than banana, although between the two systems there is no tree felling. This points at a die-back after initial burning. *Afup* had the lowest standing tree biomass because farmers usually select areas with lowest shade for groundnut. Cocoa plantation was the land use with higher biomass of standing trees compared to other land uses; tree biomass in cocoa accounted for 42% of that of the forest. The highest necromass of unburned logs was observed in *essep*. It decreased rapidly in subsequent land uses in banana: 59% of the log mass had disappeared, and 89% in the short fallow, which indicates a high decomposition rate at early stages of the chronosequence. Before the *afup*, there was a complete burning and therefore very few logs remained in subsequent land uses.

The understorey and/or grass vegetation also differed significantly between the different land uses. The highest grass biomass was observed in short fallows, with 14.7 Mg.ha^{-1}. They were dominated by *Chromolaena odorata,* elsewhere reported to be an aggressive shrub species invading disturbed sites, and a major factor hindering the regeneration of disturbed and degraded forest sites (Honu and Dang, 2002). Significantly higher litter mass was recorded in forest, *essep*, banana farm, long and short fallow, with more than 10 $Mg.ha^{-1}$of litter, compared to *afup owondo* and cocoa plantation. Comparable root mass was observed in forest and cocoa plantation where trees are maintained permanently, with more than 44 $Mg.ha^{-1}$of root biomass. The lowest root biomass was observed in *afup owondo* where very few if any trees are kept during land preparation. Between forest and *essep*, 44% of roots have disappeared, indicating that burning also affects tree roots, especially in forest where most of the roots occurred in the topsoil.

Table 1. Vegetation standing biomass in the chronosequence land uses of slash and burn agriculture in southern Cameroon

Land uses	Standing biomass ($Mg.ha^{-1}$)					
	Trees	Logs	Litter	Understorey	Roots	Total
Forest	376 a	8.2 d	11.3 a	3.5 c	44.5 a	443 a
Essep	44.8 d	246 a	11.8 a	1.1 d	24.9 b	228 b
Banana farm	7.1 d	101 b	13.0 a	1.4 d	20.2 b	143 c
Short fallow	54.4 c	27.9 c	11.5 a	14.7 a	15.5 b	124 c
Afup owondo	67.3 c	11.8 d	3.4 c	0.7 d	13.2 c	96.4 c
Long fallow	90.1 b	11.2 d	10.7 a	6.3 b	23.3 b	116 b
Cocoa plantation	158 b	1.1 e	5.7 b	0.6 d	44.5 a	209 b

Figures followed by the same letters for the different land uses are not significant at $P<0.05$

The highest standing biomass was recorded in the natural forest. Upon conversion to *essep* 48 % of the biomass was lost. The cocoa system had 53 % of biomass compared to the natural forest. For the total biomass the different systems could be classified as: forest > *essep* = cocoa > banana = long fallow > short fallow = *afup*. The major vegetation fraction making the total biomass was standing trees in forest and cocoa plantation, unburned logs in *essep* and banana, and grass vegetation in short fallow. The biggest gap is between forest and *afup*, namely a loss of 347 $Mg.ha^{-1}$ of vegetation biomass, which compromises the carbon sequestration in cropping systems.

Carbon and nutrient concentration in the vegetation

Standing biomass, and therefore carbon storage was greatest in forest compared to the different land uses (Table 2). Highest C storage was obtained in the forest, and lowest in the *afup*. The forest stored 199 $Mg.ha^{-1}$ of carbon, but conversion to *essep* induced losses of 48 % of the initial carbon storage, and between *essep* and banana, another 47% was lost. Highest C loss was observed between *essep* and banana, which can be attributed to fast decomposition. The cocoa plantation had 53% of the forest carbon storage in shade trees (C of the cocoa tree itself is not considered in this study). The conversion of forest to *essep* induced a loss of 97 $Mg.ha^{-1}$ of C, and before the plot was covered with *Chromolaena* fallow, the loss was 143 $Mg.ha^{-1}$. The carbon stock in the vegetation fraction is easily affected by land use change and the conversion of forest to agricultural land through burning is recognized as a major cause of carbon de-sequestration.

Nutrient stock in the vegetation fractions was strongly affected by the changing land use. The stocks of the different nutrients decreased sharply when the forest was slashed and burned. From the initial forest N stocks of 3.1 $Mg.ha^{-1}$, 49% was lost during conversion to *essep*, and another 27% between *essep* and banana. *Essep* and cocoa farms had similar N concentrations which were half that of the forest. Phosphorus stocks decreased by 37% upon conversion of forest to *essep*, and another 25% between *essep* and banana. Lowest P was observed in *afup*, but the short *Chromolaena* fallow accumulated as much P as the natural forest. High K was obtained in the forest vegetation, and upon conversion to *essep*, 47% of it was lost. K accumulations were comparable in *essep*, fallows, and cocoa. High quantities of Ca and Mg were observed in forest and *essep*; the Ca and Mg stocks generally followed the trend of total biomass in the different land uses.

Table 2. Aboveground carbon and nutrient stocks in the traditional land uses of southern Cameroon

Land uses	C	N	P	K	Ca	Mg
	($Mg.ha^{-1}$)			($kg.ha^{-1}$)		
Forest	199±15	3083±197	142±29	979±58	1839±120	335±34
Essep	102±15	1561±185	89.4±29	521±60	1212±125	221±33
Banana farm	64.1±8	736±91	54.6±16	304±30	681±62	139±16
S/fallow	55.8±13	1093±160	147±28	407±65	755±118	208±38
Afup	43.4±10	697±120	34.9±19	210±39	359±69	79±24
L/fallow	52.3±8	1625±96	89.4±15	418±35	777±80	175±20
Cocoa plantation	94.2±25	1529±321	64.5±27	462±20	964±43	197±63

Soil bulk density, total carbon and nitrogen

No significant difference was observed in soil bulk density between the different land uses, but differences were observed with soil depths. The top 10 cm soil layer had a bulk density of 1.25 $g.cm^{-3}$, while the deeper horizons (10-50cm) had 1.45 $g.cm^{-3}$.

Table 3 shows that total C content in the topsoil was significantly higher in *essep* at all depths compared to other land uses. In the top 10 cm forest and short fallow followed *essep*, while long fallow and cocoa had the lowest values. At 10-50 cm, forest, short fallow and *afup* were similar to *essep*. Highest total N was also observed in *essep* and at all depths (Table 3). In the top 10 cm layer, forest, short fallow, *afup*, long fallow and cocoa all had similar N. The lowest N in the topsoil was in banana at 5-10 cm. In the 10-50 cm layer, *afup* and long fallow were similar to *essep*. The different land uses had similar or even more available P compared to the forest soil. In the top 10 cm soil layer, highest P was observed in *essep* and *afup* and lowest in banana and forest. In the sub-soil, more P occurred in cocoa and long fallow. *Afup* and *essep* had the highest available K in the 0-20 cm soil layer compared to other land uses, while lowest value was observed in banana. In the 0-5 cm soil, available K in forest and short fallow was similar to those of *essep* and *afup*. Forest, *essep*, short fallow and *afup* had the highest available Ca and Mg at all soil depths compared to other land uses. Banana differed only in the 0-5 cm layer where it had lower Ca.

Table 3. Nutrient concentrations at different depths of the land uses in the slash and burn chronosequence in southern Cameroon

Nutrient	Depths (cm)	Land uses						
		Forest	*Essep*	Banana	Short fallow	*Afup*	Long fallow	Cocoa
C (%)	0-5	2.68 b	3.78 a	1.91 c	2.50 b	2.47 b	1.55 d	1.54 d
	5-10	1.63 b	1.97 a	1.21 d	1.62 b	1.42 c	1.11 e	1.04 e
	10-20	1.19 a	1.37 a	0.89 b	1.26 a	1.11 a	0.74 b	0.42 b
	20-50	0.93 a	0.89 ab	0.77 b	1.02 a	0.89 a	0.59 c	0.61 c
N (%)	0-5	0.145 b	0.215 a	0.119 b	0.146 b	0.161 b	0.151 b	0.151 b
	5-10	0.107 b	0.180 a	0.086 c	0.105 b	0.115 b	0.109 b	0.119 b
	10-20	0.075 b	0.094 a	0.064 b	0.070 b	0.095 a	0.087 a	0.075 b
	20-50	0.058 b	0.068 a	0.045 b	0.055 b	0.062 a	0.062 a	0.068 a
P ($mg.kg^{-1}$)	0-5	6.96 b	18.7 a	5.48 b	6.19 b	15.2 a	8.82 b	7.4 b
	5-10	2.48 c	5.66 a	2.59 c	3.15 b	5.28 a	4.43 a	4.63 a
	10-20	0.59 c	1.52 a	1.07 b	0.64 c	1.41 a	1.53 a	2.55 a
	20-50	0.03 c	0.17 b	0.55 a	0.05 b	0.12 b	0.89 a	1.23 a
K (mmol/kg)	0-5	1.37 a	2.46 a	0.07 c	1.29 a	2.25 a	0.90 b	0.80 b
	5-10	0.76 b	1.40 a	0.05 b	0.76 b	1.48 a	0.60 b	0.60 b
	10-20	0.43 b	0.95 a	0.08 c	0.38 b	1.05 a	0.50 b	0.30 b
	20-50	0.17 b	0.24 b	0.04 c	0.19 b	0.25 b	0.50 a	0.50 a
Ca (mmol/kg)	0-5	3.4 a	7.5 a	9.8 b	0.2 a	7.8 a	2.5 b	4.2 b
	5-10	5.0 a	7.8 a	5.2 a	7.8 a	9.9 a	1.3 b	1.6 b
	10-20	2.7 a	3.3 a	2.1 a	2.6 a	4.1 a	0.5 b	0.7 b
	20-50	2.0 a	2.1 a	1.5 a	2.0 a	2.2 a	0.6 b	0.6 b
Mg (mmol/kg)	0-5	5.3 a	8.8 a	2.1 b	6.2 a	8.8 a	1.2 b	5.0 a
	5-10	2.5 a	3.0 a	1.2 b	2.9 a	3.3 a	0.7 b	0.8 b
	10-20	1.3 a	1.4 a	0.7 ab	1.1 a	1.4 a	0.4 b	0.5 b
	20-50	0.9 a	0.5 a	0.4 a	0.6 a	0.4 a	0.4 a	0.5 a

Figures followed by the same letter for different land uses are not different at the same depth at $P<0.05$

The general trend is a high availability of P, K, Ca and Mg in *afup* and *essep* at all depths compared to other land uses, which indicates a nutrient enrichment in those land uses, resulting from burning during land preparation. *Essep* gives the most fertile soil of all land uses, and total N is rather stable in other land uses after *essep*. P and cations have large differences between topsoil and subsoil, and banana, long fallow and cocoa apparently take up cations faster than they can be replenished by the soil

Total system carbon and nitrogen storage

Figures 1 and 2 summarize changes in C and N stocks in soil and vegetation, in the different land uses of the slash-and-burn chronosequence. The high C stock originally present in the forest vegetation decreased in subsequent land uses and reached the minimum in long fallow. The C stock in shade trees of the cocoa system was higher than those in land uses between *essep* and long fallow. The soil C was relatively stable, minima were observed in banana, long fallow and cocoa. The conversion of the natural forest to crop fields led to about 50% loss in the total system carbon. N occurred more in the soil than in the vegetation. Burning significantly increased the N total stock in soil, under *essep* and *afup* land uses. Lowest stocks were observed in banana and long fallow. The vegetation pool decreased upon conversion of the forest to crop fields, and remained low between *essep* and *afup*. Maximum loss of the system total N was about 40% and occurred in banana.

DISCUSSION

The total biomass in the forest of 443 $Mg.ha^{-1}$ is in the range of the 355 $Mg.ha^{-1}$ reported by Greenland and Kowal (1960) and the 350-560 $Mg.ha^{-1}$ reported by Van Reuler and Janssen (1993) in a similar type of forest in Ivory Coast. Andriesse and Schelhaas (1987) reported 475 $Mg.ha^{-1}$ in Malaysian rainforest. Kotto-Same et al. (1997) reported more than 700 $Mg.ha^{-1}$ in southern Cameroon, which may be an estimation of fresh mass rather than dry mass. Attempts to eliminate burning in the traditional farming system of southern Cameroon will be limited by the difficulties to handle the amount of biomass resulting from the slashing. In Amazonian forest, 64.5 % of the initial forest biomass is reported left lying on the ground after burning (Graça et al., 1999). In our case also, 65% of the forest tree biomass occurred in *essep* as unburned logs, which indicates a similar rate of burning. The short fallow vegetation has a low biomass, and therefore low carbon and nutrient stocks, compared to 65 $Mg.ha^{-1}$ in *Alchornea* fallow and 100 $Mg.ha^{-1}$ in *Pennisetum* fallow reported on less acid soils (Kanmegne et al., 1999), or 61 $Mg.ha^{-1}$ in *Inga* planted fallow on similar soils (Kanmegne et al., 2000). The short fallow in this study proved to efficiently recover most of the N, P, K and Mg better than other land uses. Planted fallow is likely to be a strategic alternative to improve biomass production and nutrient stocks in short fallows. The remaining logs after burning of the forest vegetation progressively decompose, thus releasing carbon and nutrients during banana phase (Fearnside et al., 1999). Decomposition is accelerated by the *ngon* vines, which maintain humidity in the system (Duguma et al. (2001). Generally, after the banana phase, farmers allow their plot a short restorative *Chromolaena* fallow before the *afup owondo*, probably because of the very low carbon stock after banana. The use of fire is an important tool for land preparation in the traditional farming system, especially in *essep* and *afup*, as it supplies nutrients in the form of ash for subsequent crops.

Figure 1. Carbon stocks in the 0-50 cm layer, in different land uses of the slash-and-burn chronosequence in the humid forest zone. Cocoa is presented as a reference

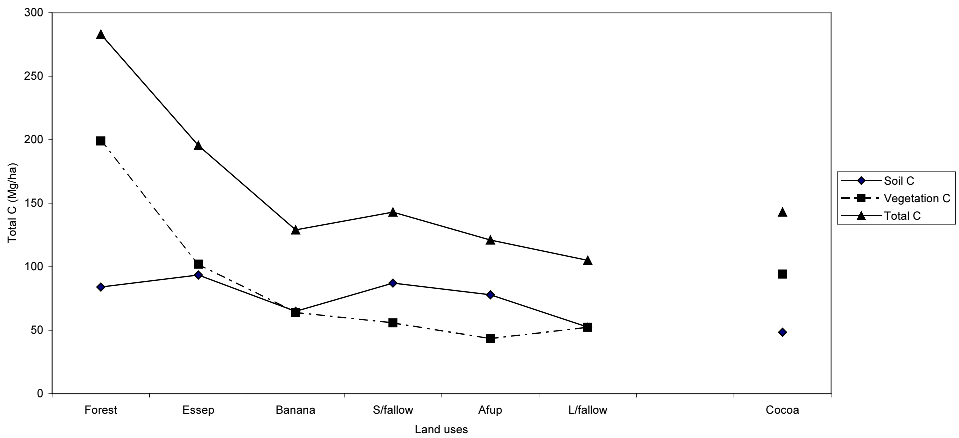
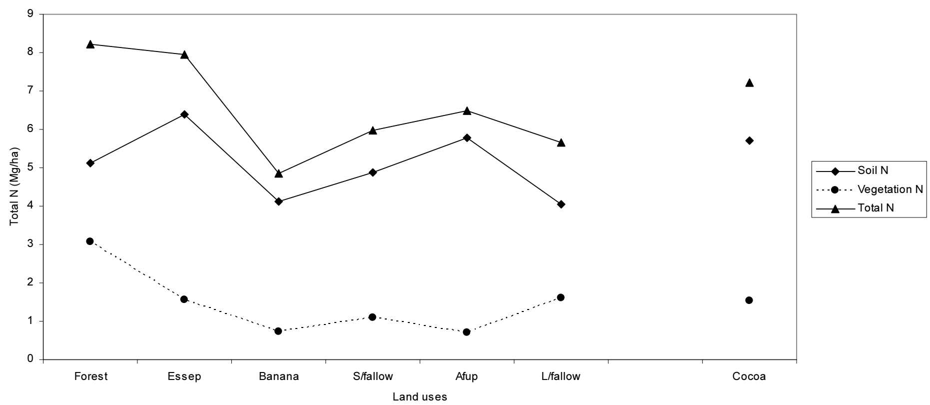


Figure 2. Nitrogen stocks in the 0-50 cm layer in different land uses along the slash-and-burn chronosequence in the humid forest zone. Cocoa is presented as a reference.



Aboveground carbon and nitrogen were heavily affected by land use change, but C stocks in the soil were less affected; increases in soil C and therefore soil organic matter after burning observed in this experiment were also reported by Stromgaar (1992), Nye and Greenland (1960), Tonye et al. (1997), and Koutika et al. (1997). It indicates that burning does not necessarily destroy soil organic matter. Across the different land uses, soil N stocks were consistently larger than the above ground stocks. Johnson et al. (2001) reported similar trends when comparing the accumulation of carbon and major nutrients in biomass and soil of the primary forest of eastern Amazonia.

Intense fires affect P availability due to ash additions and direct heat exposure (Ketterings et al., 2002). Increase in P in the topsoil is reported by Stromgaar (1992), which he attributes to additions from burned biomass and also to heating per se. The increase in available P is attributable to the ash input through burning (Voundi Nkana et al., 1998). Numerous studies in Amazonia have shown the increase in nutrients incorporated into the soil by the ashes from forest burning. Burning of the primary vegetation on an Ultisol in an Amazonian forest generates inputs of 67 $kg.ha^{-1}$ of N, 6 $kg.ha^{-1}$ of P, 38 $kg.ha^{-1}$ of K, 75 $kg.ha^{-1}$ of Ca and 16 $kg.ha^{-1}$ of Mg (Seubert et al., 1977).

Phosphorus is the primary limiting nutrient for crop production in weathered tropical soils, because of sorption of phosphate onto Al- and Fe- (hydr) oxides (Cardoso et al., 2003). The trend of lower levels of P after *essep* and *afup* can reasonably be attributed to nutrient export by the *ngon*, plantain, and mostly by cassava and groundnut in the *afup*. Increases in extractable K, Ca, and Mg caused by the addition of plant ash after burning in shifting agriculture in the eastern Amazonia was also reported by Holscher et al. (1997). However, during burning, nutrients are lost to the atmosphere (Mackensen et al., 1996), by volatilisation and particle transport of ash. Such losses, combined with leaching losses amount to between 94-98% of C, 93-98% of N, 30-47 % of P, 42-50% of K, 13-35% of Ca and 21-43% of Mg, of the initial nutrient content of the unburned biomass (Mackensen et al., 1996). Leaching after burning affects most mobile elements such as N and Na (Mackensen et al., 1996, Menzies and Gillman, 2003). Soils of the forest zone contain only modest reserves of Ca and Mg, and are generally deficient in available P, so the loss of ash rich in these nutrients should be avoided (Menzies and Gillman, 2003).

The level of potassium and phosphorus are relatively high in *ngon*, with 3.9 g K, and 3.43 g Mg, 2.8 g P, and 1.17 g Ca kg^{-1} of seed (Enujiugha and Ayodele-Oni, 2003). Banana withdraws 2.8 kg N, 0.6 kg P and 16.4 kg K per ton of harvested product (Stoorvogel and Smaling, 1990). In banana production, K may be the most limiting nutrient, whereas burning improves soil exchangeable K. Conversely, large K losses during and after burning (Johnson et al. 2001, Holscher et al. 1997, Menzies and Gillman, 2003) result in declining K stocks. Hence, banana production declines after one to two years. Alfaia et al. (2003) reported similar K export in *Theobroma grandiflorum* and *Bractris gasipaes* fruits in agroforestry systems of western Amazonia. In banana-based cropping systems of Uganda, farmers apply a wide range of additional resources to banana such as crop residues, burned residues, on-farm manure, compost and chemical inputs to sustain the productivity (Bekunda and Woomer, 1996).

CONCLUSION

The biomass estimates confirm the presence of relatively high total carbon stocks and available nutrients in tropical forest. Land use changes and farming practices affected the phytomass and nutrient stocks in different ways:

1. Biomass, carbon and nutrients in the vegetation fractions were significantly different among land uses.

2. Maximum C difference of the chronosequence is between forest and *afup*: 156 Mg C ha^{-1}. *Afup* had around 20% of the biomass of the forest.
3. Short fallows proved to recover most of the P, K and Mg, but accumulated low biomass.
4. After burning there was a short-term increase in soil C and N stocks, and availability of P and cations, followed by rapid depletion probably because of crop uptake and/or excessive leaching. Although burning is followed by an increase in soil C and nutrients in the slash-and-burn chronosequence, soil nutrients are lost rapidly 1 to 2 years after burning, which considerably compromises the sustainability of slash-and-burn agriculture.
5. Soil fertility was lowest in banana, explaining the rapid fall in plantain production in the site (1 to 2 years), and emphasizing the need of nutrient supplements for persistent banana production.
6. The cocoa system could store 45% of the carbon and 90% of the nitrogen of the forest.

With the increasing awareness on the detrimental effects of burning on soil nutrients and environmental quality (Lal, 1997; Kato et al., 1999), fire-free alternative land preparation should be developed. Farmers should be allowed to reduce the initial forest biomass by harvesting timbers of commercial quality, followed by a selective felling of non-desired tree species, in order to allow many standing trees in the cropping system. Fallow enrichment through the maintenance and/or inclusion of trees in short fallows should also be targeted as an opportunity to improve the productivity of traditional systems and provide C sinks. These alternative land uses to slash-and-burn are likely to provide an acceptable level of carbon sequestration and at the same time provide a range of sources of farmer profitability.

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Chapter 4

NUTRIENT FLOWS IN SMALLHOLDER PRODUCTION SYSTEMS IN THE HUMID FOREST ZONE OF SOUTHERN CAMEROON

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ABSTRACT

The flows and balances of N, P and K were studied in 20 farms in the Campo Ma'an area between March and August 2002 to assess the nutrient dynamics in smallholder farms. Data were collected through farmer interviews and field measurements and estimations from transfer functions. Nutrient input from mineral (IN1), animal feed (IN2a) and inorganic amendments (IN2b) was nil. Major outputs were through crop (OUT1a) and animal products sold (OUT1b). Partial budget for farmer management was negative: -67.8 kg N, -5.6 kg P and – 32.1 kg K $ha^{-1}.yr^{-1}$. For inflows not managed by farmers, deep capture (IN6) was the major source: 16.6, 1.4 and 6.6 $kg.ha^{-1}.yr^{-1}$ of N, P and K, respectively. Atmospheric deposition (IN3) was estimated at 4.3kg N, 1.0 kg P and 3.9 kg K. $ha^{-1}.yr^{-1}$, and biological nitrogen fixation (IN4) at 6.9 kg N $ha^{-1}.yr^{-1}$. Major losses were leaching (OUT 3a): 26.4 kg N, and 0.88 kg K $ha^{-1}.yr^{-1}$. Gaseous losses from the soil (OUT 4a) were estimated at 6.34 kg N, and human faeces (OUT 6) were estimated at 4 kg N, 0.64 kg P and 4.8 kg K $ha^{-1}.yr^{-1}$. The highest losses were from burning (OUT 4c), resulting in 47.8 kg N, 1.8 kg P and 14.3 kg K $ha^{-1}.yr^{-1}$. Partial budget of environmentally controlled flows was negative only for N: -4.8 kg N, +2.4 kg P and +9.6 kg K $ha^{-1}.yr^{-1}$. The general farm budget was negative, with a yearly loss of -73 kg N, -3 kg P and -23 kg K ha^{-1}. Only cocoa had a positive nutrient balance: +9.3 kg N, +1.4 kg P and +7.6 kg K $ha^{-1}.yr^{-1}$. Nutrients reaching the garbage heap (1.9 kg N, 2.79 kg P and 18.84 kg K $ha^{-1}.yr^{-1}$), animal manure (4.9 kg N, 0.4 kg P and 1.6 kg K), and human faeces (4 kg N, 0.64 kg P and 4.8 kg K $ha^{-1}.yr^{-1}$) were not recycled. Five alternative management scenarios were envisaged to redress the nutrient balance. Recycling animal dejection, kitchen residues and human faeces will bring the balance at -62.6 kg N, 0 kg P and +1kg K $ha^{-1}.yr^{-1}$. If, additionally, burning could be avoided, a positive nutrient balance would be expected. The trade-off will be to reduce *essep* and *afup* to household consumption scale and develop tree-based systems, which have a positive nutrient balance, as source of income for the household.

Key words: Nutrient budget, nutrient flows, traditional land uses, humid forest

INTRODUCTION

In sub-Saharan Africa, stakeholders and decision makers progressively recognize the depletion of soil nutrients as the major constraint to sustainable agriculture and rural development (Smaling et al., 1993; Smaling et al., 1996). Stoorvogel and Smaling (1990) estimates for southern Cameroon for 2000 were: 21 kg N, 2 kg P and 13 kg K loss per ha and per year resulting from human activities. One of the difficulties to reverse the trend is the farmers' limited access to fertilizers and the subsequent vicious circle of soil fertility depletion and poverty (Sanginga et al., 2003).

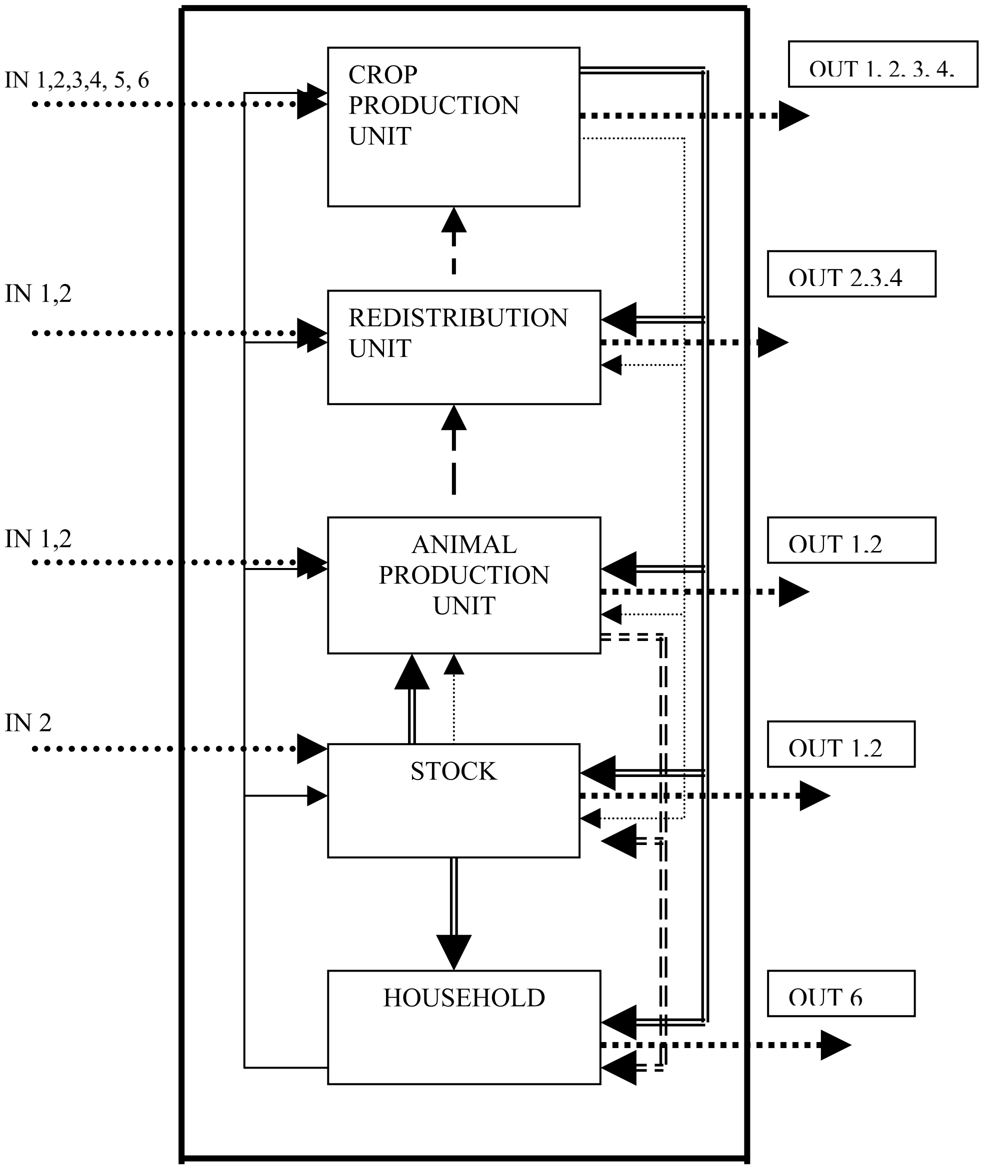
The soil quality at farm scale depends on the nutrient management by farmers, the manipulation of nutrient stocks and flows, nutrient inputs in the system through organic and chemical amendments, nutrient export via crop harvest and crop residue removal, and conversions within the production systems (Deugd et al., 1998; Bationo et al., 1998). Smallholders in southern Cameroon recognize spatial soil heterogeneity within farms and adjust land management accordingly (Westphall et al., 1981; Buttner and Hauser, 2003).

Nutrient budgets of agroecosystems can be used as a tool to increase the understanding of nutrient cycling, or as a performance indicator and awareness raiser in nutrient management and environmental policy (Oenema et al., 2003). In sub-Saharan Africa, information on the dynamics of total nutrient stocks in the primary forest ecosystem and in subsequent land uses, i.e. budgets and flows between the different production compartments, is scarce (Juo and Manu, 1996; Kotto-Same et al., 1997).

Smaling et al. (1996) and Van den Bosch et al. (1998) presented the nutrient-monitoring concept, which considers five production units within farms: crop production, animal production, household, stock or family store, and redistribution (Figure 1). They considered six nutrient flows into the farm, i.e., inorganic fertilizers (IN 1), organic inputs (IN2), wet and dry deposition (IN 3), biological nitrogen fixation (IN 4), sedimentation (IN 5), and deep capture (IN 6), and six outflows through harvested crop products (OUT 1), crop residues leaving the farm (OUT 2), leaching (OUT 3), gaseous losses (OUT 4), water erosion (OUT 5), and human faeces (OUT 6). Internal flows refer to the distribution of crop and animal products, crop residues, animal manure and household waste in the different production units of the farm.

The present paper uses this approach to calculate nutrient balances in 20 farms of the Campo Ma'an area, focusing on the farm as a whole, and then on the subsystems within the farm (crop fields and the different land uses, farm animals, and household). The main objective is to contribute to the understanding of the degree of nutrient depletion and identify major constraints to integrated nutrient management. Alternative management scenarios are also envisaged, to redress the system nutrient balance.

Figure1. Conceptual framework of nutrient flows and budgets, indicating the major inflows (IN), outflows (OUT) and internal flows (Fl) of nutrients in a farm system..



Inflows	Outflows	Internal flows
1. Inorganic fertilizers	1. Harvested crop products	- Crop products
2. Organic inputs	2. Crop residues	- Crop residues
3. Wet and dry deposition	3. Leaching	- Animal products
4. Biological nitrogen fixation	4. Gaseous losses	- Household waste
5. Sedimentation	5. Water erosion	- Manure/ compost
6. Deep capture	6. Human faeces	

MATERIALS AND METHODS

The study site

The study was conducted in 4 villages: Asseng, Ma'an-village, Messama III and Mvi'illimengale, located in the Ma'an sub-Division of the agroforestry zone of the Campo Ma'an National park, southern Cameroon. The site is located between longitude 10°10'–10°70'East and latitude 2° –3° North, and is characterized by a sub-equatorial climate, with a bimodal rainfall regime. The mean annual temperature is 24°C with a relatively low thermal variation. The mean annual rainfall is 1900 mm. The soils are Oxisols/Ultisols, which make up about 80% of the soil type in the humid forest region of Cameroon, with low cation exchange capacity but excellent physical properties, with 22% clay. The general soil properties are summarized in Table 1.

Table 1. Soil properties of the study site, Ma'an in southern Cameroon (forest soil).

Soil properties	Soil depth (cm)			
	0-5	5-10	10-20	20-50
pH (1:1 soil:water)	3.95	3.98	4.16	4.51
pH (KCl)	3.81	3.91	4.07	4.37
O.M (%)	7.55	5.17	3.55	1.98
C (%)	4.38	3.00	2.06	1.55
Total N (%)	0.215	0.161	0.116	0.067
Ca ($cmol.kg^{-1}$)	0.143	0.110	0.074	0.027
Mg ($cmol.kg^{-1}$)	0.135	0.095	0.056	0.024
K ($cmol.kg^{-1}$)	0.116	0.077	0.056	0.019
Na ($cmol.kg^{-1}$)	0.008	0.006	0.025	0.006
Total bases ($cmol.kg^{-1}$)	0.402	0.288	0.206	0.075
Extractable P (ppm)	5.96	3.56	1.82	0.29
Sand (%)	66	62	60	54
Clay (%)	24	26	30	34
Silt (%)	10	12	10	12

The population density of the site is low, 3.5 inhabitants-km^{-2}, the major ethnic groups are *Ntoumou*, *Mvae* and *Bulu*. Agriculture is the main activity of 84% of the population while hunting and fishing is practiced by 15%. The household size is 5 to 7. The major land uses in the traditional farming system of the study sites are the *essep*, banana farm, *afup owondo*, and cocoa plantation.

Every year, a mature secondary forest or a long fallow plot is slashed and burned, then planted to *ngon* (*Cucumeropsis manii*) and plantain (*Musa sp.*). This land use is called *essep*. The *ngon* is harvested within one year. This land use is the major source of household revenue. The plot will then be managed for banana and plantain production or banana farm, for one to two years. Usually after banana the plot is left for a short fallow of 2 to 3 years, then slashed and burned and planted to various food crops. The major crops are groundnut (*Arachis hypogeae*) and cassava (*Manihot esculenta*). This land use is called *afup owondo,* and largely guarantees household food security and, in areas with market access, generates marketable surpluses. Cocoa plantations are a mixture of cocoa, a multitude of trees with food and medicinal values, and timber tree species either planted by farmers or retained during the initial forest clearing. Cocoa plantations are the predominant productive land use and until the collapse of cocoa prices in the late 80s, cocoa systems were the main source of household income. Each household on average manages annually 1.16 ha *essep*, 0.4 ha banana farm, 1.0 ha *afup owondo* and 3.5 ha cocoa. A total of 120 ha of agricultural land, managed by the 20 selected households, was surveyed in the course of this study.

Quantification of the different nutrient flows

Nutrient flows managed by farmers

The survey was conducted from March to August 2002, in 20 households. Biophysical, socio-economic and farming system data were collected through a household interview. Farmers gave information on the different production compartments, the different land uses, and their major farm products and destinations. Nutrient flows directly related to their way of farming were quantified by asking farmers and through direct measurements on the farm or in the household. The inflows investigated by asking farmers were: the quantities of mineral fertilizers (IN 1), organic input such as manure, feedstuffs, concentrates and outside grazing by farm animals (IN 2a) and organic fertilizers (IN 2b), and fuel wood (IN 2c) entering the farm annually. The outflows included the quantity of crops (OUT 1a) and animal products (OUT 1b) leaving the farm as gifts or sales. Outflows measured were crop residue (OUT 2a), and animal manure (OUT 2b) leaving the farm. Nutrient loss through human faeces (OUT 6) was estimated as 80% of nutrients in crop and animal products effectively consumed by the household, assuming that the human body assimilates 20% of the nutrients contained in food. Farmers generally gave quantities in their own units, such as sacks, bags and buckets, which were converted to standard metric amounts. Also all classes of farm animals were counted and weighed. For each farmer, a field survey allowed us to identify the different land uses, the number of plots under each land use, and to estimate the surface area of each plot. This helped to estimate the different yields. The different products were sampled, and analyzed for major nutrients N, P, K, for the quantification of the different nutrient flows.

Measurement of internal flows

The flows between the different farm compartments were measured and included the redistribution of kitchen refuse (Fl 2a), animal consumption from the kitchen refuse (Fl2b), decomposition of kitchen refuse (Fl 2c), crop (Fl 6a) and animal (Fl 6b) products used for food by the household.

Consumption of household refuse by compound animals Fl (2b)

Kitchen refuse was weighed daily and supplied to household animals. The residual portion not eaten by the animal was also weighed in the evening. This operation was conducted during 30 days in the different households, and separately for the different types of crop residue leaving the kitchen. The conversion factor was then determined for each type of crop residue. Then considering the quantity of each crop consumed yearly by the household, the quantity of residue derived from the crop

(Qi), and the conversion factor (Fi), the nutrient flow from the household refuse to household animals was determined as

$$Fl2b = (Fi \times Qsi \times \text{nutrient content}) \times (\text{farm area})^{-1}$$

<u>Nutrient accumulation in the dumping site Fl (2c)</u>
The nutrient accumulation was considered to be the difference between the nutrients in the refuse produced by the household (Fl6c), and the quantities of N, P, and K consumed by the household animals (Fl2b). We assumed that the losses through volatilization and leaching during decomposition were thus negligible. So

$$Fl2c = Fl6ci - Fl2\ bi, \text{ where}$$

FL6ci is the nutrient stock in the residues of the product i ($kg.ha^{-1}.yr^{-1}$), and Fl2bi is the quantity eaten by household animals.

<u>Animals browsing on external pasture (Fl 4)</u>.
The quantity of fodder eaten by animal from pastures along the road or from the cocoa farm where they freely roam was estimated form the quantity of dejection they produce. We assumed that nutrients in animal dejection is equivalent to 80% of total consumption of feeds and fodder.

<u>Production of dejection by the household animals (Fl5a).</u>
The quantity of dejections produced by the different animal groups was estimated from the live weight of the animal. Small ruminants consume 3.2% of their live weight as feed daily, and the mean digestibility is 60%. The daily production of dejection by pigs is estimated at 0.69% of their live weight. For poultry, it is estimated at 1.68% of their live weight. Urine production is estimated at 2-6 litters for pigs, and 0.5 to 2 liters for sheep and goats (Tchoumboue, 1980). It is also considered that 60% of excreted N (Haynes and Williams, 1993) and 70 to 90% of excreted K (Barrow, 1987) are through urine.

The quantity of a nutrient Y produced by a small ruminant in dejections was estimated through the equations:

$$Fl5a\ (Y) = \{\text{live wt} \times (1-\text{digestibility}) \times (\text{percentage feed consumption}) \times 365 \times Y \text{ content of dejections}\} / \text{land surface of the system.}$$

Estimation of inflows not managed by farmers
Nutrient inflows not directly managed by farmers were estimated from transfer functions, site climate and soil data. These included the atmospheric depositions (IN3), biological nitrogen fixation (IN4), and sedimentation (IN5).

<u>Atmospheric depositions (IN3)</u> correlate to rainfall (p), and can be estimated from squared root functions developed by Stoorvogel and Smaling (1990).

$$IN3\ (N) = 0.14\ p^{1/2}$$
$$IN3\ (P) = 0.023\ p^{1/2}$$
$$IN3\ (K) = 0.092\ p^{1/2}$$

Biological nitrogen fixation (IN4) in production systems was estimated from the general equation:

IN4 (N) = [(groundnut field area x IN4a groundnut) + (area other crops x IN4b)] $[\text{total land area}]^{-1}$ (1)

IN4a is the symbiotically fixed and IN4b the non-symbiotically fixed nitrogen.
It was assumed that 60% of the total N demand of groundnut crop is supplied through symbiotic nitrogen fixation (Stoorvogel and Smaling, 1990).

IN4a = [OUT1 (N) + Fl3a (N)] 60% + [(2 + p – 1350) x 0.005] (2)

In (2), OUT1 (N) is the N exported in groundnut crop, and FL3a, the quantity of N accumulated in crop residues. In the site, the groundnut yield was 273 kg ha^{-1} (Table 1), grain to stem ratio of groundnut was 2.76, and N content was 1.96% in stems and 3.8 % in grains, therefore:

OUT1 (N) = 3.8 % groundnut yield
Fl 3a (N) = 2.76 x 1.96 % x (groundnut yield)

The non-symbiotic nitrogen fixation was estimated from the function

IN4b (N) = 2 + (P – 1350) x 0.005 (Stoorvogel and Smaling, 1990)

Sedimentation (IN5) takes place in naturally flooded irrigated areas, where salinization and iodisation naturally occur. No crop was registered on flooded or irrigated areas in the study site. This input was considered negligible.

Deep capture (IN6). Litter fall estimation in the different land uses, followed the methodology described by Anderson and Ingram (1993). Litter traps were set in the different land uses, and litter collected over the whole year. The collected material was oven-dried, weighed, sub-sampled and analysed for N, P, and K. The nutrient input to the system was calculated by combining the annual litter fall and the nutrient concentration. We assumed that 75% of nutrient in the litter is recycled in the root zone, and that 25% is deep capture from below the root zone.

Estimation of nutrient outflows not managed by farmers
Leaching below the root zone (OUT3). In tropical soils P is tightly bound to soil particles, and leaching involves only N and K. The quantity of N and K annually lost (in kg ha^{-1} yr^{-1}) was estimated from the transfer functions developed by Smaling et al. (1993).

OUT 3a (N) = (Nmin + fertilizer N) x (2.1×10^{-2} x P + 3.9)
OUT 3a (K) = (exchangeable K + fertilizer K) x (2.9×10^{-4} x P + 0.41)

Nmin is the quantity of N mineralised in the top 20 cm of the soil, and is determined from total soil N (Ntot) and the annual mineralisation rate (M). The mineralisation rate of the site was estimated at 3% (Nye and Greenland, 1960), and N total is 1.1%

$$Nmin = 20 \times Ntotal \times M$$

We assumed that no fertilizer N was applied in the fields. The exchangeable K stock in the site is 48.1 kg.ha^{-1} for *essep*, and 49.4 kg ha^{-1} for *afup*. We considered that ash is the K fertilizer to the soil. Nye and Greenland (1960) estimated K content of ash from forest and short fallow burning to 56.6 and 27 kg ha^{-1}, respectively. In our study we considered 20 ha *afup* and 23.2 ha *essep*. In the formula, the term ($2.9 \times 10^{-4} \times P + 0.41$) is the percentage of K leached from the system.

Gaseous losses from the soil (OUT 4a). The annual loss of N is related to the percentage of denitrified N (DN), and the quantity of N mineralized in the topsoil (Nmin). DN itself is a function of clay content of the soil, and the annual rainfall (p), through the transfer function (Smaling et al. (1993):

$$DN (\%) = -9.4 + 0.13 \times \%clay + 0.01\, p$$
$$OUT4a (N) = DN (Nmin + fertilizer\ N)$$

Gaseous losses from animal dejections (OUT 4b). Farmers in the study site did not collect animal dejections, and we had no hard data to quantify this nutrient loss from the system. Gaseous losses from animal dejections were therefore assumed negligible.

Gaseous losses from the burning of the natural vegetation (OUT 4c). Burning is the land preparation technique for *afup owondo* and *essep* in the study site. Nutrients lost during burning of the natural forest, and short fallow vegetation were determined by Nye and Greenland (1960) and Hölscher et al. (1997). Losses from burning of the forest vegetation are estimated as 189.6 kg N, 7.42 kg P and 52.2 kg K kg ha^{-1} yr^{-1}. The equivalent for the short fallow is 67.3 kg N, 2.4 Kg P and 25 kg K ha^{-1} yr^{-1}. For a nutrient X, if QX_f is the loss from the fallow, QX_F the loss from the forest during burning, S_{afup} and S_{essep} the land area under *afup owondo* and *essep,* then losses form burning OUT4c (X) (kg ha^{-1}.yr^{-1}) were estimated as:

$$OUT4c (X) = [(S_{afup} \times QX_f) + (S_{essep} \times QX_F)] [total\ farm\ area]^{-1}$$

Losses from erosion (OUT 5). Erosion was considered a minor factor in the humid lowland characterizing the study site; OUT 5 was thus considered negligible.

Nutrient balance

A partial nutrient balance was determined at farm level including only flows that are visible by farmers and reflecting the way of farming.

Partial budget $_1$= (IN 1 + IN 2a + IN 2b) – (OUT 1a + OUT 1b + OUT 2a + OUT 6).

Another partial budget was determined with only environmentally controlled flows

Partial budget $_2$ = (IN 3 + IN 4 + IN 5 + IN 6) – (OUT 3 + OUT 4a + OUT 4c).

The Total budget was then determined as Partial budget $_1$ + Partial budget $_2$. It included all nutrient flows entering or leaving the farm. Different management scenarios were then envisaged, to identify strategies for system improvement.

RESULTS

Nutrient flows controlled by farmers

Inorganic fertilizers (IN1)
No farmer out of the 20 interviewed in the study used mineral fertilizers. They ceased to use mineral fertilizers with the collapse of the cocoa market and the suspension of state subsidies of agricultural inputs. Farmers depend solely on fallowing and burning of the vegetation to improve the soil fertility, which is the cheapest alternative in view of the cost and availability of mineral fertilizers.

Animal feeds (IN2a)
From the 20 households surveyed in the study site, none used external feed for household animals. Pigs, sheep, goats and poultry in the area can roam freely with no additional care. They feed on kitchen refuse, and/or natural pastures along the roads.

Organic fertilizers (IN2b)
No farmer during the survey reported to use animal manure, compost, kitchen residue or any other organic residue for soil fertility improvement. Fallowing and burning of the vegetation was the only means to improve soil fertility. In the cocoa plantations farmers rely on the presence of soil fertility-indicating/improving tree species and litter fall from shade trees to maintain the soil fertility.

Wood/charcoal from the forest for cooking (IN 2c)
Wood/charcoal from the forest for cooking was estimated from the quantity of wood ash produced by the household. An average of 205 kg of wood ash was produced per household, the nutrient equivalent was 1.6 kg P and 15.6 kg K $ha^{-1}.yr^{-1}$.

Crop products sold or donated (OUT 1a)
Crop species monitored in this study included one from essep (*ngon)*, 2 from banana farm (plantain and banana), 13 from *afup owondo*, and 12 from the cocoa plantation. The different crop products leaving the farm as sales and gifts are presented in Table 2, and their nutrient equivalent in Tables 3 and 4. Crop products sold or donated accounted for 9.5 kg N, 2.0 kg P, and 9.8 kg K ha^{-1} yr^{-1} nutrient export.

Table 2. Destination of crop products in a smallholder farming system of the Campo Ma'an area, southern Cameroon (kg.household^{-1}.year^{-1})

Farm section	Crop products	Total products (a + b)	Sales and gifts OUT 1a (a)	Household consumption F16 (b)	Kitchen* Refuse F1 2a (c + d)	Animal feed F1 2b (c)	Residues F1 2c (d)
Essep (1.16ha)	*Ngon*	189	154	35.4	0	0	0
Banana	Banana	525	139	386	222	187	34.5
(0.4 ha)	Plantain	1918	978	940	459	318	141
Afup	Groundnut	276	123	153	43.3	3.0	40.3
owondo	Cassava	6237	2716	3521	886	775.5	111
(1.0 ha)	Maize	508	123	385	205	54.8	150
	Cocoyam	845	515	330	127	1.9	125
	Sweet potatoes	208	39.9	168	39.6	39.6	0
	Yam	137	25.2	112	15.3	14.3	1.0
	Sugar cane	670	281	388	180	120	60.4
	Pepper	12.7	5.0	7.7	0.60	0	0.6
	Tomatoes	64.7	22.6	42.2	0.10	0	0.1
	Okra	29.6	2.0	27.6	0	0	0
	Beans	3.2	0	3.2	2.2	0.1	2.1
	Djinja	2.1	0	2.1	0	0	0
	Onions	1.7	0	1.7	0	0	0
Cocoa	Cocoa	593	593	0	0	0	0
plantation	Guava	121	80.2	41.1	0	0	0
(3.5 ha)	Cola	8.4	5.5	2.9	0	0	0
	Andok	71.1	42.8	28.3	0	0	0
	Citrus	177	102	75.4	52.3	0	52.3
	Safou	176	62.8	112.9	35.6	2.5	33.1
	Papaw	70.7	22.4	48.3	0	0	0
	Pear	1245	534	711	161	1.6	159
	Palm oil	779	421	358	312	60.8	252
	Coco nut	105	67.8	37.7	28.2	0	28.2
	Mangoes	11.2	3	8.3	0	0	0
	Casmango	173	86.4	86.4	0	0	0

* Kitchen refuse (c + d) = waste percentage of household comsumption (b)

Table 3. N, P, K content (% dry weight) of harvested crop products and kitchen refuse from traditional farming systems in southern Cameroon

Products*	Harvested crops			Kitchen refuse		
	N	P	K	N	P	K
Andock	0.19	0.02	0.30	0.06	0.02	0.44
Banana	0.14	0.03	0.84	0.16	0.03	1.2
Beans	4.2	0.34	2.7	0.7	0.05	0.75
Casmango	0.19	0.02	0.33	-**	-	-
Cassava	0.25	0.06	0.4	0.05	0.27	0.14
Citrus	0.12	0.02	0.34	0.06	0.02	0.44
Cocoa	4.0	0.85	1.92	1.9	0.14	3.9
Coconut	3.5	0.62	2.0	2.7	0.57	2.5
Djinja	0.46	0.03	0.29	-	-	-
Groundnuts	3.8	0.35	0.65	1.0	0.05	0.65
Guava	0.20	0.02	0.20	-	-	-
Maize	1.1	0.18	0.77	0.66	0.08	1.2
Malamba	0.06	0.02	0.12	-	-	-
Mango	0.19	0.02	0.32	0.06	0.02	0.44
Ngon	0.22	0.70	5.4	0.22	0.70	5.4
Okra	0.70	0.05	0.75	-	-	-
Onion	0.01	0.24	1.4	-	-	-
Palm oil	0.36	0.06	0.34	0.37	0.06	0.33
Papaya	0.20	0.02	0.29	0.06	0.02	0.44
Pear	0.19	0.02	0.26	0.18	0.02	0.49
Pepper	0.04	0.36	3.1	-	-	-
Pineapple	0.20	0.02	0.20	0.06	0.02	0.44
Plantain	0.17	0.03	0.60	0.12	0.03	0.64
Potatoes	0.19	0.02	0.30	0.23	0.07	0.13
Safou	0.19	0.02	0.30	0.18	0.02	0.44
Sugar cane	1.1	0.15	1.1	1.6	0.14	1.5
Sweet potatoes	0.42	0.09	0.63	-	-	-
Tomatoes	0.02	0.51	4.8	-	-	-
Vegetables	0.7	0.05	0.75	0.32	0.14	0.79
Yam	0.11	4.6	3.6	0.11	4.6	3.6

* mean of composite samplea analyzed in triplicate   ** samples not analyzed

Table 4. Nutrient export and destination through crop products in the traditional farming systems of the Campo Ma'an area, southern Cameroon

	Farm sections				
	Essep (1.16ha)	Banana (0.4ha)	*Afup* (1 ha)	Cocoa (3.5ha)	Total
	kg	kg	kg	kg	$Kg.ha^{-1}$
Total production					
N	0.42	3.99	55.3	36.5	15.8
P	1.3	0.7	14.7	6.8	3.7
K	10.2	15.9	61.3	23.1	18.1
Sales and gifts (OUT 1a)					
N	0.34	1.8	25.2	30.8	9.5
P	1.1	0.34	4.7	6.6	2.0
K	8.3	7.0	27.3	17.6	9.8
Household consumption (F1 6b)					
N	0.08	2.1	30.1	5.6	6.2
P	0.25	0.4	9.9	0.8	1.9
K	1.9	8.9	40.0	5.5	9.2
Kitchen refuse (F1 2a)					
N	0	0.9	8.1	2.3	1.9
P	0	0.2	6.8	0.3	1.2
K	0	5.6	10.7	2.9	3.2
Animal feed from the refuse (F1 2b)					
N	0	0.7	3.6	0.2	0.7
P	0	0.2	3.0	0.04	0.6
K	0	4.3	5.3	0.2	1.6
Residues (F1 2c)					
N	0	0.2	4.6	2.1	1.1
P	0	0.05	0.8	0.2	0.8
K	0	1.3	5.5	2.7	1.6

Animal products sold or donated (OUT1b)

Household animal groups were pigs, poultry, sheep and goats. The total production of the 20 households, the quantity of sales and the nutrient (N, P, K) equivalent are given in Table 5. The nutrient equivalent of animal products sold or donated was 0.53 kg N, 0.18 kg P, and 0.04 kg K ha^{-1} yr^{-1}.

Nutrient loss in human faeces (OUT 6)

The total nutrients in the food products eaten by the household annually was 6.6 kg N, 2.0 kg P and 9.2 kg K ha^{-1} yr^{-1} (Figure 2), out of which 1.9 kg N, 1.2 kg P and 3.2 kg K ha^{-1} yr^{-1} were returned in the kitchen refuse (Table 4). Nutrient loss in human faeces was estimated at 80 % of the difference i.e. 3.9 kg N, 0.64 kg P and 4.8 kg K ha^{-1} yr^{-1}.

Table 5. Animal products and nutrient (N, P, K) equivalent in traditional land uses of Campo Ma'an, southern Cameroon.

Animal groups	Total*	Sales and gifts (OUT 1b) (kg.yr^{-1})				Household consumption (F1 6b) (kg)			
	(kg)	Products	N	P	K	Products	N	P	K
Pigs	4,539	2,575	25.7	12.9	2.6	1,964	19.6	9.8	2.0
Poultry	895	302	9.1	1.8	0.30	593	17.8	3.6	0.59
Sheep and goats	1,578	1,138	28.4	6.8	2.3	440	11.0	2.6	0.88
Mean kg.ha^{-1}.yr^{-1}			0.53	0.18	0.04		0.40	0.13	0.03

* Total of 20 households

Table 6. Production of N, P and K by farm animals through dejections, in the Campo Ma'an area, southern Cameroon

Animal groups	Live weight (kg)	Dejections produced (kg)	Concentration (g.kg^{-1} dejection)			Nutrient equivalent in animal dejections (kg.yr^{-1})		
			N	P	K	N	P	K
Pigs	1,149	2,896	2.5	0.48	0.65	179	13.9	94.1
Chicken	210	1,286	2.2	0.37	0.20	28.8	6.2	2.6
Ducks	63.3	450	0.95	0.01	0.16	4.3	2.2	0.72
Sheep	567	2,649	3.2	0.32	0.40	210	12.7	52.9
Goats	367	1,717	3.8	0.67	0.50	163	8.2	42.9
Total (kg.yr^{-1})	2,357	8,997				585	43.2	193
Mean* (Fl5a)						4.9	0.36	1.6

* kg.ha^{-1}.yr^{-1}

Internal nutrient flows
The codes used for the different flows in this study is similar to those defined by Smaling et al. (1996) and Van den Bosch et al.(1998).

Farm products eaten by household (Fl 6a)
From the quantity of farm products used for family consumption, the estimated quantity of nutrients was 6.2 kg N, 1.9 kg P and 9.2 kg K ha^{-1} yr^{-1}. High K value products such as cassava and leafy legumes are the staple food. Products with high N value such as cocoa and groundnuts are mostly sold.

Nutrient transfer from the household to the garbage (Fl 2a)
It was estimated that 1.9 kg N, 1.2 kg P and 3.2 kg K ha^{-1} yr^{-1} is transferred from the kitchen to the refuse, as food remains that can be consumed by animals. By including nutrient from the wood ash (1.59 kg P and 15.64 kg K $ha^{-1}.yr^{-1}$), the total nutrient in the kitchen refuse is therefore 1.9kg N, 2.79 kg P and 18.84kg K $ha^{-1}.yr^{-1}$.

Animal consumption of kitchen refuse (Fl 2b)
Estimated on annual basis, household animals recycle from the kitchen refuse 0.7 kg N, 0.6 kg P and 1.6 kg K per ha of cultivated land in the study site.

Nutrient accumulation in the kitchen refuse (Fl 2c)
The difference between nutrients transferred in kitchen refuse, and nutrients recycled by the household animals gives 1.1 kg N, 2.39 kg P and 17.24 kg K $ha^{-1}.yr^{-1}$, accumulated in kitchen refuse and loss from the system.

Browsing animals (Fl 4)
Animal browsing from external pastures was estimated as 1.25 X Fl 5a, equivalent to 6.1 kg N, 0.5 kg P and 2 kg K $ha^{-1}.yr^{-1}$.

Production of dejections by the farm animals (Fl5a)
Household animals in the study site produced 4.9 kg N, 0.4 kg P and 1.6 kg K $ha^{-1}.yr^{-1}$in dejections (Table 6). Nitrogen was the most important element in the animal manure.

Nutrient inputs not controlled by farmers
Atmospheric deposition (IN 3):

IN3 (N) = 0.14 $p^{1/2}$
IN3 (P) = 0.023 $p^{1/2}$
IN3 (K) = 0.092 $p^{1/2}$

With annual rainfall of 1,900 mm, deposition was estimated at 4.35kg N, 1 kg P and 3.92 kg K $ha^{-1}.yr^{-1}$in the different land uses.

Biological nitrogen fixation (IN 4)

IN4 (N) = [(groundnut field area x IN4a groundnut) + (area other crops x IN4b)] $[\text{total land area}]^{-1}$
IN4a = [OUT1 (N) + Fl3a (N)] 60% + [(2 + p – 1350) x 0.005] (2)

OUT1 (N) = 3.8 % groundnut yield = 273 x 3.8 % = 10.37
Fl 3a (N) = 2.76 x 1.96 % x (groundnut yield) = 14.77
IN4a = [(10.37 + 14.77) x 60 %] + [(2 + 1900 – 1350) x 0.005] = 17.84
IN4b (N) = 2 + (P – 1350) x 0.005
= 2 + (1900 – 1350) x 0.005 = 4.75 kg ha^{-1} yr^{-1}
IN4 (N) = [(20 x 17.84) + (100 x 4.75)] $[120]^{-1}$
= 6.93 kg ha^{-1} yr^{-1}

Sedimentation (IN5)
The sedimentation in the study site was estimated as negligible. No farm was reported on waterlogged area, and irrigation is not practiced in the area.

Deep capture (IN6)
Litter fall was the major source of input of N, P and K in the production systems of the Campo Ma'an area. The annual litter fall in the production systems was 5t/ha, and the equivalent nutrient input is 66.4kg N, 5.15kg P and 26,2kg K $ha^{-1}.yr^{-1}$. This occurred mainly in cocoa plantations where many trees are maintained for shade. The collected litter included litter from cocoa trees and litter from shade trees. Most trees on acid soils have 70-80% of their roots in the top 50 cm (Szott, 1995); we estimated that only 20-30% of the roots contribute to deep capture, which can be considered as an input to the system. We therefore considered 25% of nutrients from litter as input from deep capture, and 75% as nutrient recycling. IN6 is then 16.6 kg N, 1.38 kg P, and 6.55 kg K ha^{-1} yr^{-1}.

Nutrient outputs not controlled by farmers

Nutrient loss through leaching (OUT3)

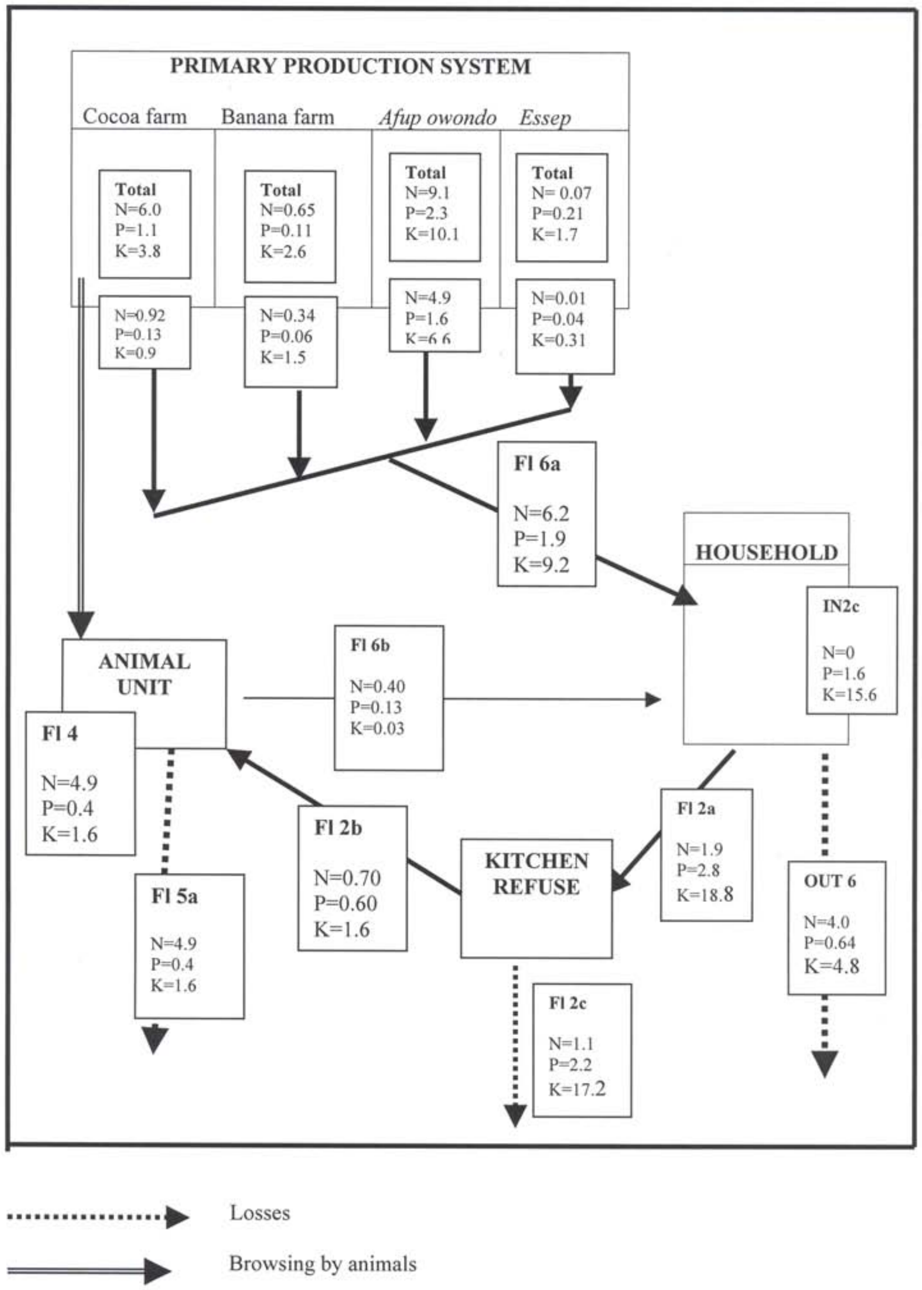
OUT3a (N) = (Nmin + fertilizer N) x (2.1 x 10^{-2} x P + 3.9)
OUT3a (K) = (exchangeable K + fertilizer K) x (2.9 x 10^{-4} x P + 0.41)
Nmin. = 20 x Ntotal x M (kg/ha/yr),
OUT 3 a (N) = (66 x (2.1 x 10^{-2} x 1900 + 3.9)
= 26.37 kg ha^{-1} yr^{-1}
$K_{fert.}$ = [(27 x 20) + (56.6 x 23.2)] $[20 + 23.2]^{-1}$ = 42.9
OUT3a (K) = (48.7 + 42.9) x (2.9 x 10^{-4} x 1900 + 0.41) x 1%= 0.88
OUT3a (N) = 26.37 kg ha^{-1} yr^{-1}
OUT3a (K) = 0.88 kg ha^{-1} yr^{-1}
Nutrient loss through leaching is estimated at 26.37 kg of N and 0.88 kg of K ha^{-1} yr^{-1}.

Gaseous losses from the soil (OUT 4a)

OUT4a (N) = (Nmin. + fertilizer N) (-9.4 + 0.13 x 22 % + 0.01 x 1900)
= 66 x 9.6 % = 6.34

Nitrogen losses through denitrification and volatilisation was estimated at 6.34 kg ha^{-1} yr^{-1}.

Figure 2. Internal nutrient flows in a traditional farming system of southern Cameroon (kg.ha^{-1}.yr^{-1})



Gaseous losses through burning of the natural vegetation (OUT 4C)

OUT4c (X) = $[(S_{afup\ x}\ QX_f)_+ (S_{essep\ x}\ QX_F)]$ [total farm area]$^{-1}$
In this study S_{afup} = 20 ha, and S_{essep} = 23.2 ha
OUT4c (N) = [(20 x 67.3) + (23.2 x 189.6)] [120]$^{-1}$ = 47.8
OUT4c (P) = [(20 x 2.4) + (23.2 x 7.42)] [120]$^{-1}$ = 1.83
OUT4c (K) = [(20 x 25) + (23.2 x 52.2)] [120]$^{-1}$ = 14.25

Therefore, losses through burning of the natural vegetation is estimated at 47.8 kg N, 1.83 kg P and 14.25 kg K ha^{-1} yr^{-1}

Partial budget of flows managed by farmers
We quantified the crop and animal products harvested in the different land uses and their destinations. The main flows were sales and gifts (OUT 1), household consumption (Fl 6a and b), the proportion reaching the garbage heap as kitchen refuse (Fl 2a), the quantity eaten by farm animals from the kitchen refuses (Fl 2b), and the residues not recycled from the kitchen refuse (Fl 2c) (Tables 2 and 5). Based on the nutrient concentration in the different crop, crop residues (Table 3) and animal manure (Table 6), we quantified the different nutrient flows managed by farmers.

The different nutrient flows managed by farmers are presented in (Figures 2 and 3). The flows of nutrient inputs as mineral and organic fertilizers, and animal feed, and outputs were: gaseous losses from burning (OUT 4c), crop and animal products sold, losses from kitchen residues (Fl 2c), losses from non recycled animal dejections (Fl 5a) and human faeces (OUT 6). The balance of nutrients managed by farmers is –67.8.0 kg N, 5.6 kg P and –32.1 kg K ha^{-1}.yr^{-1} (Table 7). Burning during land preparation accounted for 70% of N, 25% of P and 30% of K lost every year. No input is brought to the farm, and many crop products are sold by farmers (Table 2), which explains the negative budget for the three nutrients. There is a high export of K, compared to N and P. Most of the K in sold products comes from the *afup owondo*, 4.8 kg, while 1.36 is from *essep* and 1.15 kg from banana farm. But in terms of crops, K is mostly exported through *ngon* (which contain 4.45% K), cocoa (1.92%) and plantain (0.84%) (Table 3). Each household exports 11.4 kg in cocoa, 8.30 kg in *ngon*, and 8.23 kg in plantain. Then in the slash and burn chronosequence, the exchangeable K stock is likely to be exhausted after *essep* and banana, justifying the short fallow and burning before the afup owondo in the traditional system. The high nutrient deficit resulting from farming practices calls for alternative management practices to redress the nutrient balance.

The internal flows investigated are summarized in Figure 2. Most of the nutrients consumed by the household are from the *afup owondo*, 4.93 kg N, 1.62 P and 6.56 K, K being the most abundant nutrient element in the diet. The contribution of animal products to household consumption was very low. Human faeces can be a good source of K if recycled. Farm animals consume a good proportion of the kitchen refuse, but dejections are not recycled; the residual of kitchen refuses not eaten by animals has high K (17.2 kg K ha^{-1}.yr^{-1}) because of the wood ash. Nutrient losses from internal flows are from animal dejection, human faeces, and the kitchen refuse. Management options should be initiated to minimize these internal nutrient losses.

Partial budget of flows not managed by farmers

Table 7 indicates a balance of –4.8 kg N, +2.4 kg P and +9.6 kg K $ha^{-1}.yr^{-1}$, for nutrient flows not managed by farmers. The major input is through deep capture by trees; farmers maintain many trees especially in cocoa farms as shade trees, which significantly contribute to nutrient recycling in the system. In spite of no fertilizer input, cocoa farms are sustainable through nutrient recycling by the trees and the high litter production. Main losses are from burning of the vegetation, either directly through volatilisation, or indirectly through leaching.

Table 7. Farm-level nutrient budgets in traditional systems of southern Cameroon

Type of flows	N	P	K
Farmer managed			
IN 1: Mineral fertilizers	0	0	0
IN 2a: Animal feeds	0	0	0
IN 2b: Organic fertilizers	0	0	0
IN 2c: Fuel Wood	0	1.6	15.6
OUT 1a: Crop products sold	9.5	2.0	9.8
OUT 1b: Animal products sold	0.53	0.18	0.04
OUT 2a: Export of crop residues	0	0	0
OUT 4c: Gaseous losses from burning	47.8	1.8	14.3
OUT 6: Human faeces	4.0	0.64	4.8
F1 5a: Losses from animal dejections	4.9	0.40	1.6
F1 2c: Losses from kitchen residues	1.1	2.2	17.2
Partial budget 1	-67.8	-5.6	-32.1
Not farmer managed			
IN 3: Atmospheric deposition	4.4	1	3.9
IN 4: Biological N fixation	6.9	0	0
IN 5: Sedimentation	0	0	0
IN 6: Deep capture	16.6	1.4	6.6
OUT 3a: Leaching	26.4	0	1.0
OUT 4a: Gaseous losses from the soil	6.3	0	0
Partial budget	-4.8	+2.4	+9.5
Total budget	-73	-3	-23

Table 8. Nutrient budgets in the different land uses of the slash and burn chronosequence in southern Cameroon ($Mg.ha^{-1}.yr^{-1}$)

	Land uses											
FLOWS	*Essep*			Banana			*Afup*			Cocoa		
Inflows	N	P	K	N	P	K	N	P	K	N	P	K
IN 1: Mineral fertilizers	0	0	0	0	0	0	0	0	0	0	0	0
IN 2a: animal feeds	0	0	0	0	0	0	0	0	0	0	0	0
IN 2b: organic fertilizers	0	0	0	0	0	0	0	0	0	0	0	0
IN 2c: fuel wood	0	0	0	0	0	0	0	0	0	0	0	0
IN 3: atmospheric deposition	4.4	1	3.9	4.4	1	3.9	4.4	1	3.9	4.4	1	3.9
IN 4: biological N fixation	0	0	0	0	0	0	6.9	0	0	0	0	0
IN 5: sedimentation	0	0	0	0	0	0	0	0	0	0	0	0
IN 6: deep capture	0	0	0	0	0	0	0	0	0	16.6	1.4	6.6
Total inflows	4.4	1.0	3.9	4.4	1.0	3.9	11.3	1.0	3.9	21	2.4	10.5
Outflows												
OUT 1a: crop products sold	0.06	0.17	1.39	0.31	0.05	1.1	4.2	0.7	3.5	5.1	0.97	2.9
OUT 1b: animal products sold	0	0	0	0	0	0	0	0	0	0	0	0
OUT 2a: export of crop residues	0	0	0	0	0	0	0	0	0	0	0	0
OUT 3a: leaching	26,4	0	0.88	26.4	0	0.88	26.4	0	0.88	6.6	0	0.20
OUT 4a: gaseous losses from soil	6.6	0	0	6.6	0	0	6.6	0	0	6.6	0	0
OUT 4c: gaseous losses from burning	47.8	1.8	14.3	0	0	0	47.8	1.8	14.3	0	0	0
OUT 6: human faeces	0	0	0	0	0	0	0	0	0	0	0	0
Total outflows	80.9	1.97	16.6	33.3	0.05	2.0	85.0	2.5	18.6	11.7	0.97	2.9
BALANCE	-76.5	-0.97	-12.7	-28.9	+0.95	+1.9	-73.7	-1.5	-14.7	+9.3	+1.43	+7.6

Total farm nutrient budget and scenario results

Figure 3 summarizes the major nutrient inflows and outflows of the system under study. The total budget (Table 7) of the land uses investigated in this study is negative: -73 kg N, -3 kg P and –23 kg K $ha^{-1}yr^{-1}$. The deficit in nitrogen results mostly from leaching and volatilisation during burning of the forest vegetation, which emphasises the negative effects of burning in traditional land uses.

Figure 3. Inflows and outflows of nutrients in a traditional farming system of southern Cameroon

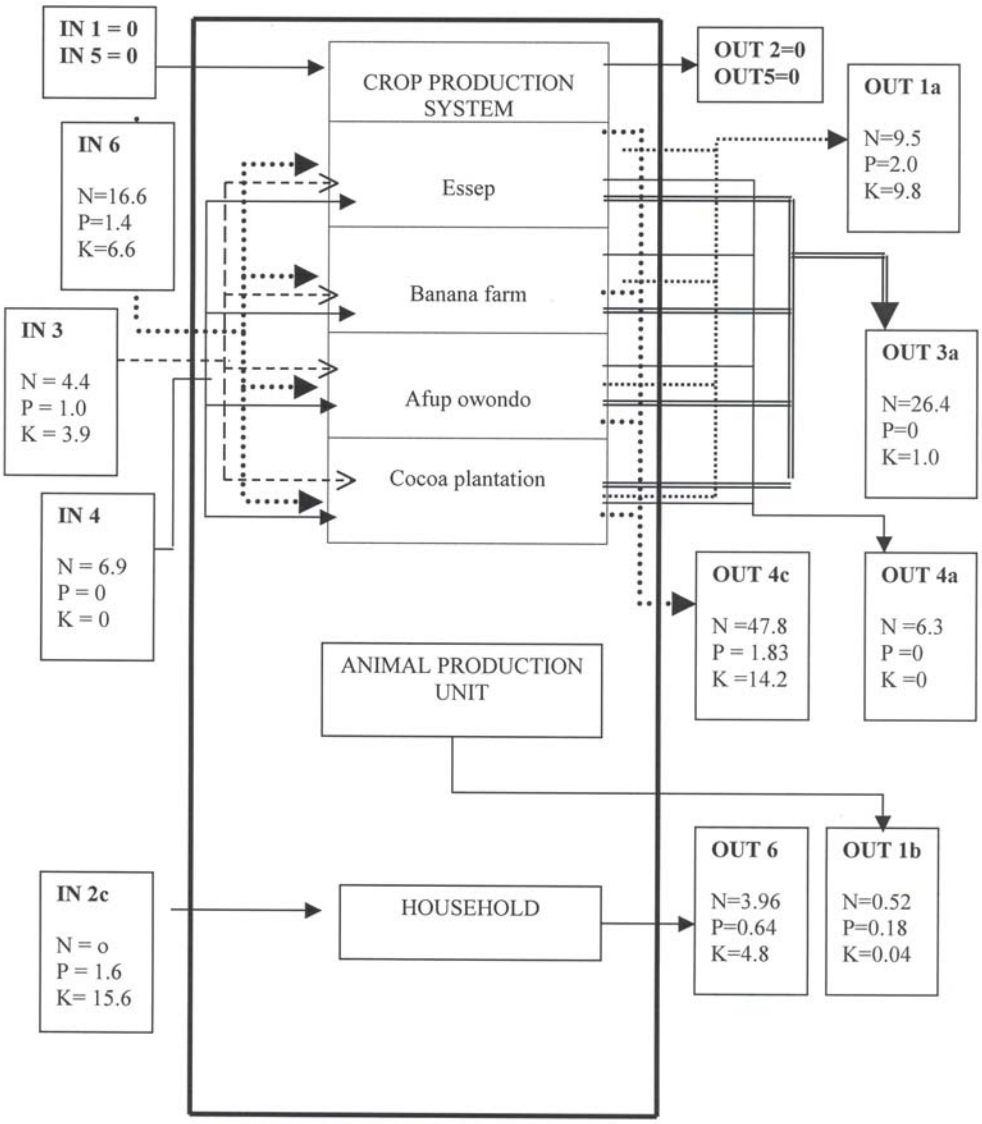


Table 9. Total nutrient balance with different management scenarios in the slash and burn agriculture in southern Cameroon

	Management scenario*														
FLOWS	S2			*S3*			S4			*S5*			S6		
Inflows	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
IN 1: Mineral fertilizers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN 2a: animal feeds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN 2b: organic fertilizers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN 2c: fuel wood	0	1.6	15.6	0	1.6	15.6	0	1.6	15.6	0	1.6	15.6	0	1.6	15.6
IN 3: atmospheric deposition	4.4	1	3.9	4.4	1	3.9	4.4	1	3.9	4.4	1	3.9	4.4	1	3.9
IN 4: biological N fixation	6.9	0	0	6.9	0	0	6.9	0	0	6.9	0	0	6.9	0	0
IN 5: sedimentation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IN 6: deep capture	16.6	1.4	6.6	16.6	1.4	6.6	16.6	1.4	6.6	16.6	1.4	6.6	16.6	1.4	6.6
Total inflows	27.9	4	26.1	27.9	4	26.1	27.9	4	26.1	27.9	4	26.1	27.9	4	26.1
Outflows															
OUT 1a: crop products sold	9.5	2	9.8	9.5	2	9.8	9.5	2	9.8	9.5	2	9.8	9.5	2	9.8
OUT 1b: animal products sold	0.53	0.18	0.04	0.53	0.18	0.04	0.53	0.18	0.04	0.53	0.18	0.04	0.53	0.18	0.04
OUT 2a: export of crop residues	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OUT 3a: leaching	26.4	0	1.0	26.4	0	1.0	0	0	0	0	0	0	0	0	0
OUT 4a: gaseous losses from soil	6.3	0	0	6.3	0	0	6.3	0	0	6.3	0	0	6.3	0	0
OUT 4c: gaseous losses from burning	47.8	1.8	14.3	47.8	1.8	14.3	0	0	0	0	0	0	0	0	0
OUT: erosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OUT 6: human faeces	4	0.64	4.8	0	0	0	4	0.64	4.8	4	0.64	4.8	0	0	0
F1 5a: losses from animal dejections	0	0	0	0	0	0	4.9	0.4	1.6	0	0	0	0	0	0
F1 2c: losses from kitchen residue	0	0	0	0	0	0	1.1	2.2	17.2	0	0	0	0	0	0
Total outflows	94.5	4.62	29.9	90.5	4.0	25.1	26.3	5.4	33.4	20.3	2.8	14.6	16.3	2.18	9.8
BALANCE	-66.6	-0.62	-3.8	-62.6	0	+1	+1.57	-1.4	-7.3	+7.6	+1.2	+1.5	+11.6	+1.82	+16.2

* S1: Actual balance, see Table 7; S2: Kitchen residues and animal manure recycled; S3: S2 plus human faeces recycled; S4: Actual management, but burning avoided; S5: No burning + S2; S6: No burning + S3

Six management scenarios are envisaged (Table 9): (S1) the actual management system is maintained, the nutrient (N, P, K) balance ($ha^{-1}.yr^{-1}$) is (-73, -3, -23); (S2) kitchen residues and animal manure are recycled (balance: -66.6, -0.62, -3.8). If the human faeces are also recycled (S3) the balance will be: -62.6, 0, +1. If burning is avoided at the actual management level maintained (S4), the budget will be: +1.57, -1.4, -7.3. Two scenarios resulted in completely positive nutrient balances. In case of no burning and recycling of kitchen residue and animal manure (S5), the budget will be: +7.6, +1.2, +1.5, and in case of no burning and all the residues recycled (S6): +11.6, +1.82, +16.2.

DISCUSSION AND CONCLUSIONS

Farm level results

Many previous works on nutrient budget have targeted high populated and agriculture intensive areas, where farmers invest in soil fertility improvement. Organic and chemical amendments, household residues and crop residues are actively recycled and redistributed in the different production compartments (Hoffmann et al., 2001; Baijukya and De Steenhuijsen, 1998; Smaling et al., 1993). The system investigated in this study is structurally different, burning and fallowing are the sole mechanisms for soil fertility improvement, resulting in extremely “depletive” cropping system. As there is little saving of nutrients and no adding, the system survives on natural fertilizing stocks. In the forest zone, the animal component is small and poorly documented; farmers do not actively redistribute household animal manure in the farm. In northwest Nigeria farmers combine the application of organic and mineral fertilizers in an effective way to maintain the fertility of their soil, adding annually 87 kg N, 33 kg P, and 120 kg K ha^{-1} (Hoffmann et al., 2001). In cattle producing areas in North West Tanzania, animal dejection contributes 68 kg N, 15 kg P and 56 kg $K.ha^{-1}.yr^{-1}$ (Baijukya and De Steenhuijsen, 1998). Inputs of 44 kg N, 23 kg P and 11 kg K $ha^{-1}.yr^{-1}$ as inorganic fertilizers are also reported in the sub-humid zone of Kenya (Van den Bosch et al., 1998). Many countries have removed subsidies on fertilizers since the collapse of the cocoa market, and smallholders cannot afford them any longer because of cost and availability. Nutrient flows not directly managed by farmers, and estimated from transfer functions are generally site-specific, depending on rainfall and soil clay fraction. Very few reports are actually available for the humid forest zone. However, most of the nutrient flows quantified in this study were similar to those reported in the humid forest of Ivory Coast (Janssen et al., 1990), humid Amazonian forest (Hölscher et al., 1997), the humid savannas of eastern Africa (Smaling et al., 1993, Van den Bosch et al., 1998).

Animal production is at small scale (Table 6) resulting in low production of manure compared to savannas. The only input to the system by farmers was fuel wood. Many losses because of burning, leaching, non-recycled household waste and animal manure, could not be balanced by nutrient inputs though natural processes. The system thus resulted in a negative nutrient balance: -73 kg N, -3 kg P and -23 kg K $ha^{-1}.yr^{-1}$. Main losses occurred from burning and leaching. Nutrient export through crop products represents 14% of N, 45% of P and 25% of K. Main inputs to the cocoa system are through deep capture.

Subsystem level results
Table 8 compares nutrient budgets in the different land uses. We assumed that because of very few trees maintained in *essep*, banana and *afup*, deep capture in those land uses is negligible. In cocoa, farmers maintained a high number of trees, which prevent nutrient leaching, and also provide deep capture of nutrients. We also assumed that the presence of these trees and the absence of burning in cocoa, might reduce leaching by 75%. Major inflows in the four systems are atmospheric depositions and biological N fixation. *Essep* and *afup* had a negative nutrient balance, with a high N and K deficit. In banana however, the P and K balance was positive. Major losses occurring in *essep* and *afup* were through burning. The cocoa plantation had a positive nutrient balance: +9.3 kg N, +1.4 kg P and +7.6 kg K ha^{-1}.yr^{-1}. Cocoa can therefore be considered as a sustainable system. The nutrient balance in banana is positive for K: + 1.9 kg.ha^{-1}.yr^{-1}. Table 4 indicates that on a 0.4 ha of land, banana production requires 15.9 kg of K, equivalent to 39.8 kg of K ha^{-1}, which is less than K requirements of *afup* (61.3 kg.ha^{-1}). In the site, banana is the staple food, and 56% of the crop is used for household consumption. In addition, the land area under banana represents only 6% of the total land use. The small production scale and the high internal consumption by the household therefore justify the positive K balance in banana. Market oriented intensification of banana production would rapidly disrupt the positive K balance, unless amendments are provided.

In *afup* and *essep* 74 kg and 76 kg N are lost yearly per hectare respectively. The introduction of nitrogen-fixing tree species in *essep* and *afup* as planted fallow can be envisaged as a viable alternative to redress the N depletion in the system, provided adequate residue management is developed to avoid losses during land preparation. Internal nutrient flows indicate that most of the household nutrients supply is from the *essep*: 4.9 kg N, 1.6 kg P and 6.6 kg K ha^{-1}.yr^{-1}. However, from the total nutrients supplied to the household, 60% of N, 32% of P and 52% of K are lost in deep latrines. High quantity of K occurred in kitchen refuse through wood ash, but neither the kitchen residues nor animal dejections are recycled.

Management scenarios
We envisaged that the recycling of kitchen residues, animal dejections and/or human faeces, and the avoidance of burning could significantly modify the nutrient balance of the system. From the different management scenario proposed (Table 9), scenario S2 and S3 are feasible, without major difficulties; in some areas, human faeces are actively recycled as feeds or organic manure. The major challenge in the system under study will be to reduce burning during land preparation, which is necessary to achieve a positive nutrient balance. Farmers cannot avoid burning in *essep* and *afup*, and cannot do without *afup*, since it is the main source of food for the household. Completely avoiding burning is therefore a difficult scenario. The trade-off will be to reduce farmer dependence on *essep* and *afup* as sources of income, and develop alternative tree-based systems with high income generating potentials, to provide household revenue. The strategy will involve enriching cocoa plantations with fruit and medicinal tree species of high commercial value, i.e. reducing *essep* and *afup* at household consumption scale, and developing tree-based systems at commercial scale.

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Chapter 5

DYNAMICS OF EARTHWORMS IN THE SLASH-AND-BURN CHRONOSEQUENCE OF LAND USE SYSTEMS ON ACID SOILS IN THE HUMID FOREST ZONE OF SOUTHERN CAMEROON

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ABSTRACT

A field study was conducted from April 2001 to March 2003 on an acid soil in Ma'an, southern Cameroon, to assess the effect of changing land use in slash-and-burn agriculture on earthworm density, their casting activity, and the chemical properties of casts they produce. Earthworm density was monitored in seven land uses and their follow-up systems in the slash-and-burn chronosequence during 2 years: natural forest, *essep*, banana farm, short fallow, *afup owondo*, long fallow and a five-months *Inga edulis* improved fallow. Earthworm density ranged between 21-118 m^{-2}; 64% of the earthworms occurred in the upper 10 cm of the soil. Lowest densities occurred in land use systems succeeding *essep* and *afup owondo*, while highest densities were in land use system succeeding short fallow. Upon the conversion of fallow to *essep* or *afup owondo*, up to 95% loss occurred in worm density; changes from *essep* to banana or cassava induced 25% loss. Highest densities of earthworms and surface cast production were achieved faster after land use change in *Inga* fallow than in crop fields. Intensive casting started in *Inga* fallow after 5 months, and six months later cumulative cast production in *Inga* was similar to that in forest. In land use systems succeeding *afup owondo* and *essep,* casting started after 14 and 19 months, respectively, after the beginning of the experiment. Land use systems succeeding *afup* needed 18 months and those succeeding *essep* 24 months to have cumulative cast production similar to that of the forest. Total cast production was higher in the forest (2.1 Mg ha^{-1}) and in *Inga* fallow (2.2 Mg ha^{-1}) at the end of the first year, compared to other systems where it was less than 0.5 Mg.ha^{-1}. At the end of the experiment, 5.9 Mg.ha^{-1} of casts had been collected in land use systems succeeding *afup*, 3.2 in forest and *Inga*, 2.9 in land use systems succeeding *essep* and 0.82 in those succeeding banana. Element concentrations of casts were higher than in the underlying soil in all land uses, leading to enrichment of the topsoil with organic carbon, P and Ca. The highest quantity of nutrients recycled was in land use systems succeeding *afup*, because of the high quantity of casts produced. Nutrient recycling through casts can be considerably improved if *Inga edulis* is introduced in the chronosequence, and the natural fallows converted to planted fallows.

Key words: Cast production, cast quality, earthworm, slash and burn, population dynamics, improved fallow

INTRODUCTION

The soil macrofauna exerts a vital function with respect to soil structure and nutrient cycling in tropical ecosystems; they modulate soil functioning by producing biogenic structures and macropores, and also determine the activities of soil microorganisms and small invertebrates that inhabit their biogenic structures (Lavelle et al., 2001). The structure and abundance of the soil macrofauna community are, however, very sensitive to the management of the vegetative soil cover (Lavelle et al., 1994). Land use practices and decrease in soil organic inputs are considered the main factors explaining the decrease of macrofauna communities and activities in crop fields (Decaens et al., 2002).

Earthworms represent an important group of the soil macrofauna in both temperate and tropical ecosystems; they play an important role in soil ecology and can serve as indicators in land quality evaluation (Mele and Carter, 1999). Earthworms influence a wide range of soil properties. They modify the physical, chemical and biological properties of the soil mainly through burrowing and production of mucus and casts (Araujo and Lopez-Hernandez, 1999). They enhance soil nutrient availability through their selective feeding habits and the passage of the ingested material through the worm gut may increase microbial activity in the casts (Mulongoy and Bedoret, 1989). The positive effects of earthworms on the availability of major nutrients have been widely reported (Sharpley and Syers, 1977; Reddy et al., 1997; Ganeshamurthy et al., 1998).

The impact of earthworms on soil properties is partly determined by the quantity of bio-structures they produce. In forest ecosystems the presence of many different tree species contributing to litterfall may significantly raise the earthworm density, species composition and casting activities, but in agroecosystems these parameters are largely influenced by agricultural practices (Scullion et al., 2002). Cultivation techniques during land preparation in the slash and burn agricultural practices are likely to adversely affect earthworm populations because of the environmental disturbances they generate. The conversion of a mature secondary forest plot to an *essep*, or a fallow to *afup owondo* through slashing and complete burning of the residues and the soil tillage during groundnut planting and harvesting, will negatively affect the soil macrofauna densities and activities along the slash and burn chronosequence. Analytical studies of the changes in earthworm densities and casting activities brought about by the slash and burn agricultural practices and subsequent land uses are limited.

The integration of trees with relatively fast growth in the case of improved fallow may favour the development of soil macrofauna, through their effects on litter and microclimate (Barros et al., 2003). Many reports indicate improved earthworm casting in alley cropping systems compared to the traditional cropping system without trees (Hauser, 1993; Henrot and Brussaard, 1997), but not all favoured tree species can grow on acid and Al-toxic soils (Fisher and Juo, 1995). *Inga edulis* is reported to have an outstanding growth performance on strongly acid soils (pH = 4.1), developing a large crown at an early stage of growth and yielding up to 61 Mg ha^{-1} of biomass 20 months after planting (Kanmegne et al., 2000).

This study was aimed at assessing the impact of land uses and related organic residues and soil nutrient management practices on (1) the dynamics of earthworm densities, (2) the production of surface casts by earthworms and (3) chemical properties of casts produced in the different land uses compared to the non-ingested soil. This study also intends to assess the potential contribution of *Inga edulis* to the recovery of earthworm density and casting activities after the slashing and burning of the natural vegetation.

MATERIALS AND METHODS

The study site

The study was conducted in the agroforestry buffer zone of the Campo Ma'an national park in southern Cameroon, located between 2°10'-2°52'N and 9°50'-10°54'E. The site is under Equatorial climate, with a bimodal rainfall pattern and four seasons. The dry seasons are from mid November to February, and from July to mid-August, and the rainy seasons cover mid August to mid November and March to June (Figure 1). The annual rainfall is 1500 to 2000 mm and the mean annual temperature is 25°C. The soils are Ferric Acrisols, reddish to yellowish in color with no pronounced profile differentiation, characterized by a low base saturation, and low cation exchange capacity. At the site the soils are highly acidic wit pH (H_2O, 1:1) close to 4. The soil nutrient analysis indicated low to deficient levels of K, P, Mn, and Zn (Table 1). The vegetation of the site forms part of the humid evergreen forest.

Figure 1. Rainfall distribution of the study area (mean of 10 years)

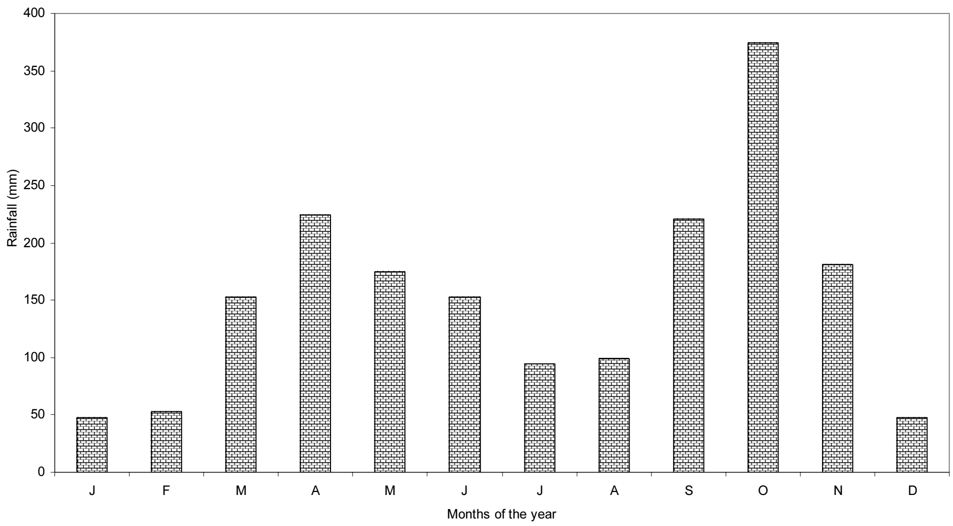


Table 1. Nutrient concentrations at different depths of the different land uses in the slash and burn chronosequence in southern Cameroon.

Nutrient	Depths (cm)	Land uses						
		Forest	*Essep*	Banana	Short fallow	*Afup*	Long fallow	Cocoa
C	0-5	2.68 b	3.78 a	1.91 c	2.50 b	2.47 b	1.55 d	1.54 d
(%)	5-10	1.63 b	1.97 a	1.21 d	1.62 b	1.42 c	1.11 e	1.04 e
	10-20	1.19 a	1.37 a	0.89 b	1.26 a	1.11 a	0.74 b	0.42 b
	20-50	0.93 a	0.89 ab	0.77 b	1.02 a	0.89 a	0.59 c	0.61 c
N	0-5	0.145 b	0.215 a	0.119 b	0.146 b	0.161 b	0.151 b	0.151 b
(%)	5-10	0.107 b	0.180 a	0.086 a	0.105 b	0.115 b	0.109 b	0.119 b
	10-20	0.075 b	0.094 a	0.064 b	0.070 b	0.095 a	0.087 a	0.075 b
	20-50	0.058 b	0.068 a	0.045 b	0.055 b	0.062 a	0.062 a	0.068 a
P	0-5	6.96 b	18.7 a	5.48 b	6.19 b	15.2 a	8.82 b	7.4 b
($mg.kg^{-1}$)	5-10	2.48 c	5.66 a	2.59 c	3.15 b	5.28 a	4.34 a	4.63 a
	10-20	0.59 c	1.52 a	1.07 b	0.64 c	1.41 a	1.53 a	2.55 a
	20-50	0.03 c	0.17 b	0.55 a	0.05 b	0.12 b	0.89 a	1.23 a
K	0-5	0.137 a	0.246 a	0.007 c	0.129 a	0.255 a	0.090 b	0.080 b
$cmole.kg^{-1}$	5-10	0.076 b	0.140 a	0.005 b	0.076 b	0.148 a	0.060 b	0.060 b
	10-20	0.043 b	0.095 a	0.008 c	0.038 b	0.105 a	0.050 b	0.030 b
	20-50	0.017 b	0.024 b	0.004 c	0.019 b	0.025 b	0.050 a	0.050 a
Ca	0-5	1.34 a	2.75 a	0.98 b	2.02 a	2.78 a	0.25 b	0.42 b
$cmole.kg^{-1}$	5-10	0.50 a	0.78 a	0.52 a	0.78 a	0.99 a	0.13 b	0.16 b
	10-20	0.27 a	0.33 a	0.21 a	0.26 a	0.41 a	0.05 b	0.07 b
	20-50	0.20 a	0.21 a	0.15 a	0.20 a	0.22 a	0.06 b	0.06 b
Mg	0-5	0.53 a	0.88 a	0.21 b	0.62 a	0.88 a	0.12 b	0.50 a
$cmole.kg^{-1}$	5-10	0.25 a	0.30 a	0.12 b	0.29 a	0.33 a	0.07 b	0.08 b
	10-20	0.13 a	0.14 a	0.07 ab	0.11 a	0.14 a	0.04 b	0.05 b
	20-50	0.09 a	0.05 a	0.04 a	0.06 a	0.04 a	0.04 a	0.05 a

Figures followed by the same letter for different land uses are not different at same depth at $P<0.05$

Slash and burn practices and land use selection

Farmers select a forest plot, slash and burn the vegetation to plant *ngon* (*Cucumeropsis manii*), and plantain banana (*Musa spp.*); this land use is called *essep*. *Ngon* is harvested after 5 to 8 months; the plot is then managed for 1 to 2 years for plantain production, and then left for a short fallow of one to two years. The same plot will be slashed again and the residues completely burnt, then planted with food crops, dominated by groundnut (*Arachis hypogaea*) and cassava (*Manihot esculenta*); the food crop farm is called *afup owondo*. After the *afup owondo* the plot is left for a long fallow of 10-15 years, before an *essep* can be established again.

Seven land uses were selected for this study and in four replicates: initial forest, *essep*, banana farm, short fallow, *afup owondo*, and a long fallow. *Inga edulis* planted fallow was also included in the study. The *Inga* fallow was established in

August 2000, and was 10 months old at the beginning of the experiment. The experimental unit was a 40 x 40 m plot in each land use.

Earthworm densities

Earthworm density was assessed in May 2001, in the forest, *essep*, banana, short fallow, *afup owondo*, long fallow, and *Inga* fallow. On each plot 8 monoliths of 25 x 25 x 30 cm were excavated along the two crossed diagonals of the 40 x 40 m plot at 10 m intervals and the soil was separated into litter (if present), 0-10 cm, 10-20 cm and 20-30 cm (Anderson and Ingram, 1993). Earthworms were hand-sorted in the field and were stored in 70% ethanol plus 5% formaldehyde. In the laboratory, they were counted and preserved for later identification. In May 2002, sampling was done in the same plots, but the land uses had changed. Long fallows had been converted to *essep* (50%) and to *afup owondo* (50%). Some *essep* had changed to banana farm, some others to cassava. The banana farm has been converted to short fallow, the short fallow to *afup owondo*, and the *afup owondo* to cassava (Table 2). *Inga* fallow and forest did not change, and were also sampled.

Collection of earthworm casts

Earthworm casts were collected in forest, *essep*, banana farm, *afup owondo* and *Inga* fallow. In each plot, four mini-plots of 50 x 50 cm were randomly selected using metal frames. Earthworm casts formed inside the mini-plots were collected 3 times a week during rainy seasons and 2 times a week during dry seasons. The collected material was oven-dried at 65 ^{O}C, and weighed. Casts were bulked per month and the monthly cast production determined for each land use. The monitoring lasted 24 months, from April 2001 to March 2003.

Cast quality determination

Casts collected from each land use were bulked for each year, then analyzed for pH, organic C, N, exchangeable Ca, Mg, and K, and extractable P. In the same plots, soil samples were also collected at 0-5 cm depth at 8 points at 10 m intervals along the cross-diagonals of the plot, and analyzed for the same elements as casts, for comparison. Casts and soil samples were air-dried and ground to pass a 2 mm mesh. Cations (Ca, Mg, K) were extracted by the Mehlich-3 procedure (Mehlich, 1984); cations were determined by absorption spectrophotometry. Phosphorus was extracted with the Bray II method and analyzed by the malachite green colorimetric procedure (Motomizu et al. 1983). Organic carbon was determined by chromic acid digestion and spectrophotometry (Heanes, 1984). Total N was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremner and Tabatabai, 1972; Nelson and Sommers, 1972).

Statistical analyses

The different land uses were compared for the earthworm density, the monthly cast production, the cumulative cast production and the chemical characteristics of casts. The collected data were subjected to analysis of variance (ANOVA), using the SAS statistical package (SAS, 1996). Standard error of the difference was used to separate means. The density and amount of casts produced under different land uses were also tested for correlation with rainfall and soil data.

RESULTS

Earthworm dynamics

Earthworm abundance differed significantly ($P<0.05$) between the land uses during the first year of the experiment. More worms occurred in banana, short fallow and long fallow compared to *essep* and *afup owondo* (Table 2). The highest density was 118 (± 28) m^{-2} in the short fallow. Earthworms were significantly ($P<0.01$) more abundant in the top 10 cm soil, where 64% of the total number was found, versus 20.5% in the 10-20 cm and 10.5% in the 20-30 cm layers. For the earthworm density, the land uses could be classified as follows: short fallow = long fallow = banana farm > forest = *Inga* fallow> *afup owondo* = *essep* (Table 2).

The second year of the experiment, 50% of the *essep* had been converted to banana and 50% to cassava; also 50% of long fallow had been converted to *essep* and 50% to *afup owondo*. The *afup owondo* of year 1 became cassava and the banana farm was left fallow. Earthworm densities decreased between 64% and 95% whenever fire was used. Moderate losses occurred upon conversion of *essep* to banana or to cassava. Worm density increased only when banana was left fallow (Table 2).

Taking the worm density in the forest as a reference, the density was depressed in *essep* and *afup owondo*. Land preparation requires intensive burning and complete cleaning of the field (in the case of *afup*), which results in soil exposure. This is probably detrimental to the earthworms in these systems. Banana and fallow plots had higher earthworm density than the forest, indicating a rapid recovery of the earthworms in the chronosequence and, possibly, the absence of natural enemies after burning. Worm densities were significantly higher in *Inga* fallow than forest, indicating that 10 months after planting *Inga* fallow had created conducive conditions for earthworms (probably shade, litterfall, and soil humidity similar to the forest), perhaps because the *Inga* was preceded by short fallow till five months before the start of the study; short fallow has higher earthworm density than forest (Table 2). Vohland and Schroth (1999) found a strong correlation between soil litter mass and earthworm density ($r^2 = 0.91$). Allowing a significant return of plant residues to the soil surface is conducive for a high earthworm density (Lavelle et al., 2001). Worm abundance in the topsoil is generally associated with organic matter, oxygen, humidity, and /or conducive pH at the soil surface (Henrot and Brussaard, 1997; Araujo and Lopez-Hernandez, 1999).

Land use practices have strong impacts on soil macro-invertebrate communities (Lavelle et al., 2001). Burning induced losses of up to 95% of the earthworms. The use of fire during land preparation leads to changes in vegetation characteristics with subsequent modifications in microhabitat conditions, the complete removal of shade and modification of organic residues of the soil surface which in turn affect earthworm density (Hauser, 1993; Lavelle et al., 2001; Sinha et al., 2003). During the establishment of *afup owondo* the soil is surface-tilled, which adds to the disturbance of the soil surface and is likely to affect worm density (Scullion et al., 2002). The conversion of *essep* to banana or cassava caused 25% loss. The disturbance of the surface soil, the removal of the *ngon* vines during land preparation, and the piling up of soil around cassava stems may have increased the soil exposure, thus further affecting earthworms (Scullion et al., 2002).

Table 2. Changes in earthworm density (individuals m^{-2})with changing land uses in the slash and burn chronosequence

Year 1*	Land use	Forest	*Essep*	*Essep*	Banana	S/ fallow	*Afup owondo*	L/ fallow	L/ fallow	*Inga*
	Density	42.3±14	21.1±7	21.1±7	92.3±21	118±28	29.4±6	89.0±17	89.0±17	64.4±20
Year 2**	Land use		Banana	Cassava	S/fallow	*Afup*	Cassava	*Essep*	*Afup*	
	Density		15.8±5	15.7±5	119±50	35.0±14	27.7±9	4.7±2	32.0±12	
Change (%)			-25	-25.5	28.6	-70	-5.8	-95	-64	

* April 2001-March 2002
** April 2002-March 2003

Earthworm density in this experiment ranged between 21 and 118 m^{-2}, which is relatively low compared to available literature. Araujo and Lopez-Hernandez (1999) reported 155 to 256 m^{-2} in forest ecosystems of Amazonia; Lavelle et al. (1994) found 4-401 in the humid tropical forest. Total N and Mg were strongly related to earthworm density (r^2 was 0.76 and 0.77 respectively). Weak relations between worm density and total carbon ($r^2 = 0.32$), potassium ($r^2 = 0.26$), and calcium ($r^2 = 0.28$) were also observed. Mele and Carter (1999) also obtained $r^2 = 0.29$ for Ca, $r^2 = 0.26$ for K and $r^2 = 0.29$ for total C.

Earthworm casting activity
Inga fallow was planted in October 2000, on a plot derived from a short fallow. The experiment started in April 2001. Forest was considered as the reference land use. Monthly cast production generally followed the rainfall distribution patterns, with minimal activity during dry months (Figures 2 and 3), but the highest quantity of casts collected did not always coincide with the highest rainfall. From 8 months after the beginning of the experiment (November 2001), cumulative cast production in *Inga* was similar to that in the forest (Figure 4). Casting in *afup* and follow-up land use systems reached the forest level after 20 months, and *essep* and follow-up land use systems after 24 months. Towards the end of the experiment, from August 2002, casting was intensified in land use systems following *afup* (particularly in fallow) compared to other land uses and even to forest. Banana and the following fallow performed poorly throughout the experimental period, although earthworm density was highest in banana, next to short fallow only (Table 2).

Figure 2. Monthly cast production in the traditional land uses of the slash-and-burn chronosequence (dotted lines indicate changes in land use)

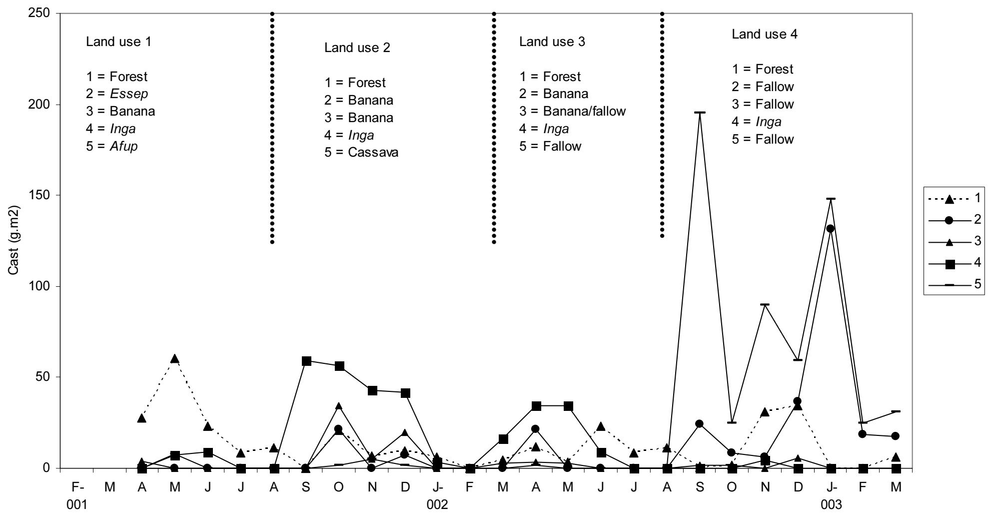


Figure 3. Earthworm cast production and rainfall pattern in traditional farming systems of southern Cameroon

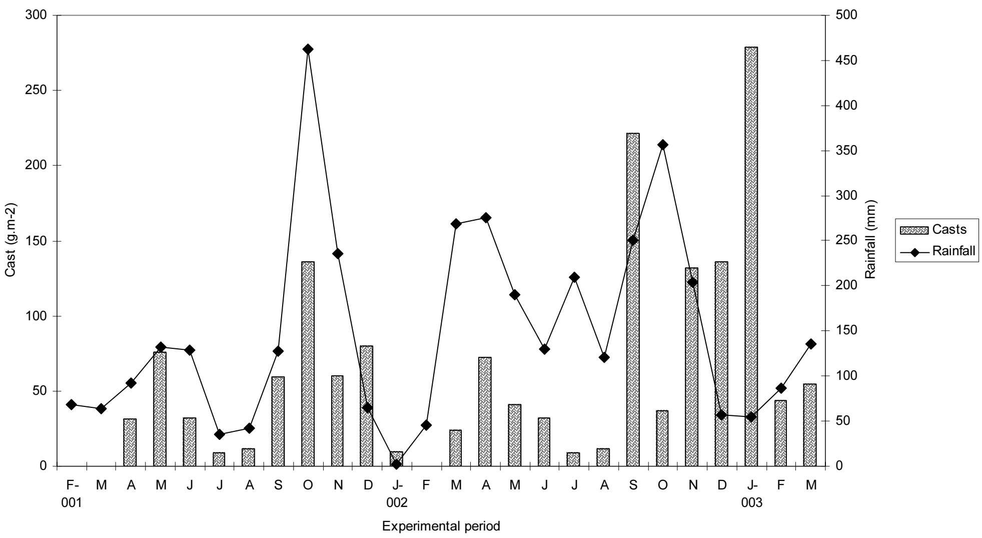
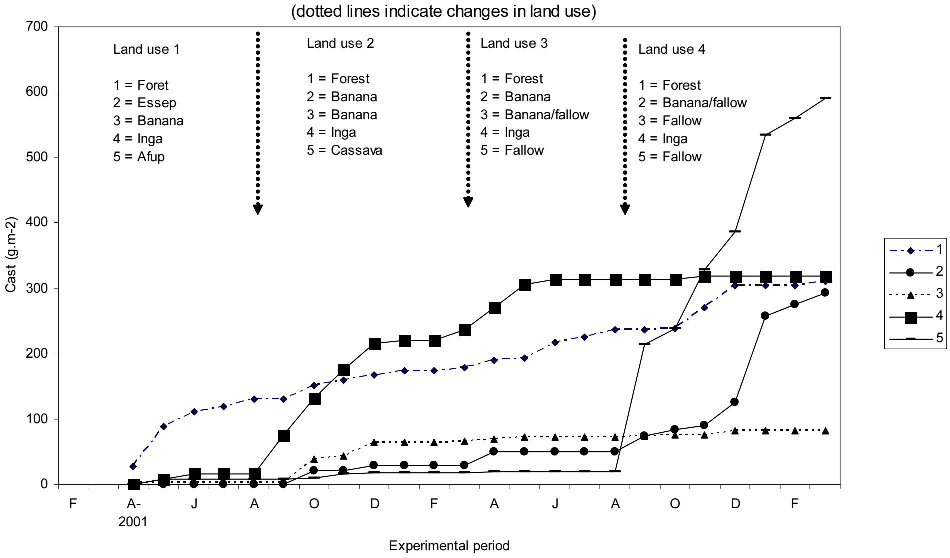


Table 3 summarizes the changes in the different land uses during the experimental period, and the effects on casting activities. Casting was improved whenever land was left to low, except in banana, where a consistent trend was not observed. This was consistent with the high worm density in short fallows (Table 2). Intensive casting only occurred in the chronosequence beginning with *afup owondo* and *essep* after 17 and 20 months, respectively. From March 2003 (after 24 months) onwards, cumulative cast production was at least comparable to forest, except for the land uses systems succeeding banana farm (Figure 4). The quantity of casts produced showed marked changes during the experimental period. During the first year (2001), the highest quantity of casts occurred in *Inga* fallow and forest with 2.16 $Mg.ha^{-1}$ and 2.07 $Mg.ha^{-1}$, respectively, possibly because *essep* and *afup* were still under the stress of burning during land preparation. *Inga* exerted a favorable effect on the soil faunal activities, presumably by keeping the soil moist and shaded and providing litter as a substrate. Burning reduced the abundance of earthworms by disturbing their physical environment, and by reducing the diversity and abundance of organic inputs that they normally use for feeding (Decaens et al., 2002; Lavelle et al., 2001). During the second year (2002), casting activity significantly ($P<0.05$) increased in *afup owondo* and *essep*, upon their conversion to cassava farm and banana, respectively (land uses 5 and 2 in Figure 2). There was possibly an increase in soil nitrogen from the groundnut residues on the soil surface, roots and nodules enriching the topsoil with N. Thereafter, the earthworms recovered from the soil management stress. Casting in the land uses systems following after *essep* was at the highest level only after (more than) 24 months. The total quantity of casts produced during the 2 years was highest in *afup*, 5.9 $Mg.ha^{-1}$, as a result of the intense casting during the second year; similar in forest, *Inga*, and *essep;* and the lowest in banana (Figure 4).

Figure 4. Cumulative cast production in the different land uses of the slash-and-burn chronosequence (dotted lines indicate changes in land use)



In this study the total quantity of casts produced in the different land uses was very low compared to data obtained by Norgrove and Hauser (2000), who reported 30 to 35 $Mg.ha^{-1}$ in agrisilvicultural systems in Central Cameroon, and about half the quantity of 2.6 to 5.7 $Mg.ha^{-1}$produced within 5 months on Ultisols in SW-Nigeria (Henrot and Brussaard, 1997). Our maximum was 5.9 $Mg.ha^{-1}$ for 2 years. The differences with other workers reflects the low number of earthworms, probably related to the very low soil pH ($pH_{KCl} = 3.8$) of the site.

Macronutrient contents of earthworm casts

For all nutrients and in all land uses, casts were richer than the topsoil (Table 4). Casts collected in banana were the richest for all nutrients, similar to those from *essep* for Ca, Mg, K and N, but significantly different from those collected in other land uses. Casts from the forest were the poorest in Ca, Mg and N. Casts from *afup* had the lowest concentrations of P, K and C. The general tendency was that relatively poor soils produced relatively rich casts.

Table 3. Changes in land uses and earthworm casting intensity in traditional farming systems of southern Cameroon ($g.m^{-2}$)

Land use 1		Land use 2		Land use 3		Land use 4		Total casts (2 years)
April 01 - August 01		September 01 - March 02		April 02 - August 02		September 02 - March 03		
Land use	Casts*	Land use	Casts	Land use	Casts	Land use	Casts	
Forest	26.2	Forest	7.9	Forest	11.7	Forest	10.5	310
Essep	0.0	Banana	4.9	Banana	4.3	Banana/fallow	34.7	294
Banana	0.75	Banana	10.4	Banana/fallow	1.3	Fallow	1.3	82
Inga	3.3	*Inga*	36.7	*Inga*	15.6	*Inga*	0.67	317
Afup	1.63	Cassava	1.5	Fallow	0.30	Fallow	82.2	589

* monthly mean

Table 4. Comparative characteristics of surface soil (0-5 and 5-10 cm) and casts produced in different land uses in traditional cropping systems of southern Cameroon

Nutrients	Sample	Depths	Forest	*Essep*	Banana	*Afup*	*Inga*
C (%)	Soil	(0-5)	2.68 b	3.78 a	1.91 c	2.47 b	2.63 b
		(5-10)	1.63 b	1.97 a	1.21 d	1.42 c	1.62 b
	Cast		4.35 b	3.93 c	4.92 a	3.61 d	4.75 b
Total N	Soil	(0-5)	0.145 b	0.215 a	0.119 b	0.161 b	0.211 a
(%)		(5-10)	0.107 b	0.180 a	0.086 c	0.115 b	0.132 b
	Cast		0.309 bc	0.354 ab	0.368 a	0.255 b	0.310 b
P	Soil	(0-5)	6.96 b	18.74 a	5.48 b	15 2 a	7.67 b
(ppm)		(5-10)	2.48 c	5.66 a	2.59 c	5.28 a	3.02 b
	Cast		18.42 b	17.42 b	20.52 a	12.62 c	20.76 a
K	Soil	(0-5)	0.137 a	0.246 a	0.007 c	0.225 a	0.071 b
($cmole.kg^{-1}$)		(5-10)	0.076 b	0.140 a	0.005 b	0.148 a	0.29 b
	Cast		0.33 b	0.42 a	0.43 a	0.21 c	0.34 b
Ca	Soil	(0-5)	1.34 a	2.75 a	0.98 b	2.78 a	1.35 a
($cmole.kg^{-1}$)		(5-10)	0.50 a	0.78 a	0.52 a	0.99 a	0.42 a
	Cast		2.79 d	5.35 a	5.42 a	4.74 b	3.88 c
Mg	Soil	(0-5)	0.53 a	0.88a	0.21 b	0.88 a	0.32 b
($cmole.kg^{-1}$)		(5-10)	0.25 a	0.30 a	0.12 b	0.33 a	0.13 b
	Cast		0.963 c	1.91 a	1.95 a	1.41 b	1.64 b

Letters compare land uses; figures with the same letters for a given sample are not different at $P<0.05$

Table 5 estimates the quantity of nutrients accumulated in the casts. Although casts from banana were the richest, the lowest quantities of nutrients were recycled, because of the low quantity of casts produced in the system. In the land uses following *afup*, earthworms could recycle the highest quantity of all the nutrients, compared to other land uses, because of the high quantity of casts produced. We also observed that casting started in *afup* only during the second year, i.e. when the plot was left fallow. Nutrients recycled from *essep* during the second year could be used by banana, since the initial *essep* was at the banana/fallow phase. However, the low cast production in banana and follow-up systems, and therefore low nutrient recycling cannot be explained. Farmers considered the soil under banana to be so poor that the second year they convert it to fallow. In this experiment, banana had the poorest soil, and the low casting activity did not allow soil fertility improvement through biological processes, therefore justifying the short fallow after banana in traditional farming systems.

Table 5. Earthworm cast production and carbon and nutrients recycled in 2 years in traditional faming systems of southern Cameroon (kg.ha^{-1})

Initial land use	Final land use	Total casts	C	Nutrients				
				N	P	K	Ca	Mg
Forest	Forest	3,100	135	9.6	57.1	1.0	8.6	3.0
Essep	Fallow	2,940	116	10.4	51.2	1.0	15.7	5.6
Banana	Fallow	820	40.3	3.0	16.8	0.35	4.4	1.6
Inga	*Inga*	3,170	151	9.8	65.8	11	12.3	5.2
Afup	Fallow	5,890	213	15.0	74.3	1.2	27.9	8.3

Many previous works have reported nutrient enrichment in casts, compared to the non-ingested soil. Brussaard et al. (1993) reported 13 kg N, 2.7 kg P, 14.4 kg K, 59.8 kg Ca and 7.2 kg Mg accumulated per hectare per year in earthworm casts, under alley cropping on an Alfisol. Our figures (Table 5) are lower. Henrot and Brussaard (1997), Ganeshamurthy et al. (1998), Mulongoy and Bedoret (1989) and Norgrove and Hauser (2000) observed between 2 and 4 times more C and N in casts compared to the surface soil. Mulongoy and Bedoret (1989) observed 3 to 5 times more P, and Hulugalle and Ezumah (1991) 2 to 3 times more K in casts. This is attributed to the preferential feeding of earthworms, which allows them to produce higher-quality casts on poorer soil, and the liberation of K from the organic material following its fragmentation during digestion. We observed high nutrient contents in casts from systems with low soil nutrient contents such as banana, and low nutrient contents in rich systems, which confirms the selective feeding of worms in a poor soil environment (Hauser and Asawalam, 1998; Hauser, 1997). Therefore, increasing the earthworm densities and activities on poor soils can enrich the surface soil with the most limiting nutrients.

CONCLUSION

This experiment indicates that in the slash and burn chronosequence, burning is the major factor responsible for soil macrofauna decline, probably because of the destruction of the vegetation, soil exposure and modification of soil organic residues. Burning can result in up to 95% loss in earthworm density in cropping systems compared to a natural forest or a long fallow. It was observed that, after burning, intensive casting activities in *esse*p and *afup owondo* occurred only after one to two years, indicating the time needed for the earthworms to recover. Earthworms enrich their casts compared to the underlying soil. The contribution of earthworms to soil fertility improvement is related to the quantity of casts they can produce in a given system. Earthworms contributed considerably to N, P, Ca and Mg accumulations on the topsoil, especially in land uses where high casting activities were observed. Strategies should be developed to improve casting activities in banana, which had the poorest soil among the different land uses. Such strategies should involve the identification and ecological constraints of earthworm species present in the system, and introduction of more adapted species with high casting attributes. Also, soil management allowing high inputs of organic residues at the soil surface and with less burning stress, will favour the development of worm populations and enhance casting activity. *Inga edulis* fallow allowed worm densities and casting activities at the same level as the forest. It has been reported that trees with relatively fast growth favour the development of the soil macrofauna, presumably through their effects on litter and microclimate (Barros et al., 2003). Therefore maintaining plant cover in the farming system can maintain active communities of 'ecosystem engineers' in soil, and therefore maintain the sustainability of the cropping system through regulation of soil biological processes (Lavelle et al., 2001). Earthworm casts were richer than the topsoil for carbon and all nutrient elements investigated in this study. In C and N depleted banana plots, nutrient contents of the casts were two- to five-fold those of the surface soil. Through their selective feeding, worms are able to enrich the topsoil in the most limited nutrients. Therefore, in our study site, where fertilizers are beyond the reach of resource-poor farmers, farming practices should be adjusted to favour soil biological processes. Improved fallow with *Inga edulis* is likely to be an alternative to the current practice of slash and burn agriculture. Its fast growth, rapid soil coverage and high litter input favour maintenance and/or rapid recolonization and high casting activities by earthworms after burning, compared to the traditional fallow system.

Chapter 6

REVERSING THE TREND IN SOIL FERTILITY DEPLETION IN SOUTHERN CAMEROON: POTENTIALS AND LIMITATIONS OF *INGA EDULIS* PLANTED FALLOW

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ABSTRACT

We investigated residual effects of *Inga* planted fallow on soil properties and crop yield on highly acidic and Al-toxic soils, to identify suitable management options in terms of tree density and residue management. *Inga* fallows produced more biomass (between 44.5 and 62 Mg ha^{-1}), than natural fallow (22 Mg ha^{-1}). Tree fallows accumulated more C, N and Ca, but not P, K, and Mg than the natural fallow, and up to 40% of nutrients in planted fallows was in wood and fruits, i.e. not available to annual crops in case of mulching. The different tree fallows suppressed weeds similarly, and had comparable root mass, between 5-7 Mg ha^{-1}, compared to 2 Mg ha^{-1} for the control plot. Biomass and nutrient accumulation in the 8 month-regrowths was high compared to 36 month-regrowths, indicating that frequent pruning of *Inga* can improve biomass production and nutrient recycling. Planted fallow with residues mulched allowed four times more maize than the natural fallow control. Plots with 5,000 trees ha^{-1} produced comparable and even higher yields than those with 10,000 plants ha^{-1}. Burning improved the soil K by 74%, P by 54%, Mg by 44% and Ca by 30% over the mulched plots in the top 10 cm soil, one week after burning. Burning also improved maize yield in tree plots by 41%, and in the control plot by 80%; it improved the *ngon* yield six-fold and in the control plot ten-fold compared to the mulched plots. But the effect of burning was limited in time: one month later the concentrations of most of the cations were similar in all plots, indicating a potentially high nutrient leaching after burning and therefore a non-sustainable nutrient management. We conclude that *Inga* fallow is superior to natural fallow. The planting density could be reduced from 10,000 to 5,000 plants.ha^{-1}, without negative effects on crop yields. We suggest that management options of *Inga* fallows include harvesting of by-products, mulching of decomposable fractions and nutrient supplements through fertilizers.

Key words: Acid soils, crop yield, *Inga edulis*, planted fallow, residue management, soil properties.

INTRODUCTION

Planted fallows are considered a viable alternative to slash-and-burn agriculture, and a strategy for improving food production and soil resources in the smallholder farm sector of the humid forest zone (Sanchez, 1999). During the fallow period there is a substantial accumulation of organic matter, P, Ca and Mg in the system (Jama et al., 1998, Sanchez, 1999, Sanchez et al., 2003). Organic matter acts as source and sink for plant nutrients, increasing the buffering capacity in low-activity clay soils, and increasing water-holding capacity (Nandwa, 2001). Fallows also increase N stocks in vegetation and topsoil through biological nitrogen fixation and retrieval of inorganic N and mobile ions such as K from subsoil layers where crops cannot access (Hartemink et al., 1996; Sanchez 1999). Fallows then transfer these nutrients to subsequent crops (Sanchez, 1999).

The soil biotic community performs a series of processes during the fallow period, which are essential to the productivity and environmental services of soils, such as decomposition, nutrient cycling, soil organic matter (SOM) formation and mineralisation, soil aggregation, and biological control of soil-borne diseases (Lavelle et al., 1994). Their potential impacts on soil properties are partly determined by the quality of bio-structures they produce, as well as the kinetics of their degradation and redistribution at the nearby soil surface (Decaens et al., 2002). Biogenic structures once produced and stabilized can persist for a long time, since they are protected from the intense weathering processes of the soil surface (Lavelle et al., 2001). Earthworm casts act as conservation structures for organic C and total N (Henrot and Brussaard, 1997).

Among the major nutrients accumulated during the fallow period, in particular K is not bound strongly to plant materials (Ganeshamurthy et al., 1998). Planted tree fallows therefore require a very high density of trees (Place and Dewees, 1999) to sequester cations for transfer to subsequent crops. The alley cropping technique was designed for 10,000 plants. ha^{-1}, planted at 4 x 0.25 m (Kang, 1997). The technology did not take into consideration farmer resource and labour constraints for tree planting and management (Buresh and Cooper, 1999; Franzel, 1999), and in spite of increased food production and enhanced soil fertility observed on-station, the adoption rate of alley cropping remained low in the humid lowlands (Franzel, 1999; Degrande and Duguma, 2000).

Substantial accumulation of biomass and nutrients is reported in tree fallows on acid soils with Al-tolerant tree species. *Inga edulis* can produce up to 61 Mg ha^{-1} of biomass 20 months after planting, 80 % of which is wood (Kanmegne et al., 2000). The biomass produced during the fallow period constitutes an important resource; residue management (quantity and quality of biomass applied to the soil) has a significant impact on soil quality and resilience, agronomic productivity and green house gas emissions from soil to atmosphere (Lal, 1997). A large part of nutrients accumulated in the fallow phase is in the woody component of trees, therefore unavailable to the annual crops if the residues are mulched (Tonye et al., 1997). Nolte et al. (2003) found 57 to 60% of biomass in *Calliandra* fallow to be woody stems and 23 to 27 % to be woody branches; the woody component contained 18% N, 21% P, 28% K, 16% Ca and 14% Mg. Exportation of by-products such as fuel wood and fruits, without compensation might cause a high nutrient loss from the system, and most of the nutrients accumulated in the total biomass might not be available to annual crops.

Burning the fallow mass is viewed as a viable residue management option in tree fallows (Nye and Greenland, 1964; Tonye et al., 1997; Nolte et al., 2003). Burning increases the concentration of exchangeable cations in the top soil, increases soil pH from the ash alkalinity, improves access for sowing and reduces weeds and pests (Nye and Greenland, 1964; Kato et al., 1999; Menzies and Gillman, 2003). But the key disadvantage to burning is losses due to volatilzation of N, S and small quantities of P and K, and losses by leaching of K, Ca, Mg and Na if the nutrients contained in the ash are not rapidly used by the growing crops (Menzies and Gillman, 2003). Field preparation without the use of fire can help to avoid these losses, allowing more efficient nutrient cycling and improved sustainability (Kato et al., 1999).

Mulching or incorporation of the slashed vegetation modifies the soil environment for plants and soil biota. The organic material serves as a carbon-rich substrate that is decomposed to SOM by microbes (Kato et al., 1999). Mulching also induces permanent cover of the soil surface, which promotes the density and activities of soil macrofauna such as earthworms (Hauser and Asawalam, 1998; Norgrove and Hauser, 2000). The challenge is to develop a sustainable cropping system that maintains active communities of ecosystem engineers in soils, favours soil biological processes, and at the same time produces enough outputs to be attractive to farmers.

The present study explores some management options to improve the sustainability and adoption potentials of tree fallow. More specifically, the experiment compares different densities and/or arrangements of *Inga edulis* and two residue management options, burning or mulching, to assess the residual effects of *Inga* planted fallow on soil properties and crop yields, maize and *ngon* being the test crops. It is hypothezised that reducing the tree density and/or modifying tree arrangement in the field without compromising the soil fertility attributes of the planted fallow can significantly reduce the costs of fallow management and improve its adoption potential.

MATERIALS AND METHODS

The experimental site

The study was conducted at the IRAD (Institut de la Recherche Agricole pour le Développement) research station, in Nkoemvone, southern Cameroon (situated between longitude 11^{o} 6’ E and 11^{o} 10 ’ E, latitude 2^{o} 53’ N, and 2^{o} 57’ N, and altitude of 615 m). The average annual rainfall over 20 years is 1820 mm with a bimodal distribution and the mean daily temperature is 23.5^{o}C. The soils are Ferric Acrisols characterized by a low base saturation and a low cation exchange capacity (Table 1). At the site the soils are highly acidic, with pH (1:1 H_2O) between 3.5 and 4.5. These soils are dominated by kaolinites and sesquioxydes, which cause cation exchange capacity to be low in such soils. Replenishment from other sources is crucial for proper plant/crop growth. The vegetation consists of secondary humid forest.

Table 1. Soil properties of the experimental site at *Inga edulis* planting, Nkoemvone, southern Cameroon (April 1995)

Soil properties	Soil depths (cm)	
	0-10	10-20
PH (1 : 1 soil: water)	4.10	4.20
Organic matter (%)	5.20	2.92
Organic carbon (%)	3.02	1.70
Ca (cmole/kg)	0.76	0.44
Mg (cmole/kg)	0.82	0.38
K (cmole/kg)	0.36	0.10
Na (cmole/kg)	0.08	0.05
Total exchangeable bases (cmole/kg)	2.03	0.98
Bray II-extractable P (ppm)	10.9	6.8

Design

An *Inga edulis* planted fallow was established on the site in March 1995. The *Inga* genus (*Leguminosae*) occurs from central Mexico to central South America. They are fast growing trees and apt to a rapid establishment of mature shade vegetation, non-deciduous; *Inga* leaves have a low decomposition rate and form a dense litter layer on the soil, suppressing the growth of herbs (Peeters et al., 2003). The experiment was established with four treatments: (T1) *Inga* planted at 1 m x 1 m spacing, for a planting density of 10,000 plant.ha^{-1}, (T2) *Inga* planted at 1 m x 2 m spacing, for a planting density of 5,000 plant.ha^{-1}, (T3) *Inga* planted in the arrangement of alley cropping at 4 m x 0.25 m spacing, for a planting density of 10,000 plants.ha^{-1}, and (T4) a natural fallow control plot. The experiment was set in quadruplicate, following a randomized complete block design (RCB). The plot size was 16 m x 10 m. In March 1999, the plots were slashed and mulched, and planted with maize for one cropping season (3 months), then left fallow. The experiment reported in this paper was conducted in the same plots from March 2002 to July 2003. Field operations are summarized in Table 2.

Table 2. Field operations in the *Inga edulis* planted fallow experiment

Timing	March 1995	March 1999	April 2002	April 2003	June 2003
Tree management	*Inga* planted	*Inga* pruned	*Inga* pruned	*Inga* pruned	
Residue management	-	mulched	mulched (Tables 3 & 4)	mulched/burned (Tables 3 &5)	
Soil management	sampled (Table 1)	not sampled	sampled (Table 6)	sampled (Table 7)	sampled (Table 8)
Crop management	-	maize crop	maize (Table 9)	maize and *ngon* (Table 9)	

Plot management

In April 2002, hereafter referred to as year 1, ten trees were selected per experimental unit for biomass determination. The selection included the different sizes present in the plot: 3 small, 4 medium and 3 large ones. The trees were pruned at 2 m above ground, then separated in wood, leaves, and fruit components and weighed. The different fractions were then sub- sampled and oven-dried at 65^{o}C for 48 hours for dry mass determination. The standing biomass of *Inga edulis* was expressed on a tree basis and then converted to per hectare basis considering the plant population density in the different treatments. The soil litter and the understorey vegetation were collected in duplicates from 1x1 m quadrates in the different plots, then oven-dried at 65^{o}C for 48 hours, and expressed in Mg.ha^{-1}. Roots were sampled from soil monoliths collected manually from two points in each subplot. The soil and roots were excavated from a 50 cm x 50 cm block at 0-10 cm, 10-20 cm and 20-50 cm. The samples were washed over a 0.5 mm mesh sieve, and roots collected. Roots were manually separated from debris, then oven-dried and weighed (Anderson and Ingram, 1993).

The different vegetation fractions wood, leaf, fruits, soil litter, understorey, and roots were sub-sampled and analyzed for major nutrients. The leafy material including leaves and green twigs was evenly applied in the plot as mulch, while the woody material was removed. Maize (*Zea mays*) was the test crop, planted at 40,000 plants.ha^{-1}, to assess the residual effects of soil-improving tree species. Trees were pruned again 6 weeks after maize planting, and green manure from the pruning (leaves and twigs) broadcast on the soil surface. At maize maturity, maize plants from a 8 x 8 m plot were harvested for yield determination. Maize grain yield was expressed in Mg ha^{-1} at a standard 14% moisture content.

In April 2003 (year 2), the plots were split into two sub-plots, the trees were pruned again during land clearing. The residues were completely burnt (including woody component) on one sub-plot, and on the other residues were mulched. After burning the ash was evenly distributed on each sub-plot to avoid fertility islands. Two test crops were used, *Ngon* (*Cucumeropsis manii*) was planted at 1 m x 1 m spacing (10, 000 plant ha^{-1}), and maize planted at 30,000 plants ha^{-1}. *Ngon* is a high commercial value crop in the area, but requires newly cleared and burned long fallow or forest plots. It generally comes in first in the slash and burn chronosequence.

Soil sampling

In April 2002 before slashing the fallow, composite soil samples were taken along two cross diagonals, at 10 points from each plot, at 0-10, 10-20, and 20-30 cm depth. In April 2003 another soil sampling was conducted one week after burning (at crop germination) from 5 randomly selected points in each sub-plot (burn or no-burn) at the same depths as above. At maize flowering (in June 2003) another soil sampling was done at 0-10 cm in all sub-plots.

Plant and soil analyses and determination of nutrient accumulation

Soil samples were analyzed for pH, organic C, N, exchangeable Ca, Mg, K, and extractable P. Soil samples were air-dried and ground to pass a 2 mm mesh. Cations (Ca, Mg, K) were extracted by the Mehlich-3 procedure (Mehlich, 1984); cations were determined by absorption spectrophotometry. Phosphorus was extracted with the Bray II method and analyzed by the malachite green colorimetric procedure (Motomizu et al. 1983). Soil pH was determined in water at a 2:5 soil: liquid ratio. Organic carbon was determined by chromic acid digestion and spectrophotometry (Heanes, 1984). Total N was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremner and Tabatabai, 1972; Nelson and Sommers, 1972). For plant samples, all fresh biomass samples were oven-dried at 65^{o}C, then ground to pass a mesh of 0.5 mm, and digested according to Novozamsky et al. (1983). Total N was determined with an ammonium sensitive electrode (Powers et al., 1981). Ca, Mg and K were analyzed by atomic absorption spectrophotometry. Total P was determined by the malachite green colorimetric procedure (Motomizu et al., 1983). Nutrient accumulation in the different fractions of plant biomass was calculated by multiplying the dry mass per hectare with the nutrient content of the samples.

Data analyses
The collected data on biomass production, soil properties and crop yield were subjected to analysis of variance (ANOVA) for a randomized complete block design, using the SAS package (SAS, 1996). During the second year, the design of the experiment was a split-plot factorial. In case of significance of the F-test at $p < 0.05$, the standard error of the difference was used to separate means.

RESULTS

Biomass production
Inga biomass production of 36-month regrowths (year 1) was significantly ($P<0.05$) higher for trees planted in hedges (T3) compared to other tree treatments. T3 produced 14.5 Mg ha^{-1} of leaves, 27.6 Mg ha^{-1} of wood, and the highest total biomass. Lowest leafy material and total biomass was recorded in T2 (Table 3). The total *Inga* biomass varied between 19.3 and 44.5 Mg ha^{-1}. Soil litter collected in the different tree fallows was similar, and significantly higher than litter from the natural fallow. Understorey biomass was also similar for all treatments with trees, ranging between 0.12 and 0.25 Mg ha^{-1} compared to 12.5 Mg ha^{-1} of weeds in the control plot. Root mass was similar for the tree fallows, but significantly lower in the control plot. Root mass ranged between 5 and 7.6 Mg ha^{-1} for tree fallow and 2.0 Mg ha^{-1} for the natural fallow. More than 85% of the roots were found in the top 10 cm soil in all treatments. The total standing biomass production was highest in T3, while T1 and T2 were similar. A planted fallow could accumulate 62.3 Mg ha^{-1} total standing biomass, compared to 22.1 Mg ha^{-1} for the natural fallow (Table 3).

During the second year, trees planted at 10,000 plants ha^{-1} (T1 and T3) produced significantly more biomass, compared to trees at 5,000 plants ha $^{-1}$ (T2). Soil litter ranged between 5.5 and 7.3 Mg ha^{-1}, much of which was non-decomposed residues of the previous year. Tree fallows produced higher biomass than the control.

Table 3. Biomass production in *Inga edulis* planted fallow and natural fallow on acid soils in southern Cameroon (year 1: 36 month- and year 2: 8 month-regrowth of *Inga edulis*)

	Inga biomass ($Mg.ha^{-1}$)				Grass biomass $Mg.ha^{-1}$	Roots biomass $Mg.ha^{-1}$	Litter biomass $Mg.ha^{-1}$	Total biomass $Mg.ha^{-1}$
Year 1	Leaves	Wood	Fruits	Total				
T1*	7.5 b	16.1 b	1.5 b	25.1 b	0.12 b	7.6 a	11.7 a	44.5 b
T2	5.8 c	12.3 b	1.2 c	19.3 c	0.17 b	5.1 a	11.3 a	35.8 b
T3	14.5 a	27.6 a	2.4 a	44.5 a	0.25 b	7.2 a	10.3 a	62.3 a
T4	na	na	na	na	12.5 a	2.0 b	7.5 b	22.1 c
Year 2								
T1	6.6 a	6.9 a	na	13.6 a	2.3 c	-	7.3 a	23.1 a
T2	3.7 b	3.8 b	na	7.5 b	5.0 b	-	7.2 a	19.7 b
T3	7.1 a	7.8 a	na	14.9 a	4.6 b	-	5.5 b	25.0 a
T4	na	na	na	na	9.2 a	-	6.8 a	15.9 c

a,b,c: treatment means followed by same letters are not different at $P< 0.05$.
na: not applicable; -: not sampled
* T1: *Inga* planted at 1 m x 1m; T2: *Inga* planted at 2 m x 1 m; T3: *Inga* planted at 4 m x 0.25 m and T4: natural fallow control

Nutrient accumulation in the vegetation

For planted fallows, decomposable biomass and therefore carbon and nutrients were significantly higher in trees planted in hedges (T3), compared to other tree fallows (Tables 4 and 5). The natural fallow accumulated lower total biomass compared to planted fallows, but with the advantage that all the material produced was available for decomposition, no by-products were removed. After removal of *Inga* wood and fruits, C accumulation in natural fallow was similar to that of T1 and T2. The natural fallow also accumulated similar and even more Mg, K, and P compared to tree fallows. Highest Mg was observed in natural fallow.

Nutrient accumulation was faster in 8-month regrowth compared to 36 months regrowths. 60 to 67% N, P, and Mg, and 36-44 % K occurred in the decomposable vegetation fraction in 36-months regrowths, and in 8-months regrowth, it was 82-89% N, 80-90% P, K and Mg, and 73-83% Ca. This is an indication that frequent pruning of planted fallow accelerates the nutrient recycling process. Planted fallow with trees at 5000 ha^{-1} did not perform better than those at 10000 ha^{-1}, but compared to the natural fallow, it accumulated more N and Ca, but less P, K, and Mg (Table 5).

Table 4. Nutrient accumulation (kg ha^{-1}) in leaf, wood, soil litter, understorey and fruit fractions of 36-month regrowths of *Inga edulis* planted fallow on acid soils, in southern Cameroon.

		N	P	K	Mg	Ca
Leaves						
	T1*	246 c	15.7 b	29.9 b	22.4 c	97.1 c
	T2	191 d	12.2 c	23.2 c	17.4 d	75.3 d
	T3	478 a	30.4 a	57.9 a	43.4 b	188 a
	T4	314 b	31.4 a	62.5 a	65.0 a	138 b
Wood*						
	T1	221 b	10.5 b	32.2 b	23.5 b	131 b
	T2	168 b	8.0 b	24.6 b	18.0 b	99.6 b
	T3	379 a	18.0 a	55.3 a	40.3 a	224 a
	T4	na	na	na	na	na
Litter						
	T1	234 a	8.8 a	7.1 b	26.9 a	145 a
	T2	227 a	8.5 a	6.9 bc	26.1 a	141 a
	T3	205 b	7.7 b	6.3 c	23.6 b	127 b
	T4	64.1 c	3.0 c	12.1 a	14.3 c	40.7 c
Understorey						
	T1	3.6 a	0.21 a	0.92 a	0.22 a	0.25 a
	T2	5.5 a	0.32 a	1.4 a	0.34 a	0.36 a
	T3	7.8 a	0.45 a	2.0 a	0.47 a	0.53 a
	T4	na	na	na	na	na
Fruits**						
	T1	45.9 b	4.2 b	17.8 b	2.1 b	2.7 b
	T2	37.7 b	3.4 b	14.6 b	1.7 b	2.2 b
	T3	75.4 a	6.8 a	29.2 a	3.4 a	4.4 a
	T4	na	na	na	na	na
Nutrients in plant parts available for decomposition						
	T1	484	24.7	37.9	49.5	242
	%	64	63	43	66	64
	T2	424	21.0	31.5	43.8	217
	%	67	65	36	58	68
	T3	691	39.0	66.2	67.5	316
	%	60	61	44	61	58
	T4	378	34.4	74.6	79.3	179
	%	100	100	100	100	100

a b c: Treatment means followed by the same letters are not different at $P<0.05$
na: not applicable
* T1: *Inga* planted at 1m x 1m; T2: *Inga* planted at 2m x 1m; T3: *Inga* planted at 4m x 0.25m and T4: natural fallow control
** Not available for decomposition

Table 5. Nutrient accumulation (kg ha^{-1}) in 8-month regrowth of *Inga edulis* at various tree densities of planted fallows compared to the natural fallow on acid soil, in southern Cameroon

		N	P	K	Mg	Ca
Leaves						
	T1	219 a	13.9 b	26.5 b	19.9 b	86.1 a
	T2	123 b	7.8 c	14.8 c	11.1 c	48.3 b
	T3	233 a	14.8 b	28.3 b	21.2 b	91.9 a
	T4	231 a	23.1 a	46.0 a	47.8 a	101 a
Wood*						
	T1	95.0 a	4.5 a	13.9 a	10.1 a	56.2 a
	T2	51.9 b	2.5 b	7.6 b	5.5 b	30.7 b
	T3	107.3 a	5.1 a	15.7 a	11.4 a	63.4 a
	T4	na	na	na	na	na
Litter						
	T1	147 a	5.5 a	4.5 b	16.9 a	91.1 a
	T2	144 a	5.4 a	4.4 b	16.5 a	89.1 a
	T3	109.b	4.1 b	3.3 c	12.6 b	67.7 b
	T4	57.4 c	2.7 c	10.8 a	12.8 b	36.5 c
Undergrowth						
	T1	69.7 b	4.1 b	17.6 b	4.3 b	4.7 b
	T2	155 a	9.0 a	39.0 a	9.5 a	10.1 a
	T3	143 a	8.3 a	35.9 a	8.7 a	9.7 a
	T4	na	na	na	na	na
Nutrients in plant parts available for decomposition						
	T1	435	23.5	48.5	41.1	182
	%	82	84	78	80	76
	T2	421	22.1	58.2	37.1	147
	%	89	90	88	87	83
	T3	485	27.2	67.4	42.5	170
	%	82	84	81	79	73
	T4	288	25.8	56.8	60.7	138
	%	100	100	100	100	100

a b c: Treatment means followed by the same letters are not different at $P<0.05$
na: not applicable
* Not available for decomposition

SOIL CHARACTERISTICS

Effects of Inga density

Soil chemical properties were negatively affected by *Inga edulis* during the fallow period. Soil C, N, P and cations were lower at the beginning of this experiment (in 2002) than at tree planting in March 1995 (Table 1 and 6). Soil pH also was higher at tree planting than after 8 years fallow. *Inga edulis* is a fast growing tree species, adapted to acid soil environment, and therefore able to sequester soil nutrients faster than the natural vegetation. Most of these nutrients were found in *Inga* biomass at the end of the fallow phase.

After the fallow phase, soil C and nutrient concentrations differed significantly with tree densities and soil depths (Table 6). The topsoil was richer in all treatments compared to deeper horizons. In the top 10 cm soil, tree fallows were similar for N, P, Ca and Mg. Higher pH was observed for T3 and lower C in T2. The natural fallow was similar to planted fallow with trees in hedges (T3) for all nutrients, except Mg. At 10-20 cm, T1 and T2 were similar for all soil nutrients investigated, the natural fallow was similar to T3 for all parameters. Differences between *Inga* fallow and natural fallow for soil chemical properties after the fallow phase were not as consistent as differences in biomass production. For some parameters, natural fallow was even better than planted fallow. This is an indication the key factor in planted fallows is in the residue management. Differences in soil fertility and crop yields will depend on how efficiently nutrients from the fallow biomass are made available to crops.

Table 6. Soil properties as affected by different plant densities of *Inga edulis* in an improved agroforestry system in southern Cameroon (April 2002)

	pH (H_2O 1:1)	Total C (%)	Total N (%)	Available P (ppm)	Exchangeable K	Exchangeable Ca	Exchangeable Mg
					-------- cmole.kg^{-1} -------		
0-10cm							
T1	3.4 b	1.85 b	0.148 a	7.22 a	0.07 ab	0.39 a	0.15 a
T2	3.5 b	2.11 a	0.152 a	7.91 a	0.08 a	0.33 a	0.13 a
T3	3.9 a	1.85 b	0.142 ab	6.69 ab	0.05 b	0.31 a	0.14 a
T4	3.9 a	1.74 b	0.134 b	5.78 b	0.06 b	0.42 a	0.10 b
10-20cm							
T1	3.7 c	1.22 ab	0.103 a	3.48 a	0.05 a	0.15 b	0.06 a
T2	3.8 b	1.29 a	0.101 a	3.91 a	0.04 a	0.12 b	0.04 a
T3	4.1 a	1.13 b	0.089 b	2.74 b	0.04 a	0.29 a	0.08 a
T4	4.1 a	1.25 ab	0.098 ab	3.0 b	0.04 a	0.25 b	0.05 a

a,b,c: treatment means followed by the same letters are not different at $p<0.05$.

T1: *Inga* planted at 1m x 1m; T2: *Inga* planted at 2m x 1m; T3: *Inga* planted at 4m x 0.25m and T4: natural fallow control

Table 7 Soil properties in an *Inga edulis* planted fallow one week after mulching/burning

	Residues	T1	T2	T3	T4
0-10 cm					
pH	Burning	3.38 ±0.09*	3.50 ±0.07	3.77 ±0.1	4.60 ±0.89
	Mulching	3.37 ±0.12	3.52 ±0.06	3.50 ±0.02	3.73 ±0.05
C**	Burning	2.14 ±0.09	2.49 ±0.12	2.03 ±0.09	2.32 ±0.21
	Mulching	2.06 ±0.20	1.96 ±0.08	2.02 ±0.09	2.27 ±0.20
N	Burning	0.136 ±0.006	0.163 ±0.009	0.136 ±0.008	0.195 ±0.01
	Mulching	0.145 ±0.006	0.143 ±0.008	0.132 ±0.006	0.183 ±0.02
P	Burning	10.44 ±2.17	13.91 ±2.63	15.80 ±1.81	27.31 ±14.52
	Mulching	8.53 ±0.98	9.16 ±0.45	10.44±0.74	10.71 ±1.24
K	Burning	0.096 ±0.02	0.189 ±0.02	0.151 ±0.02	0.274 ±0.17
	Mulching	0.088 ±0.007	0.088 ±0.003	0.078 ±0.007	0.088 ±0.004
Ca	Burning	0.599 ±0.157	1.06 ±0.14	0.99 ±0.14	0.62 ±0.04
	Mulching	0.725 ±0.122	0.543 ±0.037	0.524 ±0.07	0.544 ±0.084
Mg	Burning	0.222 ±0.054	0.425 ±0.068	0.419 ±0.078	0.319 ±0.039
	Mulching	0.209 ±0.04	0.220 ±0.028	0.181 ±0.032	0.265 ±0.02
10-20cm					
pH	Burning	3.45 ±0.02	3.68 ±0.04	3.87 ±0.07	3.97 ±0.04
	Mulching	3.49 ±0.08	3.69 ±0.06	3.82 ±0.04	3.97 ±0.04
C	Burning	1.46 ±0.05	1.56 ±0.03	1.31 ±0.14	1.16 ±0.08
	Mulching	1.42 ±0.19	1.55 ±0.36	1.18 ±0.07	1.15 ±0.06
N	Burning	0.079 ±0.003	0.086 ±0.001	0.082 ±0.01	0.092 ±0.02
	Mulching	0.085 ±0.007	0.089 ±0.017	0.068 ±0.002	0.080 ±0.006
P	Burning	4.06 ±0.43	5.28 ±1.0	5.76 ±1.85	3.10 ±0.78
	Mulching	3.77 ±0.26	4.70 ±1.5	3.44 ±0.52	3.77 ±0.61
K	Burning	0.048 ±0.004	0.052 ±0.011	0.054 ±0.019	0.042 ±0.004
	Mulching	0.041 ±0.003	0.037 ±0.003	0.034 ±0.004	0.036 ±0.004
Ca	Burning	0.249 ±0.048	0.307 ±0.136	0.202 ±0.061	0.169 ±0.037
	Mulching	0.187 ±0.014	0.194 ±0.012	0.103 ±0.013	0.249 ±0.032
Mg	Burning	0.085 ±0.007	0.124 ±0.031	0.095 ±0.034	0.076 ±0.02
	Mulching	0.074 ±0.008	0.064 ±0.015	0.055 ±0.007	0.091 ±0.016

**Units are same as in Table 6

* standard error

Effects of residue management on soil properties

Irrespective of tree planting density, burning of residues significantly raised K by 74%, P by 54%, Mg by 44% and Ca by 30% over the mulched plots in the top 10 cm. The same trend was observed in 10-20 cm (Table 7). The nutrient concentrations were significantly higher in the top 10 cm soil compared to the deeper horizons, T2 and T3 had higher Ca and Mg after burning compared to other plots. The positive effects of burning on soil nutrient availability were limited in time. One month after burning (Table 8), significant differences were observed between the two residue management options only for pH. Plots with burning treatment had higher soil pH compared to plots with mulching, although this effect was not significant for all tree densities. After burning, the soil pH was higher in tree plots (P=0.006) compared to the control without trees. The effect of burning compared to mulching was significant only for K in T1, C in T2, and Ca and Mg in T3 where plots with burning had higher values. However, soil nutrient were higher in 2003 (Table 8), than in 2002 (Table 6), even in plots with mulching treatments.

Table 8. Selected soil properties (0-10 cm) at one month after crop planting in an *Inga* fallow management trial in southern Cameroon

	Management	T1*	T2	T3	T4
pH	Burning	3.78 ±0.03Aa	3.67 ±0.02 Ab	3.74 ±0.08 Aab	3.42 ±0.03 Ac
	Mulching	3.71 ±0.08 Aa	3.24 ±0.04 Bd	3.57 ±0.04 Bb	3.41 ±0.02 Ac
C	Burning	2.26 ±0.07 Ab	2.42 ±0.08 Aa	1.83 ±0.11 Ac	2.34 ±0.10Aab
(%)	Mulching	2.29 ±0.04 Aa	2.27 ±0.06 Ba	1.89 ±0.23 Ab	2.15 ±0.23 Aab
Total N	Burning	0.138 ±0.007Aa	0.152 ±0.011Aa	0.117 ±0.08Aa	0.140 ±0.090Aa
(%)	Mulching	0.138 ±0.003Ab	0.149 ±0.007Aa	0.116 ±0.014Ab	0.128 ±0.019Ab
P	Burning	11.02 ±1.82Aab	12.31 ±1.64Aa	10.67 ±1.37Aab	9.07 ±1.74 Ab
(ppm)	Mulching	10.53 ±1.87Aab	11.47 ±0.19Aa	8.46 ±2.59Ab	9.60 ±1.85 Aab
K	Burning	0.108 ±0.014Aa	0.102 ±0.011Aa	0.088 ±0.011Ab	0.079 ±0.018Ab
(cmole.kg^{-1})	Mulching	0.068 ±0.011Bb	0.093 ±0.011Aa	0.075 ±0.06Aab	0.079 ±0.009Aab
Ca	Burning	0.655 ±0.097Aa	0.653 ±0.215Aa	0.460 ±0.018Ab	0.484 ±0.048Ab
(cmole.kg^{-1})	Mulching	0.446 ±0.179Aa	0.524 ±0.113Aa	0.335 ±0.076Ba	0.553 ±0.172Aa
Mg	Burning	0.282 ±0.041Aa	0.269 ±0.087Aa	0.197 ±0.017Ab	0.195 ±0.013Ab
(cmole.kg^{-1})	Mulching	0.197 ±0.101Aa	0.228 ±0.028Aa	0.142 ±0.012Bb	0.234 ±0.055Aa

a,b,c: Density means followed by same lower case letters are not different.
A,B: Residue management means followed by same upper case letter are not different
* T1: *Inga* planted at 1m x 1m; T2: *Inga* planted at 2m x 1m; T3: *Inga* planted at 4m x 0.25m and T4: natural fallow control

CROP YIELD

Effects of tree density

Highly significant differences (P<0.01) were observed between the different treatments for maize grain yield during the first year of the experiment. Improved fallows yielded an average of 1.3 $Mg.ha^{-1}$ of maize grain compared to 0.3 $Mg.ha^{-1}$ for the natural fallow (Table 9), i.e four times more maize grain yield than the natural fallow control. Among the planted fallow treatments, T1 and T2 had the highest grain yield with 1.6 and 1.4 Mg ha^{-1}, respectively. The plot with trees in hedges yielded 50% less than T1, although trees in hedges produced highest biomass. Also although only minor differences were observed between the planted fallow and natural fallow for readily decomposable biomass and soil properties after the fallow period, highly significant differences are observed for crop yields. The biomass produced in planted fallows was of higher quality, the C: N ratio in planted fallow was 16.3, compared to 24.3 in natural fallow. The differences in natural and planted fallow for maize yield is better explained by the quality of the biomass produced. Then in fallow management, the quality of the residue is more important than its quantity in case of mulching.

Table 9. Effects of *Inga edulis* densities and residue management (burning or mulching) on maize (*Zea mays*) and *ngon* (*Cucumeropsis manii*) yield in an *Inga* improved fallow on acid soils. (Year 1: mulching (M); Year 2: mulching or burning (B).

Year 1 (maize)		T1	T2	T3	T4
Grain yield (Mg. ha^{-1})		1.6 a	1.4 a	0.8 b	0.3 c
Crop residues (Mg. ha^{-1})		1.3 a	1.2 a	1.1 a	0.4 b
Year 2 (maize)					
Grain yield (Mg. ha^{-1})	B	2.22 Xa	1.92 Xa	1.05 Xb	0.39 Xc
	M	1.5 Ya	1.2 Ya	1.0 Xa	0.2 Xb
Year 2 (*ngon)*					
Grain yield ($kg.ha^{-1}$)	B	301 Xa	294 Xa	275 Xb	104 Xc
	M	51.6 Ya	48.1 Ya	46.1 Ya	10.5 Yb

a, b, c, d: Tree densities followed by the same lower case letters are not differents
X,Y: Residue management means for a given tree density followed with same upper case letters are not different

Effects of residue management

During the second year, maize and *ngon* grain yields were similar in all tree plots and significantly higher than the natural fallow, when the residues were mulched. But when the residues were burned, T1 and T2 performed better than T3, for the two crops. The control was the lowest (Table 9). After burning, the maize grain yield on the average in tree fallows was 1.73 $Mg.ha^{-1}$, compared to 0.39 $Mg.ha^{-1}$ for the control, and the *ngon* average was 290 $kg.ha^{-1}$ compared to 104 $kg.ha^{-1}$ for the control. Burning in tree plots improved the maize yield by four times and the *ngon* yield by 2.8 times over the natural fallow. Differences between burning and mulching in the different treatments were spectacular especially for *ngon* yield. Tree fallow with burning had 6 times more *ngon* than plots with mulching.

The average *ngon* production from *essep* deriving from a secondary forest or a long fallow in the area was 303 kg.ha^{-1}, which is similar to our results in T1 and T2 after burning. This indicates that two years *Inga* planted fallow can be converted to *essep* and can yield enough *ngon* to be attractive to farmers. However, this conversion is possible only after burning. Tree plots T1 and T2 performed better than T3 for maize and *ngon* yield, although T3 had more fallow biomass (see Table 3), probably because of high competition for nutrients between trees and crops in T3.

DISCUSSION

Tree fallow produced more total biomass than the natural fallow; trees in hedges accumulated more biomass than other tree fallows. For the readily decomposable fraction and, therefore, nutrients Mg, K and P recycling, the natural fallow was similar to T1 and T2. The different tree densities can explain differences in biomass production and nutrient accumulation in T2 and T3, but significant differences between T2 and T3 indicate that the tree planting patterns can affect the growth rate of *Inga edulis*, which portrays a potential difference in competition in case of intercropping. The tree plots produced the same amount of litter, and controlled weed similarly irrespective of tree density. But because of slow decomposition of *Inga* and considerable amounts of nutrients in the woody biomass, most of the nutrients accumulated in tree fallows may be unavailable for annual crops coming immediately after the fallow period. Harvesting of planted fallow by-products such as fruits and fuel wood, which are in some areas very attractive for farmers (Franzel, 1999), will lead to considerable nutrient export (Nolte et al., 2003; Kato et al., 1999). Farmers should be advised to return the kitchen ash to the field to reduce the nutrient loss; when the household does not use the wood, it should be spot-burned and the ash broadcast in the plot.

Soil nutrient concentration was lower after the fallow period compared to when the trees were planted. Trees have sequestered the soil nutrients in their biomass, and therefore the benefits of the planted fallow lies in the residue management (Lal, 1997). Residue removal as practiced by some farmers in the region when they are constrained by early rains is therefore not advisable. After mulching tree fallow improved the crop yield over the control. Comparing the planted fallows, the low yields in T3 in spite of its high biomass production, indicates a potentially high competition with companion crops, for trees in hedges compared to other planting density/design in T1 and T2, which is critical in intercropping. Many reports indicate improved crop yields in alley-cropping and planted fallows, but farmers are still hesitant to adopt the technology. The key issue is the cost of using the technology. Before taking any decision, farmers take into account not only crop yield, but also systems involving less labour (Tonye et al., 1997). In terms of weed suppression, litter production and crop yield, the performance of planted fallow with trees at 5,000 plants ha^{-1} was comparable or even higher to that of T3 with trees at 10,000 plants ha^{-1}. Although T2 contributed less than T3 for soil nutrient accumulation, it requires less labour and management input, and therefore can be highly recommendable.

Figure 1. Total carbon stocks in planted and natural fallows in the forest zone of southern Cameroon (Available stock = total vegetation stock - export in by-products)

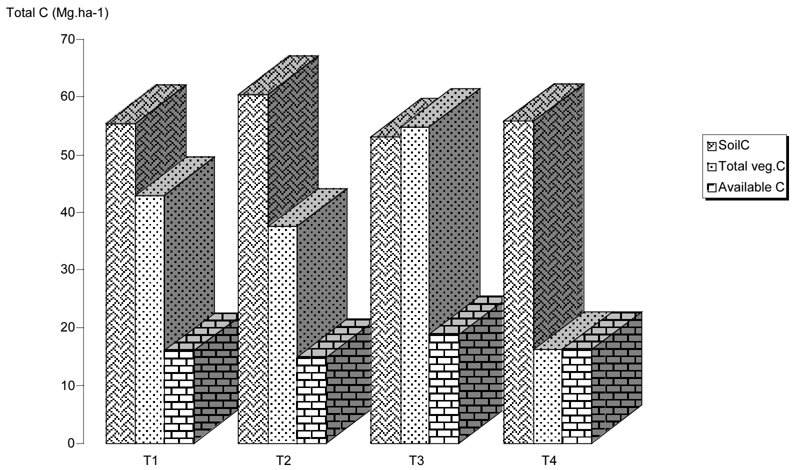
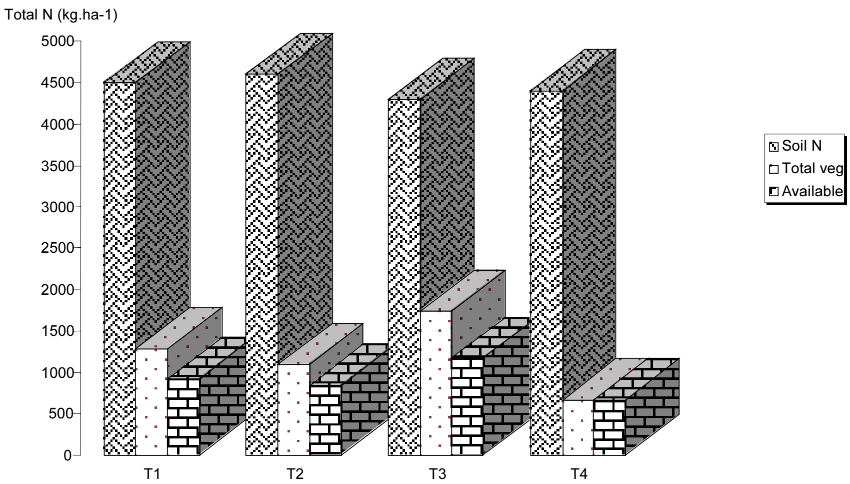


Figure 2. Total nitrogen stocks in planted and natural fallows of southern (Available stock = total vegetation stocks - exports in by-



In terms of total carbon and nitrogen accumulation, the natural fallow was similar to planted fallow for C; it accumulated close to 500 kg ha^{-1} less N (Figures 1 and 2). For P, K, Ca and Mg the natural fallow was at least similar to one of the planted fallows (Tables 4 and 5). However, in terms of crop yields, planted fallow outperformed the natural fallow. Added advantages of tree fallow over grass fallow may be nutrient supply to crops through belowground tree-crop interactions.

Burning improved the soil pH through the liming effects of ash, and released major nutrients such as Ca, P, K and Mg, but nutrients after burning are at risk of loss through leaching and erosion of ash.

CONCLUSIONS

- Planted fallows performed better than the natural fallow, in terms of quality biomass, C and N accumulation during the fallow period, and in terms of crop yield after fallow.
- Among the tree fallows, *Inga edulis* planted at 10,000 plants ha^{-1} gave the highest biomass and nutrient accumulation in the biomass, but lower crop yields compared to other planted fallows. *Inga* planted at 5000 plants ha^{-1} requires lower labour for tree planting and managing, and therefore, more attractive for farmers in terms of crop yields, and profit margins.
- After the fallow period, most of the soil nutrients were accumulated in the *Inga* biomass, and very few differences were observed between planted and natural fallows. Residue management in planted fallow is therefore of highest importance.
- Nutrients accumulated rapidly in young regrowths, indicating that frequent pruning of *Inga* can accelerate nutrient recycling in planted fallows.
- Burning significantly improved soil fertility and crop yields over mulching in both planted and natural fallows. Planted fallow management should therefore consider burning as a residue management option.
- The collection of by-products in planted fallow is a priority for farmers. Fallow management should include nutrient supplements to compensate for nutrients removed with wood and fruits.
- Burning cannot be avoided if planted fallows are converted to *essep* (*ngon* production). Controlled or spot burning can be envisaged to minimize the fire hazards in cropping systems.
- The conversion of *Inga edulis* planted fallow to *essep* is a breakthrough to reduce deforestation in traditional land uses of southern Cameroon.

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Chapter 7

ESTABLISHMENT OF *INGA EDULIS* AND *CALLIANDRA CALOTHYRSUS* IN IMPROVED FALLOW SYSTEMS IN SOUTHERN CAMEROON

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ABSTRACT

The adoption of planted fallow largely depends on the cost and feasibility of using the technology; easy, inexpensive and simple fallow establishment methods are known to greatly enhance adoption. It was the objective of this study to assess the effects of weeding regime on the establishment of *Calliandra calothyrsus* and *Inga edulis* on degraded acid soils in southern Cameroon. A combination of the two fallow species and two weeding regimes, weeding or not weeding, were compared to a natural fallow. The trial was conducted in two sites of different base status with four replications. The results indicate that differences between the two species and the two weeding regimes were statistically significant (p < 005) on both sites for all measured tree growth parameters, as well as the residual effects on subsequent maize grain yield. Presence of weeds reduced stem diameter and height of *C. calothyrsus* and *I. edulis* at the early stage of their establishment. Weeding doubled the leaf biomass of both species. The highest woodmass was produced by *Inga* in plots with weeding treatment, with 48 t/ha of dry material. Tree fallow improved the yield of succeeding crops by twofold over the natural grass fallow. Weeding treatment improved maize yield, from 1.9t/ha to 2.8 t/ha after *Calliandra* fallow, and from 2.22 t/ha to 3.0 t/ha after *Inga* fallow. The significant effects of weeding treatments implies that fallow-improving tree species should be planted in relay intercropping for trees to benefit from the weeding of crops, thus reducing the labour spent on fallow establishment.

INTRODUCTION

Soil fertility depletion in smallholder farms is now recognized as the fundamental biophysical cause responsible for declining food security in sub-Saharan Africa (Sanchez et al. 1997). As population increases, fallowing and fallow periods are reduced, cultivation is extended to marginal areas, causing decline in crop yields and land degradation. Although it is shown that external chemical inputs are needed to achieve high crop yields, their availability and cost may be prohibitive for the use in food crop production in many developing countries (Kang 1997; Sanchez et al. 1997). Improved tree fallow, the deliberate planting of trees and shrubs in rotation with crops, is reported to have great potential for improving soil fertility. The restoration of N, P and K stocks during vegetated fallow on acidic and infertile soils is well documented (Szott and Palm 1996; Kwesiga et al. 1999). The identification of appropriate tree/shrub species is the key to developing efficient improved fallow systems, and much has been invested on screening trials. *Calliandra calothyrsus, Inga edulis, Indigofera zollingeriana, Pterocarpus santatinoides* have high potentials for use in such soils (Duguma and Mollet 1997; Kanmegne et al., 2000). Unfortunately, the rate of adoption of improved fallow has been slow in the humid forest zone, in spite of encouraging crop response in on-station and researcher-managed on-farm trials, leading to little or no change in the gloomy trend of the deteriorating natural resource base (Kang 1997).

The challenge now is to determine why farmers are not willing to incorporate improved tree fallow into their farming systems, and design more attractive and efficient fallow management techniques. The success of planted fallow is optimum in conditions such as soil erosion, labor availability, and a scarce supply of land (Sanchez 1995), which is not generally the case in the humid forests. In southern Cameroon, the spread of the technology to neighboring farmers has been low (Institut de la Recherche Agricole pour le Developpement (IRAD)/ICRAF 1997; Franzel 1999). Farmers are constrained by the timely planting and weeding of trees, which usually coincides with their peak period for planting and weeding their crops. This peak period labor constraint then usually limits the area planted to improved fallow (Franzel 1999). Management flexibility to reduce labor spent on fallow establishment can, therefore, be of top priority in such systems, in order to allow compatibility with other farmer enterprises and enhance the adoption of improved fallow (Buresh and Cooper 1999; Franzel 1999).

The main objective of this study is to assess the effects of weeding regime on the establishment, and soil fertility restoration potentials of two agroforestry tree *species Inga edulis* and *Calliandra calothyrsus* (here after referred to as *Inga* and *Calliandra*). The experiment is also designed to determine the effects of the initial soil fertility level on the performance of the two tree species.

MATERIALS AND METHODS

The study was conducted at the IRAD (Institut de la Recherche Agricole pour le Developpement) research station, in Nkoemvone, southern Cameroon (located at longitude 11° 8 E, latitude 2° 55 N, and altitude 615 m). The average annual rainfall over 20 years is 1820 mm with a bimodal distribution, and the mean daily temperature is 23.5 °C. The soils are Ferric Acrisols characterized by a low base saturation, a low cation exchange capacity, the vegetation consists of degraded humid forest.

The seedlings were tended in the nursery for 16 weeks then transplanted into the field at 1 m by 1 m, and the growth performance was monitored under weeding and no-weeding regimes. The trial was conducted at two locations at the same research station with different base status, 3.6 cmole/kg and 7.9 cmole/kg for site I and site II respectively in the top 0–5 cm. Details of soil characteristics of the two sites are presented in Table 1.

Table 1. Soil properties of *Inga edulis* and *Calliandra calothyrsus* evaluation sites in Nkoemvone, Cameroon.

	Site 1			Site 2		
Soil properties	0-5cm	0-15cm	15-30cm	0-5cm	0-15cm	15-30cm
C (%)	3.49	3.10	1.75	4.70	2.90	1.94
N (%)	0.34	0.31	0.21	0.42	0.28	0.23
C/N	10.3	10.0	8.3	11.2	10.2	8.9
Available P (mg/kg)	24.0	17.0	7.0	19.0	8.0	4.0
Ca (cmole/kg)	1.8	1.0	0.4	5.3	2.3	1.4
Mg “	1.4	0.7	0.3	2.3	1.6	1.2
K “	0.15	0.08	0.14	0.10	0.10	0.10
Total base “	3.6	2.0	0.9	7.9	4.1	2.9
CEC “	11.9	10.8	8.5	14.4	11.2	10.0
pH (1:1 water:soil)	4.50	4.20	4.20	5.30	4.80	4.60

The design of the experiment included completely randomized blocks and a factorial arrangement of tree species and weeding regimes, making 2 × 2 factorials, with 4 replications, on each of the two sites. The gross plot size was 10 m × 10 m and the net plot 8 m × 8 m. The tree species were all planted in monoculture, at 1 m × 1 m in each treatment (Duguma and Mollet 1997). Plots with weeding regime treatments were weeded at 4 weeks interval and manually. Data collection on plants commenced 12 weeks after planting (WAP) the seedling in the field. Parameters measured were total height using a graduated pole, and stem diameter at 0.3 m above ground using a pair of calipers, on ten randomly selected plants per experimental unit, at 12 weeks interval. For species with multiple stems, the diameter of all the stems was measured, and mean calculated as a quadratic average of the individual stem diameter.

The trees were pruned at 0.05 m above ground level at 120 WAP. Then, 10 trees were selected per experimental unit and retained for biomass determination. The selection included the different sizes present in the plot: 3 small, 4 medium and 3 large ones. Biomass was separated into wood and leaf material; the leafy material including leaves and green twigs was then incorporated in the soil, while the woody material was burnt and the ash evenly applied in the plot.

Maize (*Zea mays*) was used as a test crop, at a plant density of 40,000 plants/ha, and planted in all plots to assess the residual effects of soil improving tree species. The trial was then managed as five fallow systems, by combining the two tree species and two weeding regimes, and a natural fallow control. Trees were pruned again 6 weeks after maize planting, and green manure from the pruning (leaves and twigs) broadcasted on the soil surface. At maturity maize plants from 8 × 8 m plot were harvested for yield determination. Maize grain yield was expressed in t/ha at 14% moisture content. The collected data was subjected to analysis of variance (ANOVA) using the Genstat statistical package (Genstat 5 1987). The LSD and SED were used to separate the significant means at $p < 0.05$.

RESULTS

Plant height and stem diameter

The difference between the two species and the effect of the weeding regime on plant height was statistically significant ($p < 005$). Compared to *Inga, Calliandra* had a faster initial growth for the first 60 weeks of the experiment. The mean plant height of *Calliandra* was 1.5 times that of *Inga*. The parameter was improved by 40% for both species between site 1 and site 2. In the non-weeded plots height growth of *Inga* was suppressed by 30% and 51% (at sites I and II, respectively), compared to weeded plots. The corresponding figures for *Calliandra* were 10% and 22% (Table 2).

In addition, weed reduced the stem diameter of *Calliandra* and *Inga* at many sampling times. At early stage it was clear that *Inga* was more negatively affected by the no weeding treatment than *Calliandra*. At 48 WAP, stem diameter of *Inga* in the weeded plot was 2 times that in the non-weeded plots. Similarly, the stem diameter of *Calliandra* in the weeded plot was 1.5 times that in the non-weeded plots. *Inga* had a slow initial start, but was significantly improved with weeding (Table 3). Stem diameter was improved by 44% for *Calliandra* and 72% for *Inga* between site 1 and site 2. The two species reacted positively on higher soil base status. In the best treatment combination, *Inga* tends to grow to a fairly larger tree with multiple branches and a broader and denser crown compared to *Calliandra* in both sites. *Inga* could reach 66 mm diameter and 7.8 m height compared to 39.8 mm and 5.9 m respectively for *Calliandra* stem diameter and height.

Table 2. Effect of management regime on *Calliandra* and *Inga* height (m) on acid soils of southern Cameroon.

	12 WAP*	24 WAP	48 WAP	60 WAP	72 WAP	84 WAP	120 WAP
T1 (*Calliandra* weeded)	1.30	1.84	2.81	3.36	3.64	4.40	4.79
T2 (*Calliandra* not weeded)	1.36	1.53	2.39	2.78	2.81	3.78	4.78
T3 (*Inga* weeded)	0.59	1.29	2.22	3.09	3.41	4.27	6.23
T4 (*Inga* not weeded)	0.52	0.67	1.38	1.80	2.15	3.61	5.0
LSD (0.05)	0.54	0.64	0.45	0.65	0.54	0.80	1.25

* Weeks after planting

Table 3. Effect of management regime on *Calliandra calothyrsus* and *Inga edulis* stem diameter on degraded acid soils in Nkoemvone, Cameroon.

Treatments	12 WAP*	24 WAP	48 WAP		60 WAP	72 WAP	84 WAP	120 WAP
				(mm)				
T1 (*Calliandra* weeded)	10.1	12.4	20.9		23.9	25.6	29.0	31.8
T2 (*Calliandra* not weeded)	7.3	9.3	13.2		16.1	17.6	20.7	29.0
T3 (*Inga* weeded)	9.1	14.8	22.2		29.4	33.4	38.6	47.7
T4 (*Inga* not weeded)	4.8	6.6	9.1		11.7	15.0	22.5	37.7
LSD (0.05)	3.04	2.8	3.46		4.67	4.56	5.0	5.27

*Weeks after planting

Leaf mass

The effect of weeding and that of site were significant for both tree species. Weeding improved *Calliandra* leaf mass on site I by 78% and that of *Inga* by 88%. But on site 2 with more favourable conditions, weeding improved *Inga* leaf mass by only 48%, and was of little effect on *Calliandra*. *Calliandra* leaf mass on site II was twofold that of site I. For *Inga*, the leaf mass was improved by 39% in site II compared to site I (Figure 1).

Wood mass

The weeding effect was significant mostly for *Inga*, as its wood mass was improved by 36% and by 163% in site I and site II, respectively. For *Callliandra* weeding only improved wood mass by 6% and only on site II. The soil base status significantly affected the wood mass production of both tree species. *Calliandra* yielded 11.6 t/ha and 39.1 t/ha, and *Inga*, 14.8 t/ha and 33.4 t/ha in site I and site II, respectively. Thus weeding on high soil base status is a determinant treatment combination for biomass production of *Inga* (Figure 1).

Figure 1. Effects of weeding (w) and not weeding (nw), and initial soil fertility on biomass production of Inga and Calliandra

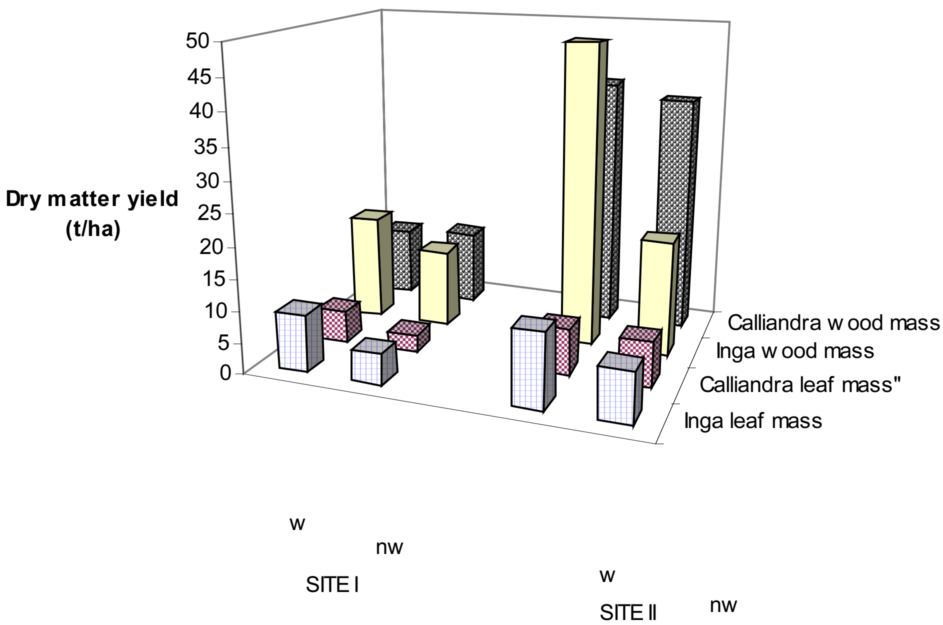
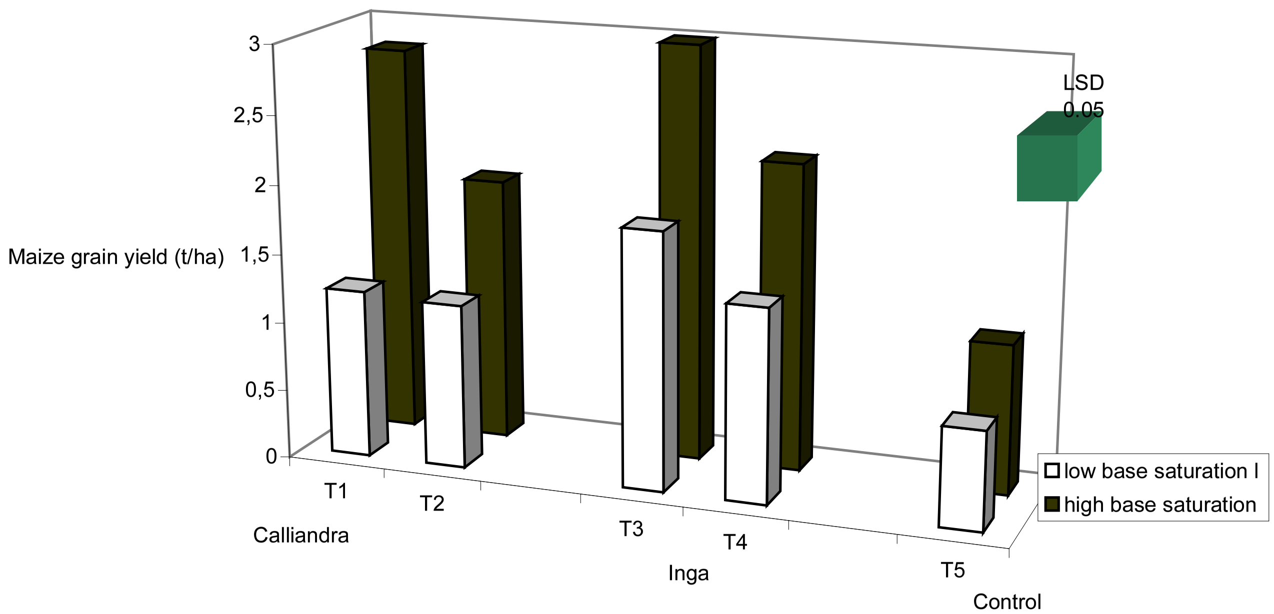


Figure 2. Maize grain yield after *Inga edulis* and *Calliandra calothyrsus* fallow on degraded acid soils in southern Cameroon



Fallow system: T1 = *Calliandra* weeded, T2 = *Calliandra* not weeded, T3= *Inga* weeded, T4= *Inga* not weeded , T5 natural fallow

Maize grain yield
Improved fallow had significantly higher yields compared to the natural fallow. Tree planting improved the crop yield by 2 fold over the natural grass fallow as the residual effect of 120 weeks fallow. Weeding treatment, and subsequent effects on tree growth, improved maize yields from 1.9 t/ha to 2.8 t/ha in *Calliandra* plots, and from 2.22 t/ha to 3.0 t/ha in *Inga* plots. The residual effect of *Inga* on soil fertility was higher than that of *Calliandra*. There was 31% more maize after *Inga* fallow than after *Calliandra* fallow (Figure 2).

DISCUSSIONS AND RECOMMENDATIONS

Plant height and stem diameter are important growth parameters especially in Southern Cameroon where *Chromolaena odorata* and *Mimosa invisa* are serious weed pests. *Calliandra* has the potential to establish fast and rapidly over shade competitive weeds. *Inga* has a slow initial growth and thus a higher vulnerability to weeds compared to *Calliandra*. Weeding significantly improves the growth performance of both tree species. Both species performed better on a fertile site, particularly with weeding treatment. The same trend is observed for height and diameter and for biomass yield.

The biomass yield obtained from this trial is comparable to that reported by Duguma and Mollet (1997) who obtained 34 t/ha of wood and 15 t/ha of leaves for *Calliandra* at 136 WAP on similar soils. Kanmegne et al. (2000) also obtained 48 t/ha of wood and 13 t/ha of leaves from *Inga* after 60 weeks fallow on more fertile soils. Soil fertility differences started from 48 WAP; Szott (1995) similarly reported that soil fertility constraints usually act only at certain stages of stand development, usually near stand closure when high rates of nutrient immobilization in biomass occur.

Inga and *Calliandra* should be introduced when farmers are willing to weed the trees. Weeding the trees improved the subsequent maize yield by 35% in *Inga* fallow and by 47% for *Calliandra*. Intercropping agroforestry tree species with crops in a relay intercropping system during the last cropping season before fallowing (Young 1997), is therefore highly indicated. They may benefit from weeding crops, thus reducing labor investment in establishing improved fallow (Franzel 1999). This requires trees to be planted on rather fertile soils, to allow acceptable crop yields as an incentive for farmers to weed the trees. In this experiment higher soil fertility level contributed to 131% of the maize yield improvement, and the best yields occurred in plots with weeding treatment. On more fertile sites, better biomass yield was obtained for both species (Duguma and Mollet 1997; Kanmegne et al. 2000).

On degraded acid soils, introducing *Calliandra* or *Inga* consistently improves the crop yields. Young (1997) estimated that a well managed tree fallow can increase crop yields to the order of 50 to 100%. In this experiment, improved fallow on degraded acid soils improved the crop yield by 132%. This can be an economic incentive for farmers, provided the yield increase compensates for labor invested in nursery and tree planting. High value by-products such as *Calliandra* fallow for honey-production, yam and tomato stakes, and *Inga* fallow for fuel wood, are some elements of harvest from the fallow which may necessarily reduce soil effects but increase acceptability (Buresh and Cooper 1999).

From this experiment, if the establishment cost of a tree fallow can be reduced, *Inga* and *Calliandra* fallow can raise the productive levels of degraded soil for subsequent crops, thus improving the profitability of improved fallow (Franzel 1999). Improved fallow also needs to be tested with high-value crops to achieve higher returns to land and labor. Further research also needs to focus on the cost and feasibility for using the technology, the prices and other values of benefits produced by the improved fallow, for a better quantification of farmer incentives for adoption.

Chapter 8

FROM ALLEY CROPPING TO ROTATIONAL FALLOW: FARMERS' INVOLVEMENT IN THE DEVELOPMENT OF FALLOW MANAGEMENT TECHNIQUES IN THE HUMID FOREST ZONE OF CAMEROON

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ABSTRACT

Alley cropping was introduced in the humid forest zone of Cameroon to increase soil fertility in 1987, but until 1992 the adoption rate had remained low. To better understand the reasons behind this, three types of on farm trials were established from fully researcher controlled to fully farmer controlled. During the evaluation of the technology with farmers a number of modifications were registered (1) *Pruning height and frequency*: Because of the difficulties to consistently cut back at 30 cm, farmers decided to slash at ground level as they normally do while slashing the natural fallow vegetation. This equally allowed for more flexibility in time of pruning. (2) *Cropping intensity and pattern*: Initially, alleys were cropped each year. This however had several shortcomings. Having observed the positive impact of incidental fallow period in a farmer's field, it was decided to introduce a fallow phase of at least one year. During the fallow period the plot can be used for fodder production, bee farming and production of stakes. (3) *Residue management*: Fire went incidentally in a farmer's tree plot after slashing, and the trees were not affected. This gave farmers an alternative way to manage the residue, by controlling the fire, before bringing in other crops such as groundnut and cassava. (4) *Agroforestry species*: Because *Leucaena leucocephala*, in spite of it soil fertility restoration potential, rapidly became a noxious weed, farmers have asked for a less invasive species. *Calliandra calothyrsus* was introduced for this purpose and became a good bee forage. With these modifications, the original alley cropping system has evolved into a rotational tree fallow with higher adoption potential. From about 15 farmers who were testing the technology in 1992, the number increased to 52 in 1996, 120 in 1997 and 236 in 1998.

INTRODUCTION

Alley cropping has been widely reported to improve soil productivity and nutrient recycling in smallholder farming system of the humid tropics (Kang, 1997). It has been recommended as a viable alternative to the traditional shifting cultivation generally practised in the area. In the humid forest zone of Cameroon, a team of researchers from IRAD (Institut de la Recherche Agricole pour le Développement) and ICRAF (International Centre for Research in Agroforestry) introduced alley cropping to farmers, using a step-wise approach. The first step was the participatory survey that identified soil fertility as an important agricultural constraint and alley cropping as a possible alternative. The second step was the on-station tree screening and technology development and the third the testing of alley cropping in farmers' fields (Tonye et al., 1994). The initial interest of farmers gave high expectation on the adoption of the technology, but the rate of adoption remained low (IRAD/ICRAF, 1993), despite the high potential of the technology for soil fertility replenishment and weed suppression. It is widely known that farmer managed trials with complex technologies may not be suitable in drawing useful conclusions on treatment effect (Shepherd et al., 1997). But such trials can be used to assess the adoption potential of the technology, as farmers take into account not only crop yield, but also labour and management requirements, among other factors, before making any decision (Franzel, 1999).

Fujisaka et al. (1996) observed that resource poor farmers have complex technical knowledge and that understanding their practices is a prerequisite to problem solving. This underscores the importance of farmer participation in technology development. To better understand the reasons behind farmer's behaviour, the IRAD/ICRAF team emphasised the involvement of farmers in the process of technology development and room was left for creativity and innovative ideas. The IRAD/ICRAF experience with this participatory approach has shown that, in response to problems and opportunities, farmers have initiated changes in the conventional alley cropping system, which has now become a rotational tree fallow with more chances of adoption. This paper presents the IRAD/ICRAF approach to capture farmers' feedback and modifications in the alley cropping system solicited by farmers and how it enabled researchers to develop appropriate fallow management techniques for the humid forest zone.

METHODOLOGY

The study site

The study was conducted in Abondo and Nkolfep, two villages in the Yaoundé neighbourhoods, Southern Cameroon. Geographically, the study zone is situated between latitude 3º51′ and 3º53′ N, and longitude 11º25′ E and 11º27′ E and has an altitude of 813 m. The climate is equatorial with two rainy seasons corresponding to two cropping seasons: March to June and August to November. The average rainfall is 1692 mm with bimodal distribution; the mean daily temperature ranges from 19.2 to 28.6 ºC. The soils are Ferric Acrisols, characterised by low base saturation and a low cation exchange capacity. The vegetation is evergreen forest, severely degraded by human activities, especially agriculture and timber exploitation. The farming system is based on shifting cultivation and mixed cropping. Livestock is of minor importance. Groundnuts (*Arachis hypogeae*) and cassava (*Manihot esculenta*) are the main crops in the area. They are planted in a mixture with maize, plantain (*Musa acuminata*) and a wide range of vegetables. Usually cassava and plantain remain in the field after other crops have been harvested. At maturity, generally six months to one year after planting, cassava is harvested plant by plant for home consumption, and the plot gradually enters its fallow period (Tonye et al., 1994; Mutsaers et al., 1981). In recent years, population densities have increased causing reduction in fallow period length to two or three years. The main constraints to the production system, that can be addressed by agroforestry are, among others, low soil fertility and weed infestation (Tonye et al., 1994). Moreover, agroforestry can help address deforestation and reduce the need for slash-and-burn.

Farmer involvement in the technology development

To evaluate the performance of the technologies developed through on-station research under a wide range of conditions, collaborative adaptive research was carried out in farmers' fields with their participation during all stages of the research process. The small farmer participation in the design of on-farm trials is well documented. Ashby (1986) emphasized on the need to allow farmers utilize their expert knowledge of their local farming system, their skill and their capacity for self-help. The participatory client-driven research and technology development in agriculture is also documented, with the development of farmer capacity to lead adaptative research testing (Ashby and Sperling, 1995). A closer contact between farmers and researchers usually reveals the unexpected richness of farmer knowledge and the dynamic process of farmer innovations (Scherr, 1991). To ensure partnership between farmers and researchers and better capture their innovative ideas, three types of trials were established, ranging from researcher designed and managed trials to farmers own experiment (Rocheleau, 1991). The responsibilities of farmers and researchers were clearly defined (Table 1).

Type I: researcher designed and researcher managed, for biophysical data collection with complete control of researchers over the experiment. The trial prototype consisted of planting leguminous trees (*Gliricidia sepium*, *Leucaena leucocephala* and *Calliandra calothyrsus*) at 4 m by 0.25 m and cut back after one year at 0.30 m. Prunings were applied as mulch and maize was planted in the alleys. To minimize aboveground competition, trees were pruned before planting and then twice during the cropping phase. Each trial had two main treatments: T1 = a tree plot of minimum 16 m x 10 m and T2 = a control plot without trees with minimum area of 25 m^2. Each farm represented a replicate. The tree fallow could exist either of one of the species, or a combination of the species. There were 10 type I trials, three with a combination of *Gliricidia* and *Leucaena* hedges and seven with hedges of *Calliandra*. The aim was to compare tree fallow with the natural fallow.

Type II: researcher designed and farmer managed to obtain biophysical data and farmer reaction to the technology and its management requirement.

Table 1. Contribution of farmers and researchers to the implementation and management of type I, II and III trials in the humid forest zone of Cameroon

Activities	Type I trials	Type II trials	Type III trials
Site selection	Farmer and researcher	Farmer and researcher	Farmer
Tree seed supply	Researcher	Researcher	Farmer and researcher
Tree nursery	Farmer	Farmer	Farmer
Land clearing	Researcher	Farmer	Farmer
Design of experiment	Researcher	Researcher	Farmer
Tree planting	Farmer and researcher	Farmer	Farmer
Weeding the plot	Researcher and farmer	Farmer	Farmer
Tree pruning	Researcher	Farmer	Farmer
Selection of test crops	Researcher	Farmer and researcher	Farmer
Crop planting	Researcher	Farmer	Farmer
Data collection	Researcher	Researcher	-
General observations on the plot	Researcher and farmer	Researcher and farmer	Researcher and farmer
Crop harvesting	Researcher and farmer	Researcher and farmer	Farmer
Evaluation	Researcher and farmer	Researcher and farmer	Researcher and farmer
Field day	Researcher, farmer, NGOs	Researcher, farmer, NGOs	-
Marketing of crops and by-products	Farmer	Farmer	Farmer

Type III: farmer designed and farmer managed to allow farmers to select an appropriate technology and experiment with it as they wish. The type II and type III trials had the same treatments as type I trials, but in type III, other lay-outs and management were possible. The farms were regularly visited and information was collected on the changes and innovative ideas of farmers compared to the technologies proposed in type I.

The type I, type II and type III trial approach is intensively used by ICRAF and is well documented (IRAD/ICRAF, 1996; Franzel et al., 1999; Franzel et al., 1999; Degrande and Duguma, 2000). Apart from biophysical data collection in type I and type II plots, innovative changes were monitored in type III trials through informal discussions, group meetings and direct observations in the field.

RESULTS AND ANALYSES

During the monitoring and evaluation of the three types of trials, major modifications were observed in the type 2 and type 3 trials on pruning height and frequency, cropping intensity and pattern, residue management, and agroforestry tree species used.

Pruning height and frequency

In type I trials, pruning was done at 30 cm above ground level; hedges were pruned three times during each cropping phase: before crop planting, then four and eight weeks later. The plots were cropped twice a year, making six prunings per year. Farmers complained of inappropriate equipment (tools), excess labour and too much time required to respect the 30 cm height compared to the traditional system where slashing is done at ground level. In type II and type III trials, they decided to prune the hedges at ground level. All the interviewed farmers appreciated the change in cutting height, which also reduced the pruning frequency. The first pruning after planting was carried out in 80% of the farms, but the second pruning after planting was done only in 33% of the farms. Farmers considered the regrowths not to be harmful to companion crops at that stage. This was considered as an added advantage of pruning at ground level.

Cropping intensity and pattern

The presence of a control plot was of minor importance for many farmers. Thirty-three per cent of experimenting farmers said they knew exactly what they would have produced on the same plots without trees. Only 50% of type II farms had a control plot and generally they were smaller than the tree plots and managed in a different way. While in the type I trials, maize was the sole test crop, most of the type II farms were planted with maize, associated with groundnut, cassava and beans. The introduction of cassava in the tree plots required more time for the crop to mature (six months to one year), and after a cassava crop, farmers usually allow the plot to enter a fallow phase of at least one year before a new crop is planted. With the introduction of a fallow phase, the initial alley cropping or hedgerow intercropping shifted to a rotational tree fallow, with more returns in terms of crops and by-products, compared to continuous cropping with trees. The majority of farmers (93%) mentioned the improvement of soil fertility and 71% of farmers reported increased yield in the tree plots compared to the control plot as major benefits (Table 2). Weed suppression, the production of stakes, fuel wood, and the possibility of keeping bees as added advantages were mentioned by 67% of the interviewees. The technology provided secondary benefits, which were not apparent when the system is first implemented (Muschler and Bonnemann, 1997).

The rotational tree fallow is actually reported to improve soil chemical properties and reduce the risk of nutrient loss through leaching, compared to alley cropping system (IRAD/ICRAF, 1996, 1997).

Table 2. Effects of the tree fallow on cassava and maize yield, on farm trials in the humid forest zone of Cameroon.

Location	Maize dry grain yield ($Mg.ha^{-1}$) in type I trials		Cassava fresh tuber yields ($Mg.ha^{-1}$) in type I trials	
	Tree fallow	Natural fallow	Tree fallow	Natural fallow
Nkolfep	3.63	2.38	6.69	11.0
	4.75	3.16	7.84	2.63
	5.26	2.88	4.06	2.88
	2.87	2.00	7.19	2.81
	2.23	1.71	14.50	9.50
	3.29	2.43	6.81	2.63
			0.52	1.06
Abondo	3.61	3.20	12.44	8.38
	3.29	2.76	6.44	1.94
			2.88	4.00
			8.94	7.88
Mean	3.62	2.57	7.12	4.97
SED	0.24*		0.94*	
CV (%)	15.0		36.5	

* Significant at P<0.05

Residue management

Initially, the leafy materials of the prunings were applied as mulch while the wood was removed from the plots. With the introduction of a fallow phase the wood biomass increased. *Leucaena* wood mass for example increased from 4.5 t ha^{-1} to 10.1 t ha^{-1} and *Gliricidia* from 1.9 t ha^{-1} to 3.4 t ha^{-1} after the fallow phase. This increase in tree biomass made management of the residues a time-consuming and labour-intensive activity.

Farmers gained experience from a plot incidentally burnt, to modify the residue management. The best branches are removed and used as stakes (mentioned by 80% of the interviewed farmers), for fuel-wood (67%) and the remaining wood was burnt. Generally leaves were applied as mulch but 60% of farmers admitted that some leafy material was burnt. Farmers generally pile the woody residues in the middle of the alley before burning.

Spot burning is reported to increase phosphate and cation levels of the surface soil from addition of ash. It cleans the land of great mass of residues, reduces weed seeds in the soil and increases soil pH (Kang and Saggapongse, 1980; Tonye et al.,1997).

Agroforestry species

Leucaena and *Gliricidia* were initially introduced as adapted agroforestry species for the humid forest zone (Tonye et al., 1994). After experimenting a number of years, farmers complained that *Leucaena* was too invasive and that the biomass yield of *Gliricidia* was not satisfactory. In response, researchers introduced *Calliandra calothyrsus*, which was previously screened on-station. This species produces few seeds, so is not invasive, and performs as well as *Leucaena* for soil fertility restoration. *Calliandra* also has the added advantage of producing flowers throughout the year and is recommended for bee-forage and fodder (Duguma and Mollet, 1997). With the general interest of farmers for bee farming, *Calliandra* was the most suitable tree species and farmers shifted from *Gliricidia* and *Leucaena* to *Calliandra* fallow. Actually the type III trials are all planted with *Calliandra*.

CONCLUSION

The key objective of involving farmers in the process of technology development is to bridge the gap between the on-station research results and farmers' reality. This approach increases both the relevance and the acceptability of the research findings, which are necessary conditions for successful technology transfer (Muschler and Bonnemann, 1997). The alley cropping technology, as developed on-station and proposed to farmers from 1987 to 1992, had several shortcomings and was not fully adapted to the food crop system of the humid forest zone. Continuous on-farm evaluation and iterative modifications to suit farmers' needs and competence has resulted in a rotational tree fallow that now fits into the local cropping system and has higher adoption potential than before. During the fallow phase the plot is used for fodder production, stakes, apiculture, which bring additional returns to farmers. Then the plot is slashed at ground level and the residues burnt (controlled fire) and a diversity of crops introduced.

The experience is now being replicated across sites. From about 15 farmers who were testing the technology in 1992, the number increased to 52 in 1996, 120 in 1997 and 236 in 1998. The spread of the tree fallows is mainly due to efforts from NGOs. They actively promoted the technology by distributing tree seeds to interested farmers, and by providing them with technical assistance.

Subsequent research on agroforestry systems should take into account this experience and involve farmers fully from the beginning. On the other hand, researchers should make full use of the complementarities of type 1, 2 and 3 trials. Type 1 trials with high researcher involvement are very useful for the evaluation of technology performance under a wider range of biophysical conditions, but do not capture farmers' reaction and modifications to the innovation, constraining its suitability. Therefore, other types of experimentation (type 2 and type 3) with greater flexibility for management changes responding to farmers' needs are required. Very important in this kind of on-farm research is the collaboration with NGOs, community organized self-help groups and extension services, which are closer to farmer reality (Place and Dewees, 1999). Moreover, this collaboration allows researchers to test technologies with a much greater number of end-users than would be possible without partners, thereby validating research results on a wider scale and facilitating further transfer.

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Chapter 9

GENERAL DISCUSSION AND SYNTHESIS

Farmers' perception of land degradation

Slash-and-burn agriculture as practiced by smallholders is generally considered as the root cause of land degradation, but hardly any study investigated the mechanisms involved, or if the main actors (farmers) are affected. Weed scientists usually attribute land use changes to weed infestation (Akobundu, 1987), whereas soil experts attribute it to soil fertility decline (Sanchez, 2000). Although the farmers in the forest zone consider both weed/disease and soil fertility problems as part of a complex of interacting constraints, approximately 44% of the decline in crop yields was attributed to soil-related factors, while 56% was attributed to diseases and weed infestation.

Farmers decide on the land use, crop associations and soil fertility management based on how crucial these production constraints are in affecting the crop yields. Fallowing is a way to get rid of weeds and diseases. The indigenous knowledge of farmers for composting, collection and redistribution of animal dejections and kitchen refuse is poorly developed, compared to areas with high population density and intensive agriculture (Ceccolini, 2002). Farmers use a diversity of techniques for soil fertility management, many of which fit well in local conditions, and can lead to conservation and regeneration of the natural resource base, but not all are effective. Therefore, modifications and adaptations are necessary (Altieri, 2002). Such modifications should take into consideration farmers' rationale and knowledge (Buttner and Hauser, 2003; Altieri, 2002). This should be based on a thorough knowledge on how farmers use household and field characteristics to make adoption decisions (Bannister and Nair, 2003). This thesis provides important data on carbon and nutrient stocks and flows that have to be considered in supporting farmers' management decisions.

Carbon and nutrient stocks

High biomass and C are sequestered in the forest vegetation, 199 $Mg.ha^{-1}$, which is characteristic of the humid forest of West and Central Africa, and the Malaysian rainforest (Greenland and Kowal, 1960; Andriesse and Schelhaas, 1987; Van Reuler and Jansen, 1993). The rate of C loss is approximately 70% within 3 years after the conversion of forest to crop fields. Short fallows have low carbon and nutrient stocks. We give evidence that planted fallow is likely to be a strategic alternative to improve biomass production and nutrient stocks in short fallows.

The C stocks in the soil were less affected by land use; there was even an increase in C after burning, which is consistent with the available literature (Stromgaar, 1992; Nye and Greenland, 1960; Tonye et al., 1997; Koutika et al., 1997). The carbon loss is the main consequence of slash-and-burn agriculture.

From a natural forest to *afup* in the chronosequence, which takes 4 to 5 years, the loss was 7 $Mg.ha^{-1}$ of soil carbon and 162 $Mg.ha^{-1}$ of the system total C stock. The speed at which the C and nutrient stocks are diminished along the slash-and-burn chronosequence was a key finding of this thesis and is of high concern. The soils are poor, and although the total aboveground and belowground nutrient stocks in the system are high, the cropping phase is short, because of the rapid depletion of soil nutrients. This study showed that after 2 to 3 years, the soil C and nutrient stocks are too low to grow crops such as *ngon*, plantain and groundnut and, therefore, farmers are forced to shift. Other factors such as weeds and diseases also contribute to the yield decline (Akobundou, 1987). Our results support the opinion of Sanchez (2000), that soil fertility depletion is the root cause of declining yields in the tropics, and should be addressed first for food security in Africa.

Agricultural lands are believed to be a major potential sink and could absorb large quantities of C, if trees are reintroduced in these systems and judiciously managed together with crops (Albrecht and Kandji, 2003). The cocoa system considered in this study illustrates this assertion. Shade trees alone in the cocoa system maintained 53% C of the initial forest system compared to 20% in *afup owondo*. The many trees present in the system provide permanent soil cover, recycling of nutrients and deep capture of nutrients, thereby contributing to the system sustainability. The diversity of tree species preserved and/or planted by farmers in this system indicates that cocoa systems favour biodiversity conservation relative to other systems.

Integrated nutrient management

Three fundamental factors determine the level of nutrient management in a cropping system:

1. ADD new nutrients to the system. In our case study, no attempt was made by farmers to add nutrients to the systems: nutrient input from mineral, inorganic amendments and animal feed was nil.
2. SAVE nutrients from being lost from the system. This refers mainly to low-external input systems, which focus much on good use of 'internal flows', such as the links between crop residue removal and application of manure. In the humid forest, farmers are not involved in the removal and redistribution of residues. Nutrients reaching the garbage heap (1.9 kg N, 2.79 kg P and 18.84 kg K $ha^{-1}.yr^{-1}$), animal manure (4.9 kg N, 0.4 kg P and 1.6 kg K), and human faeces (4 kg N, 0.64 kg P and 4.8 kg K $ha^{-1}.yr^{-1}$) were not recycled. This is a major difference with Sahelian, millet-based systems without inputs, that rely on composting and manuring.
3. CASH IN on natural soil fertility. Farmers rather cashed in on nutrient reserves through slash and burn, but the direct consequence is high nutrient depletion. Losses due to farmer management resulted in a negative nutrient balance: -67.8 kg N, -5.6 kg P and – 32.1 kg K $ha^{-1}.yr^{-1}$.

Nutrient export in crop and animal products was low compared to nutrient inputs to the system, such as deep capture, atmospheric deposition and biological nitrogen fixation, because of high nutrient losses. The major losses resulted from leaching, gaseous losses from the soil, human faeces and burning. The general farm budget was negative, with a yearly loss of -73 kg N, -3 kg P and -23 kg K ha^{-1}. So the sustainability of shifting cultivation in the forest zone with low population density (10 inhabitant km^{-2} in our case), is hardy substantiated. Hence, the challenge is to:

4. ROUTE nutrients for highest agronomic efficiency.

Routing refers to both 'adding' and 'saving'. Adding may call for external actors such as government subsidies, which are currently not available. Our study suggests several management scenarios to redress the nutrient balance. A judicious manipulation of internal flows, recycling animal dejection, kitchen residues and human faeces which will bring the balance at -62.6kg N, 0 kg P and +1kg K $ha^{-1}.yr^{-1}$ is foremost. This already compensates for the P and K deficit. Introducing a nitrogen-fixing tree in the system, such as *Inga* planted fallow can further compensate for the nitrogen deficit. If, above all, burning is reduced, a completely positive nutrient balance will be achieved: +11.6 kg N, +1.82 kg P and +16.2 kg K $ha^{-1}.yr^{-1}$. The trade-off will be to reduce *essep* and *afup* to household consumption scale and develop tree-based systems, with a positive nutrient balance, as a source of income for the household.

We will henceforth highlight some innovative management components of INM, i.e. nutrient recycling through earthworm casting activities and *Inga* planted fallows.

Nutrient recycling through earthworm casting activities

The systems under study had low earthworm density, probably because of high soil acidity. The highest density was 118 (± 28) m^{-2} in the short fallow. Earthworm densities decreased between 64% and 95% whenever fire was used during land preparation, and thereafter intensive casting was suppressed by 14 and 19 months in land use systems succeeding *afup owondo* and *essep*, respectively. Planted *Inga* fallow proved to favour high earthworm density and intensive earthworm casting activities, similar to the natural forest.

Earthworms enriched their casts compared to the underlying soil, which is attributed to the preferential feeding of earthworms, which allows them to produce higher quality casts on poorer soil. In our study the quantity of nutrients recycled and, therefore, the contribution of earthworm casts to soil fertility improvement remained low, because of the low quantity of casts produced. It is envisaged from this study that improved fallow with *Inga edulis* is likely to improve earthworm casting activity and nutrient recycling, more than in traditional systems. Strategies should include introducing *Inga edulis* at early stages of the chronosequence of land uses, to maintain the worm density after the initial burning. Worms were generally abundant in the topsoil, probably because of associated organic matter, oxygen, humidity, and /or conducive pH (Henrot and Brussaard, 1997; Araujo and Lopez-Hernandez, 1999). Residue management is likely to play a critical role for optimum earthworm density and casting activities. The quantity of organic residues on the topsoil, the soil organic matter and mulching instead of burning, should all be considered when designing alternative land use management.

Inga planted fallows

Sanchez (1999) considered improved fallows as key components of many sustainable tropical-farming systems, as they can increase agroecosystem resilience. Our study indicated that planted fallows can play a fundamental role in nutrient management in the forest ecosysem. *Inga edulis* can produce more total biomass, accumulate more nutrients, improve the soil biological processes, and allow higher crop yields compared to the natural fallows. It is a way for *in-situ* accumulation of high quantities of N for cycling to subsequent crops. Nevertheless, as rightly pointed out by Lal (1997), the key factor with planted fallows is the ways the residues are managed. Residue management quality and quantity of biomass applied to the soil has a significant impact on soil quality and resilience, organic productivity, and greenhouse gas emissions.

Harvesting of by-products such as fruits and fuel wood, which is very attractive for farmers (Franzel, 1999), will lead to considerable nutrient export (Nolte et al., 2003; Kato et al., 1999). But a rational residue management led to 3 to 5 times more crop yields in planted fallows than in natural grass fallow. Two years of *Inga* fallow was able to sequester 55 $Mg.ha^{-1}$ C, and its potential conversion to *essep* would be a breakthrough in the slash and burn farming system: the normal sequence required between 15-20 years of natural fallow versus 2 years of planted fallow.

The bottleneck in planted fallows is actually the establishment and management and the costs involved. We investigated some of those determinants: tree density, tree establishment, residue management and farmers' responsiveness. We showed that in *Inga* fallows tree planting density could be reduced from 10,000 to 5,000 trees per ha, without affecting the crop yields. The success of planted fallow also depends on good establishment of *Inga edulis* in the cropping system. *Inga* has a slow initial growth and thus a high vulnerability to weeds at early stages. We found that planting *Inga edulis* in a relay system with the last crop before the fallow period, is beneficial for fallow establishment. Then if the establishment cost can be reduced, planted fallow can raise the productive levels of degraded soil for subsequent crops, thus improving the profitability of improved fallow (Franzel 1999). The key objective of involving farmers in the process of technology development was to bridge the gap between the on-station research results and farmers' reality. This approach increased both the relevance and the acceptability of the research findings, which are necessary conditions for successful technology transfer (Muschler and Bonnemann, 1997). Continuous on-farm evaluation and iterative modifications to suit farmers' needs and competence has resulted in a rotational tree fallow that now fits into the local cropping system and has higher adoption potential then before. The spread of the tree fallows is mainly due to efforts of NGOs, community-organized self-help groups and extension services, which are closer to farmer reality (Place and Dewees, 1999). Subsequent research on agroforestry systems should take into account this experience and involve farmers fully from the beginning in order to capture farmers' reactions and modifications to the innovation.

The scale of adoption of planted fallows is in the order of tens or hundreds of thousands of farmers in the world; the challenge is how to scale these numbers to millions of farmers (Sanchez, 1999).

Concluding remarks

The estimated nutrient balance for the humid zone of Cameroon for the year 2000 was –21 kg N, -2 kg P and –13 kg K $ha^{-1}.yr^{-1}$ (Stoorvogel and Smaling, 1990). The humid zone of Cameroon includes the humid savanna and the humid forest zone. Our study focused on the humid forest zone and yielded: -73 kg N, -3 kg P and –23 kg K $ha^{-1}.yr^{-1}$. We obtained a six times higher N deficit, similar P balance and higher K deficit. The main differences for the N balance is due to the excessive N loss through burning and leaching (total of 74 kg $ha^{-1}.yr^{-1}$). In the humid savanna, burning is not often used. Fallow residues are generally incorporated in ridges during land preparation (SAVING system), while in the forest zone farmers practice the zero-tillage system, and burning is compulsory. Major outflows of K are through harvested products, losses from burning, and losses in non recycled kitchen refuse.

For harvested products, the most depleting system for K is *afup*, 61 kg of K in harvested products from which 40 kg.ha^{-1} are used for household consumption. This is an internal recycling rather than loss. The highest quantity of nutrients exported in harvested products are from *afup*: 55 kg N, 15 kg P and 61 kg K ha^{-1}.yr^{-1}, and the highest nutrient loss is also expected from this system, because of complete burning and field cleaning during land preparation.

Stoorvogel and Smaling (1990) used the rainfall regime as a basis for land uses classes, but our study shows that very different subsystems coexist within the land use classes, more related to vegetation, farming practices and population density; such internal factors should be considered when estimating nutrient budgets at a higher scale.

The complete removal of vegetation and residues from the soil surface in *afup*, is contrasting with the nutrient stocks investigated in the slash-and-burn chronosequence. In *afup*, only the soil C and nutrient stocks are available. Therefore comparing forest and *afup* brings differences of close to 199 Mg C ha-1, which is the C stock found in the forest vegetation. In our case few trees were maintained, probably because farmers were unabe to fell them, and the difference between the richest and the poorest systems in terms of C stocks was 150 Mg ha^{-1}. The soil pool was stable and minor differences were observed between the different land uses. For the N pool, the vegetation pool decreased from 3 Mg to 1 Mg between forest and *afup*, and the soil pool increased whenever there was burning (*essep* and *afup*). The most degraded system in the chronosequence was the *afup*, because of the complete removal of vegetation and residue, and complete burning. Unfortunately, cropping systems in the forest cannot be envisaged without *afup,* it is the main crop field on which the household survives, and only surpluses are sold.

Burning appeared to be the most determinant factor in nutrient balance, far more than nutrient SAVING, or nutrient ADDING approaches. In our study, it induced losses of 48 kg N, 1.8 Kg P and 14 kg K ha^{-1}.yr^{-1}, added to the indirect effects of nutrient leaching. Additionally, burning suppressed earthworm density and casting activity for close to 2 years. Burning however increased soil N stock, and proved to be an important tool in residue management in planted fallow, as well as in traditional land uses. In the acid soils, with soil nutrient available only in the top layers, the incorporation of residue cannot be envisaged, because of high toxicity in deeper soil layers, and the many tree root in the top fertile soil layer. Also mulching in *afup* is not realistic, burning cannot be avoided. We proved from this study that without burning in *essep*, the *ngon* yield was 3 times less compared to burned plots. In traditional farming systems, burning is a must. The challenge is to reduce the burning hazards, at time and space scales.

At the time scale, this study proved that if *Inga* is introduced in the fallow system, the earthworm casting activity, and therefore biological processes would start faster than in the natural fallow, and within 2 years an *Inga* fallow can produce 60 Mg.ha^{-1} of biomass compared to 16 Mg ha^{-1} in *Chromolaena* fallow. The system resilience, that is the time needed for the system to come back to its initial stage after disturbance, therefore, shifted from 15-20 years in the natural system, to 2-3 years in planted fallows.

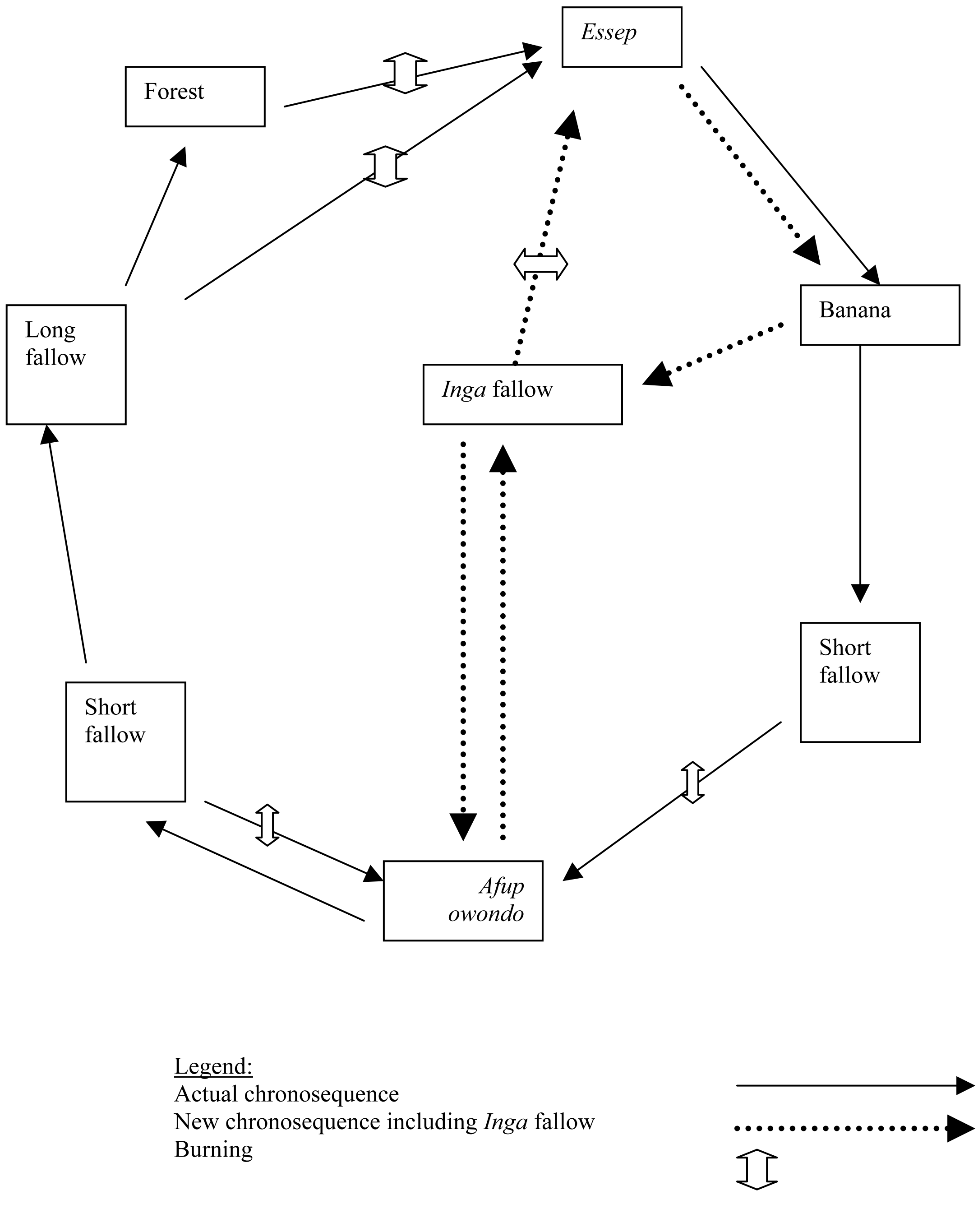
At the space scale, planted fallows yielded 3 times more crops than natural fallow. With the adoption of planted fallow, only one-third of the actual crop fields would be necessary, for the same crop production. And if planted fallows are converted to *essep* for the same yield, the C stocks saved will be 140 Mg ha^{-1} (difference between forest and short fallow). Sanchez (2000) in addressing the issue of C sequestration, rightly said that improved/planted fallows in the tropics are key components of many sustainable farming systems: they are components whose time has come.

The banana land use was a very contrasting issue, compared to other land uses. It had the lowest standing biomass and, therefore, the lowest nutrient stocks in the vegetation. Nutrient exports in crops from banana were 10 kg N, 1.7 kg P and 40 kg K $ha^{-1}.yr^{-1}$. Considering that there is no burning when converting *essep* to banana, and that K from the initial burning was exhausted during the *essep*, availability of K would seriously limit crop production in banana. The sustainability of banana production in the area will depend on how efficiently farmers can add K to the system. We found that kitchen refuse contained 17 $kg.ha^{-1}$ of K not recycled, and we found 60 times more K in earthworm casts than in topsoil in banana. Therefore, a rational recycling of kitchen refuse, and a strategic improvement of earthworm casting activity in banana is of high priority.

This study was an in-depth investigation of the causes of land degradation in the slash and burn agriculture, including farming practices and environmental factors, based on innovative methodology in quantifying the impact of the different farming practices on nutrient stocks and flows, and a systematic approach to involve farmer participation in alternative technology development. The study shows that *Inga* planted fallow has great potential to reduce deforestation and increase crop production and the quality of the environment. Planted fallows create a short cut (banana-*Inga* fallow-*essep*-banana, Figure 1), modifying the slash-and-burn chronosequence. The conversion of planted fallows to *essep* and *afup* will considerably reduce the rate of deforestation and carbon loss to the atmosphere.

The south Cameroon, where the study was conducted, has been identified as the benchmark area of the humid forest of Central and West Africa for developing alternatives to slash-and-burn agriculture. This study has adapted the methodology of nutrient monitoring to specific realities of the humid forest zone, and can be scaled up to cover tropical humid forest zones with similar biophysical and socio-economic characteristics.

Figure 1. Planted fallow in the slash-and burn chronosequence.



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SUMMARY

Problems with agriculture in humid forest zones
Forest clearing associated with slash-and-burn agriculture is a common practice among smallholder farmers. Burning is an essential part of their agricultural system; it improves access to sowing by eliminating large amounts of valuable biomass of slashed vegetation and felled trees. Crop yields are improved by higher soil fertility resulting from ash. Soils of the humid forest zone are very old, leached and inherently infertile. They are mostly Oxisols and Ultisols, characterized by low-activity clays, low pH (between 3.5 and 5), high P retention and an Al saturation of at least 40% in the top 15 cm.

Burning causes a short-lived increase in pH and availability of nutrients from the ash, and it reduces infestation by weeds, pest and diseases. These are generally short-term advantages, as soil exposure after slash-and-burn results in rapid soil degradation and rapid nutrient loss, attributed to volatilization of N, leaching of N and cations and soil erosion (Nye and Greenland, 1964). Key disadvantages to burning also include increased CO_2 emission with adverse effects on global climate change. Slash-and-burn agriculture is usually characterized by low crop yields and a short cropping phase of 2 to 3 years followed by a long restorative fallow of 15-20 years due to low pH, soil nutrient decline and management constraints.

Farmers' perception of land degradation
Farmers perceived land degradation as a complex of interacting constraints, resulting in low crop yields. They attributed up to 44% of their crop yield decline to soil related factors, while 56% was attributed to diseases and weed infestation. Farmers decide on the land uses, crop associations, and soil fertility management based on how crucial these production constraints are in affecting the crop yields. The indigenous knowledge of farmers for composting, collection and redistribution of animal dejections, and kitchen residue is not rooted, compared to areas with high population density and intensive agriculture. Farmers use a diversity of techniques for soil fertility management, many of which fit well in local conditions, and can lead to conservation and regeneration of the natural resource base, but not all are effective. Therefore, modifications and adaptations are necessary. They relied mostly on burning and fallowing for soil regeneration, and to eliminate weeds and diseases.

Measurement of aboveground and below-ground nutrient stocks
This study proved that the major factor responsible for yield decline is the rapid depletion of C and nutrient stocks in the chronosequence. High C stock occurred in the forest vegetation, 199 $Mg.ha^{-1}$, characteristic of the humid forest of West and Central Africa, and Malaysian rainforest. Standing biomass, carbon and nutrient stocks in the vegetation fractions were heavily affected by land use changes, and decreased sharply upon conversion of the forest to cropland. From the original C stock in the forest**,** 48% was lost after conversion of forest to *essep*, and another 20% the following year. Nutrient stocks followed the same trend, but the short *Chromolaena* fallow recovered most of the P. Soil carbon stock was not heavily affected by land use change; there was even an increase in C after burning. Burning also increased P, K, Ca and Mg available stocks in *essep* and *afup*, but thereafter the P and K fell to extremely low levels, suggesting important nutrient export through crop harvest, and/or excessive leaching after burning.

In the cocoa system shade trees alone maintained 53% C of the initial forest system compared to 20% in *afup owondo*. The many trees present in the system provide permanent soil coverage, recycling of nutrients and deep capture of nutrients thereby contributing to system sustainability. The diversity of tree species preserved and/or planted by farmers in this system indicates that cocoa systems favour biodiversity conservation compared to other land uses. The rapid decline in C and nutrient stocks after conversion of forest to crop field implies that for land use sustainability, an efficient management of nutrient stocks and flows is required. Land users should be able to improve the nutrient inflows and reduce nutrient losses.

Nutrient balances

In our case study, no attempt was made by farmers to add nutrients in the systems: nutrient input from mineral, inorganic amendments, and animal feed, was nil. Farmers also were not involved in the removal and redistribution of residues. Nutrients reaching the garbage heap (1.9 kg N, 2.79 kg P and 18.84 kg K $ha^{-1}.yr^{-1}$), animal manure (4.9 kg N, 0.4 kg P and 1.6 kg K), and human faeces (4 kg N, 0.64 kg P and 4.8 kg K $ha^{-1}.yr^{-1}$) were not recycled. Farmers rather cashed in on nutrient reserves through slash and burn, but the direct consequence was the high nutrient depletion in the slash and burn agriculture. The partial budget of farmer-managed nutrients resulted in a negative nutrient balance: -67.8 kg N, -5.6 kg P and – 32.1 kg K $ha^{-1}.yr^{-1}$.

The nutrient balance at the farm level also was negative: -73 kg N, -3 kg P and –23 kg K $ha^{-1}.yr^{-1}$. The high N deficit was mostly due to losses during burning, and K deficit from burning and non-recycled residues, both related to farming practices. The partial budget of the different nutrient inputs and outputs in the different land uses indicated a positive budget for the cocoa plantation, where fire is not used, and many trees in the system recycle nutrients, preventing them from leaching. Major losses occurred in *afup* and *essep*, and were attributed to burning and the subsequent nutrient leaching. Management options proposed in this study to route nutrients for highest agronomic efficiency and redress the balance would include: recycling of household residues and animal manure, and at the same time minimizing the land area under *essep* and *afup*. A completely positive nutrient balance can be expected if burning is avoided. To compensate for the N deficit, the introduction of N-fixing trees in cropping systems appears to be a viable alternative.

Two components of nutrient management strategies are investigated in some details in this study: the potentials of biological processes such as nutrient recycling through earthworm casting activity, and the potentials of planted fallows.

Nutrient recycling through earthworm casting activities

The systems under study had low earthworm density in the land uses, probably because of high soil acidity. The highest density was 118 (± 28) m^{-2} in the short fallow. Earthworm densities decreased between 64% and 95% whenever fire was used during land preparation, and thereafter intensive casting was suppressed in land use systems following *afup owondo* and *essep* by 14 and 19 months, respectively. Planted fallow proved to favour high earthworm density, and intensive earthworm casting activities, similar to the natural forest.

Earthworms enriched their casts compared to the underlying soil, which is attributed to the preferential feeding of earthworms, allowing them to produce higher quality casts on poor soil. However, the quantity of nutrients recycled and, therefore, the contribution of earthworm casts to soil fertility improvement remained low, because of low quantity of cast produced. It is envisaged from this study that improved fallow with *Inga edulis* is likely to improve earthworm casting activity and nutrient recycling, more so than in traditional systems. The quantity of organic residues on the topsoil, the soil organic matter and mulching instead of burning, all should be considered when designing alternative land use management.

Inga planted fallow and natural fallow
Inga edulis can produce more total biomass, accumulate more nutrients, improve the soil biological processes, and produce higher crop yields compared to the natural fallows. It is a way for *in-situ* accumulation of high quantities of N for cycling to subsequent crops. Residue management, quality and quantity of biomass applied to the soil had a considerable impact on soil quality and resilience, organic productivity, and greenhouse gas emissions.

Harvesting of planted fallow by-products such as fruits and fuel wood, will lead to considerable nutrient export. But rational residue management led to 3 to 5 times more crop yields in planted fallows than in natural grass fallow. The potential conversion of *Inga* fallows to *essep* is a breakthrough in the slash and burn farming system. However, costs related to establishment and management of trees can be a limitation to planted fallow adoption.

We investigated tree density, tree establishment, residue management and farmers' responsiveness to *Inga* planted fallows. Tree density can be reduced from 10,000 to 5,000 plants per ha, without affecting the crop yields. For a good establishment of *Inga edulis* in the cropping system, it should be established in relay intercropping with food crops, to benefit from weeding of the food crops. Farmers were involved in the initial stages of planted fallow technology development. Three types of on-farm trials were established from fully researcher-controlled to fully farmer-controlled, which helped to capture farmers' reactions and modifications to the innovation. The approach also helped to bridge the gap between the on-station research results and farmers' reality. This approach increased both the relevance and the acceptability of the research findings, Continuous on-farm evaluation and iterative modifications to suit farmers' needs and competence has resulted in a rotational tree fallow that now fits into the local cropping system and has higher adoption potential than before. The spread of the tree fallows is mainly due to efforts of NGOs, community-organized self-help groups and extension services, which are closer to farmer reality (Place and Dewees, 1999).

Concluding remarks

This study is an in-depth investigation of the causes of land degradation in the slash and burn agriculture, including farming practices' and environmental factors. It uses innovative methodology in quantifying the impact of the different farming practices on nutrient stocks and flows, and to involve farmer participation in alternative technology development. The study proved that *Inga* planted fallow has great potential to reduce deforestation and increase crop production and the quality of the environment.

SAMENVATTING

Landbouwkundige problemen in tropische boszones

Kleinschalige landbouw in tropische boszones wordt gekenmerkt door de kap van stukken natuurlijk bos en de hieraan gerelateerde zwerflandbouw. Branden is een essentieel onderdeel van dit systeem en onder anderen noodzakelijk om toegang tot het te gebruiken veld te krijgen. Verbranding voert grote hoeveelheden van de gekapte bladeren, takken en stammen af. Gewassen profiteren van een bodemvruchtbaarheid die tijdelijk verhoogd is dankzij de assen die achterblijven na het branden. Dit is essentieel aangezien bodems in tropische bosgebieden doorgaans zeer oud en onvruchtbaar zijn als gevolg van langdurige verwering en uitspoeling. Ze worden geclassificeerd als Oxisolen en Ultisolen die gekenmerkt worden door een dominantie van kaolinitische kleimineralen en sesqui-oxiden, een lage pH (tussen 3,5 en 5), hoge fosfaatretentie en een aluminiumverzadiging van minstens 40 procent in de bovenste 15 cm van het profiel. Naast het verhogen van de vruchtbaarheid veroorzaakt branden een verhoging van de pH en brengt het schade als gevolg van onkruiden, ziektes en plagen terug. Het betreft echter in het algemeen korte termijn voordelen, aangezien de bodem na het kappen en branden niet langer wordt beschermd door vegetatie en grote bodemvruchtbaarheidverliezen optreden als gevolg van uitspoeling, vervluchtiging en erosie (Nye and Greenland, 1964). Een bijkomend belangrijk nadeel van branden is bovendien de forse uitstoot van CO_2 waarmee een negatieve bijdrage wordt geleverd aan het broeikaseffect. Zwerflandbouw wordt doorgaans gekenmerkt door lage gewasopbrengsten en een korte periode van ingebruikname van land (2-3 jaar), gevolgd door een lange, noodzakelijke periode van braak (15-20 jaar).

Deze studie laat zien hoe boeren in zuidwest Kameroen zwerflandbouw bedrijven. Er blijkt een bepaalde volgorde in het landgebruik in de tijd te worden aangehouden. Na een vluchtige brandfase wordt het veld, nog vol met boomstammen en andere resten vegetatie, onder komkommer (*essep*) gebracht en vervolgens onder banaan. Een korte braakperiode is dan nodig, waarna een tweede, completere brand plaatsvindt. Het veld is dan geheel toegankelijk en wordt hoofdzakelijk benut voor cassave en pinda (*afup*). Hier ligt het zwaartepunt van de productie van voedselgewassen. Daarna is de uitputting zo sterk dat een lange braakperiode essentieel is. Een deel van de velden wordt benut voor de cacaoteelt. Hier staat nog een aanzienlijk deel van de oorspronkelijke bosvegetatie overeind, die de voor cacao noodzakelijke schaduw levert. De verschillende systeemcomponenten zijn vergeleken op basis van hun rijkdom aan koolstof, nutriënten en bodemleven, alsmede de afname of toename hiervan in de tijd. Verder is bekeken of door verbetering van de braakvegetatie het landbouwsysteem als geheel productiever en duurzamer gemaakt kan worden, waarmee de snelheid van kap van het natuurlijk bos zou kunnen worden afgeremd.

Hoe kijken boeren tegen landdegradatie aan?

Boeren vatten landdegradatie op als het resultaat van een complex van factoren die tot lage gewasopbrengsten leiden. In het studiegebied in zuidwest Kameroen wordt afname van gewasopbrengsten voor 44% toegeschreven aan bodemdegradatie en voor 56% aan ziektes en onkruiden. De mate waarin een limiterende factor een rol speelt of lijkt te spelen, weegt zwaar mee bij de bedrijfsbeslissingen van de boer. Kennis van de boer omtrent zaken als compostering, hergebruik van organisch afval waaronder dierlijke mest en huishoudafval is in deze regio niet wijd verbreid, in tegenstelling tot gebieden waar de bevolkingsdruk hoog is en de landbouw intensiever. Op het gebied van herstel van bodemvruchtbaarheid hanteren boeren technieken, die grotendeels zijn gebaseerd op braaklegging. Omdat die noodzakelijkerwijs lang van duur zijn en leiden tot hernieuwde boskap zijn verbeteringen en aanpassingen op dit terrein wenselijk en noodzakelijk.

Systeemrijkdom: koolstof en nutriënten in bodem en vegetatie

De studie laat zien dat door de verschillende landgebruiktypen heen de koolstof- en nutriëntenvoorraad achteruit gaat. In het bos werd een koolstofvoorraad in de vegetatie gemeten van 199 ton/ha, die goed overeenkomt met gemeten waarden voor tropische bos elders in West- en Centraal Afrika en in Maleisië. De eerste fase van branden en kappen naar *essep* leverde een verlies op van 48% en tijdens de daaropvolgende fase naar banaan ging nog 20% van de oorspronkelijke C voorraad verloren. De stikstofvoorraad vertoonde dezelfde trend, al was er een aanzienlijke overdracht van N van vegetatie naar bodem na de beide brandperiodes. De korte braak na de banaan, gedomineerd door *Chromolaena,* wist veel P in de vegetatie vast te leggen.

In de bodem waren de veranderingen minder groot en de beschikbaarheid van de meeste nutriënten ging omhoog als gevolg van branden. Na een periode van gewasteelt zakten met name de gehaltes aan beschikbaar P en K scherp als gevolg van gewasonttrekking, uitspoeling en retentie.

In de cacaovelden was dankzij de vele schaduwbomen nog 53% van het koolstofgehalte van het oorspronkelijke bos aanwezig, een scherp contrast met de 20% in de *afup.* De schaduwbomen bieden een permanente bodembedekking en houden nutriënten die anders zouden uitspoelen met hun wortelstelsel binnen het systeem. De soortenrijkdom die hier wordt aangetroffen geeft aan dat cacao een functie vervult in het handhaven van een zekere mate van biodiversiteit. De forse achteruitgang in met name C en ook in nutriëntenvoorraden door de landgebruiksequentie duidt op niet-duurzame landbouw en vraagt om andere, verbeterde vormen van bodemvruchtbaarheidbeheer. Boeren zullen nutriënten moeten toevoegen of op zijn minst de afvoer van nutriënten moeten afremmen.

Nutriëntenbalansen

In de Zuid-Kameroenese situatie is toevoeging van nutriënten van buitenaf niet gebruikelijk, zeker na het inzakken van de cacaoprijs. Behalve kunstmest worden ook geen voeders of andere materialen (ruwe fosfaten, kalk, compost) aangekocht die direct of indirect bijdragen aan de nutriëntenvoorraad van het landbouwsysteem. Daarnaast vindt niet of nauwelijks recycling van gewasresten en andere organische residuen plaats. Nutriënten in het huishoudafval (1.9 kg N, 2.8 kg P, 18.8 kg K per hectare per jaar), in dierlijke mest (4.9 kg N, 0.4 kg P, 1.6 kg K) en die van de mens (4.0 kg N, 0.6 kg P, 4.8 kg K) vinden niet hun weg terug naar het productieve systeem. De bedrijfsstijl is gericht op exploitatie van bestaande reserves via kappen en branden, leidend tot negatieve nutriëntenbalansen gedurende de landgebruiktypen waarbij een gewas wordt geteeld. Voor die processen waarop de boer invloed kan uitoefenen was de balans –67.8 kg N, -5.6 kg P and –32.1 kg K per hectare per jaar en de totale nutriëntenbalans –73.0 kg N, -3 kg P en –23 kg K. De sterk negatieve waarde voor stikstof werd grotendeels veroorzaakt door verliezen als gevolg van branden, die voor kalium door branden en het niet recyclen van gewasresten, beiden een gevolg van de bedrijfsstrategie. Met name de *essep* en *afup,* vormen van landgebruik die direct volgen op het branden kenden sterk negatieve N en K balansen. De cacaovelden daarentegen vertoonden een positieve nutriëntenbalans. Hier wordt niet gebrand en staan veel schaduwbomen die verliezen als gevolg van uitspoeling reduceren en die nutriënten uit diepere bodemlagen, waar de cacaoplant niet bij kan, oppompen. Suggesties die voortvloeien uit de metingen en berekeningen van de balansen en die een hogere productie per eenheid nutriënt kunnen bewerkstelligen liggen op het gebied van het recyclen van bovengenoemde en thans niet hergebruikte organische residuen, het reduceren van het areaal onder *essep* en *afup,* en het inzetten van stikstofbindende soorten. Wanneer niet gebrand zou worden (een theoretische optie) kan de nutriëntenbalans zelfs positief worden.

Twee aspecten van verbeterd nutriëntenmanagement zijn verder uitgewerkt in deze studie: het kennen en benutten van het biologisch potentieel van het systeem via de activiteit en veerkracht van regenwormen en de mogelijkheden via verbeterde braak, door middel van aanplant van *Inga edulis.*

Recycling van nutriënten via de activiteit van regenwormen

De gemiddelde regenwormdichtheid in het bestudeerde systeem was vrij laag, waarschijnlijk als gevolg van de lage pH. De hoogste dichtheid was 118 per m2 in de korte braakperiode. De dichtheid in de landgebruikstypen die voorafgegaan waren door brand (*essep* en *afup*) lagen 64-95% lager en het duurde 14-19 maanden voordat de regenwormpopulatie zich had hersteld. Aangeplante braak (*Inga edulis*) veroorzaakte een hoge regenwormactiviteit, vergelijkbaar met die onder natuurlijk bos.

Regenwormen verrijkten hun excrementen in vergelijking met de omringende bodem, hetgeen toe te schrijven was aan de selectieve consumptie van voedsel. Toch was de hoeveelheid op deze wijze gerecyclede nutriënten en daarmee de invloed van regenwormen op verbetering van de bodemvruchtbaarheid laag. De aanplant van *Inga edulis* en de daarmee samenhangende verhoogde activiteit van regenwormen was daarentegen gunstig en onderscheidde zich positief van het traditionele systeem.

Aangeplante braak versus natuurlijke braak

De studie openbaarde dat de aangeplante braak (*Inga edulis*) meer biomassa produceert, meer nutriënten vastlegt, de bodembiologische status sterker verbetert en hogere gewasopbrengsten geeft na terugsnoei dan natuurlijke braak. Het beheer van snoeisel en bladval en de kwaliteit en kwantiteit van deze biomassa had een aanzienlijke impact op de bodemkwaliteit, de veerkracht van het systeem, de productiviteit en het beheersen van CO_2-emissies.

Van *Inga* kunnen hout en vruchten worden geoogst. Weliswaar betekent dit nutriëntenexport, maar ook inkomen. Verder waren opbrengsten van maïs en komkommer (het voornaamste product van *essep*) 3 tot 5 maal hoger tussen teruggesnoeide *Inga* dan na de natuurlijke braakvegetatie. *Inga* zou daarmee natuurlijk bos kunnen vervangen als landgebruiktype dat voorafgaat aan *essep.* Dit kan een belangrijke doorbraak zijn in het terugdringen van de boskap, hoewel de kosten en arbeidsinput die gepaard gaan met het installeren en onderhouden van *Inga* in eerste instantie beperkend kunnen zijn.

Tijdens het experiment werden boomdichtheid, groeisnelheid, en snoeisel- en bladvalmanagement onder de loep genomen, alsmede de bereidheid van boeren om *Inga* in hun bedrijfsplan op te nemen. Het bleek dat een dichtheid van 10000 planten per hectare geen voordelen bood ten opzichte van 5000 planten. Het samenspel met gewassen is van het type 'relay-intercropping', waarbij *Inga* en gewas door elkaar staan, maar waarbij de handelingen aan de twee typen planten elkaar opvolgen en versterken (snoeien, wieden, mulchen, kort branden).

De experimenten werden zowel op het onderzoekstation als op boerenvelden uitgevoerd, waarbij door boeren gesuggereerde wijzigingen in het rigide patroon van het moederexperiment hebben geleid tot aanpassingen die het systeem voor boeren aantrekkelijker en realistischer maken. Het verspreiden van de aangepaste technologie is geschied via niet-gouvernementele organisaties, zelfhulp-boerenorganisaties en voorlichtingsdiensten.

Slotopmerkingen

Deze studie omvat een diepgaande analyse van de oorzaken van landdegradatie in het zwerflandbouwsysteem in zuidwest Kameroen, met speciale aandacht voor de gangbare boerenpraktijk en milieufactoren. Er is gebruik gemaakt van meerdere methodologische invalshoeken gericht op het kwantificeren van de impact van bedrijfsstrategieën op nutriëntenvoorraden en –stromen en het (met boeren) ontwikkelen van geschikte alternatieve, meer duurzame technologieën. De studie laat zien dat een aangeplante braak, gedomineerd door de soort *Inga edulis,* aanzienlijke mogelijkheden in zich bergt om ontbossing terug te brengen zonder dat de boer offers moet brengen op het gebied van de noodzakelijke productie van voedsel en andere goederen die inkomen verschaffen, zoals cacao en nuttige producten van *Inga*. Ten slotte wordt in het voorgestelde systeem de biologische bodemkwaliteit gegarandeerd en is er een netto reductie van CO_2 uitstoot ten opzichte van het traditionele systeem.

RESUME

Problèmes liés à l'agriculture en zone de forêt humide
L'agriculture itinérante sur brûlis est la principale méthode de production pour les petits paysans en zone de forêt dense humide. Elle consiste à défricher une parcelle de forêt en abattant la majorité des arbres, et à détruire l'importante biomasse qui en résulte par le feu, avant les semis. Le brûlis est l'élément principal de ce système de production. Il facilite les semis en réduisant la biomasse végétale défrichée, et les cendres qui en résultent permettent des rendements élevés à la mise en culture. La zone de forêt humide est dominée par des sols vieux, lessivés et infertiles. Ce sont en général des Oxisols et Ultisols, caractérisés par la présence d'argiles peu gonflant, un pH très faible (entre 3.5 et 5), une forte rétention de P, et un taux de saturation en Al d'environ 40% dans les 15 premiers centimètres.

Les centres issues du brûlis permettent une élévation du pH et augmentent la disponibilité d'éléments nutritifs du sol pendant une courte période; le brûlis permet également de réduire l'infestation des mauvaises herbes et des maladies. Ces avantages sont cependant à court terme, car l'exposition du sol après le brûlis accélère les processus de dégradation du sol, et la perte d'éléments nutritifs, à travers la volatilisation et le lessivage de l'azote, le lessivage des cations, et l'érosion du sol (Nye et Greenland, 1964). Les inconvénients majeurs du brûlis incluent également l'augmentation des émissions de CO_2, et leurs effets sur les changements climatiques. L'agriculture sur brûlis est en général caractérisée par de faibles rendements, une courte période de culture de 2 à 3 ans suivie par des longues jachères de 15 à 20 ans, ceci à cause du faible pH, de la perte rapide d'éléments nutritifs, et des contraintes de gestion.

Perceptions paysannes de la dégradation des sols
Les paysans perçoivent la dégradation des sols comme l'interaction d'un ensemble de contraintes, résultant à la baisse des rendements de cultures. Ils attribuent 44% des baisses de rendements aux facteurs liés au sol, et 56% aux maladies et à l'invasion de mauvaises herbes. Les formes de gestion des terres, les associations de cultures, et les techniques d'amendement des sols telles que pratiquées par les paysans, dépendent du degré d'adversité de ces différentes contraintes. Les pratiques indigènes de compostage, de collecte et de redistribution des déjections animales et les résidus de cuisine, sont peu connues. Notre zone d'étude diffère significativement des zones à forte densité de population, et où se pratique une agriculture intensive. Les paysans utilisent diverses techniques d'amendement des sols, adaptées aux conditions locales et pouvant permettre de reconstituer ou conserver les ressources en sol. Seulement ces techniques ne sont pas toutes efficaces, des modifications et adaptations sont nécessaires. Le brûlis et la jachère sont les techniques majeures de régénération des sols, d'élimination des maladies et de mauvaises herbes.

Estimation des stocks d'éléments nutritifs
Cette étude montre que le principal facteur responsable de la perte des rendements, est la détérioration rapide des stocks de C et de nutriments dans la chronosequence d'utilisation des terres. Les stocks élevés de C sont obtenus en forêt, 199 $Mg.ha^{-1}$, caractéristiques des forêts humides d'Afrique centrale et de l'ouest, ainsi que des forêts humides de Malaisie. La biomasse sur pied, les stocks de carbone et de nutriments dans la végétation sont fortement affectés par les changements

d'utilisation des terres, et chutent rapidement après conversion de la forêt en terres agricoles. Du stock initial de C en forêt, 48% sont perdus quand celle-ci est convertie en *essep*, et 20% l'année suivante, quand l'*essep* est convertie en bananeraie. La dégradation des stocks de nutriment suit la même tendance, seules les courtes jachères de *Chromolaena odorata*, sont capables de récupérer l'essentiel de P dans le système. Le stock de carbone du sol n'a pas été fortement affecté par l'utilisation des terres, ces stocks augmentent chaque fois après le brûlis. Le brûlis permet aussi d'augmenter les stocks disponibles de P, K, Ca et Mg dans l'*essep* et l'*afup owondo*. Seulement l'année suivante, les stocks de P et K tombent à des niveaux extrêmement bas, probablement à cause des exportations dans les récoltes, et/ou l'intense lessivage après le brûlis.

Dans les cacaoyères, les arbres d'ombrage à eux seuls ont permis de conserver 53% du carbone de la forêt initiale, contre 20% dans l'*afup owondo*. Ces arbres maintenus dans la cacaoyère permettent une couverture permanente du sol, la séquestration des nutriments dans les horizons de profondeur, et leur recyclage, permettant ainsi la durabilité du système. La diversité d'espèces d'arbres protégés/maintenus par les paysans dans ce système, montre que les cacaoyères favorisent la conservation de la biodiversité, mieux que les autres forme d'utilisation des terres. La dégradation rapide des stocks de carbone et de nutriments après conversion de la forêt en champs agricoles indique que, pour parvenir à un système de production durable, la gestion appropriée des stocks et des transferts de nutriments dans le système est un préalable. Les paysans doivent être capables d'améliorer les apports de nutriments dans le système, et en même temps, en réduire les pertes.

Budget des nutriments dans les systèmes de production

Dans notre site d'étude, aucun paysan n'apporte de nutriments dans le système ; ainsi les apports à travers les engrais minéraux, fertilisants organiques, aliments pour animaux, sont nuls. Les paysans ne pratiquent pas non plus la collecte et la redistribution des résidus de cuisine et déjections animales. Les nutriments accumulés dans la poubelle (1.9 kg N, 2.79 kg P et 18.87 kg K ha^{-1}. yr^{-1}), les déjections animales (4.9 kg N, 0.4 kg P et 1.6 kg K), et les déjections humaines (4 kg N, 0.64 kg P et 4.8 kg K $ha^{-1}.yr^{-1}$) ne sont pas recyclés. Les paysans puisent uniquement dans les réserves naturelles à travers le brûlis, et la conséquence directe de cette forme de gestion, est la perte intense de nutriments dans l'agriculture sur brûlis. Le bilan partiel de la gestion des nutriments par le paysan est déficitaire: -67 kg N, -5.6 kg P et –32.1 kg K $ha^{-1}.yr^{-1}$.

Le bilan total des nutriments à l'échelle de l'exploitation est également déficitaire: -73 kg N, -3 kg P et –23 kg K $ha^{-1}.yr^{-1}$. Le fort déficit de N est surtout dû aux pertes pendant le brûlis, et celui de K, dans le brûlis et les résidus non recyclés. Ces pertes dépendent donc des techniques agricoles. De toutes les formes d'utilisation des terres, seules les cocaoyères présentent un bilan positif. Dans ce système, le brûlis n'est pas pratiqué, et la présence d' arbres d'ombrage limite le lessivage. Les pertes les plus importantes s'observent surtout dans l'*essep* et l'*afup owondo*, à cause du brûlis et le lessivage subséquent. Des alternatives de gestion pouvant permettre une productivité optimale tout en corrigeant le déficit budgétaire, proposées dans cette étude sont: le recyclage des résidus de cuisine et des déjections animales, et la réduction des superficies des *essep* et *afup owondo*. Si le brûlis pouvait être complètement supprimé, un bilan positif en résulterait. Le déficit en N pourrait être réduit par l'introduction des légumineuses fixatrices d'azote dans les systèmes de production.

Deux approches stratégiques de gestion des nutriments sont élaborées dans cette étude: le potentiel des processus biologiques tel que le recyclage des nutriments à travers l'activité turriculaires des vers de terre, et le potentiel des jachères améliorées.

Recyclage des nutriments a travers l'activité turriculaire des vers de terre
Les systèmes de production considérés dans cette étude présentaient une faible densité de ver de terre, probablement à cause de la forte acidité du sol. La densité la plus élevée était de 118 (± 28) m^{-2}, obtenue dans les courtes jachères. Cette densité diminuait de 64% à 95% après l'utilisation du feu lors de la préparation des champs. Dans les parcelles d'*afup owondo* et d'*essep*, et les utilisations qui en découlent, l'activité turriculaire intense était inhibée pendant 14 et 19 mois respectivement. Dans les jachères améliorées, la densité des vers de terre ainsi que l'intensité de formation des turricules étaient similaires à la forêt naturelle.

Les turricules des vers de terre étaient plus riches en nutriments comparativement au sol de surface dans les différentes parcelles, ce qui indique une nutrition préférentielle des vers de terre, leur permettant de produire des turricules plus riches que les sols òu ils vivent. Cependant dans cette étude, la quantité des nutriments ainsi recyclés, et par conséquent la contribution des turricules de vers de terre à l'amélioration de la fertilité des sols en zone de forêt humide reste faible, à cause de la faible quantité de turricule produite. De cette étude, il est envisagé que les jachères améliorées de *Inga edulis* peuvent stimuler l'activité turriculaire des vers de terre et le recyclage d'éléments nutritifs mieux que dans les systèmes agricoles traditionnels. La quantité de résidus organiques en surface, le taux de matière organique du sol, et le paillage du sol plutôt que le brûlis devraient être considérés dans les alternatives de gestion de la fertilité des sols.

Amélioration des jachères naturelles par l'introduction de Inga edulis
Les jachères de *Inga edulis* peuvent produire plus de biomasse, accumuler plus de nutriments, améliorer les processus biologiques et permettre des rendements plus élevés comparativement aux jachères naturelles. C'est une méthode d'accumulation *in-situ* de grandes quantités d'azote, qui sont ensuite utilisables par les cultures subséquentes. La gestion des résidus, la quantité et la qualité de biomasse appliquée, déterminent la dynamique de la qualité et du pouvoir tampon des sols, ainsi que l'émission des gaz à effet de serre.

La collecte des produits secondaires des jachères tels les fruits et le bois, contribue à un export important de nutriments hors du système. Cependant une gestion rationnelle des résidus permet d'obtenir des rendements de culture, 3 à 5 fois plus élevés dans les jachères plantées comparativement aux jachères naturelles. La possibilité de conversion des jachères d'*Inga edulis* en *essep*, offre une opportunité unique d'intégration des jachères améliorées dans le système d'agriculture itinérante sur brûlis. Cependant, les coûts de mise en place et de gestion peuvent constituer un frein à l'adoption des jachères plantées en zone de forêt.

Nous avons évalué des paramètres des jachères améliorées tels que: la densité des arbres, le mode d'introduction des arbres dans le système actuel, la gestion des résidus, et la réaction des paysans quant à la technique des jachères améliorées. La densité des arbres pouvait être réduite de 10,000 à 5,000 arbres à l'hectare sans compromettre les rendements des cultures. Pour assurer une bonne introduction de *Inga edulis* dans les systèmes de production, il doit être planté suivant un système de relais avec les cultures vivrières, pour ainsi tirer profit du sarclage des cultures associées. Les paysans ont été associés aux étapes de développement des techniques de jachères plantées. Trois types de recherche en milieu réel ont été adoptés, allant du système complètement contrôlé par le chercheur, au système complètement contrôlée par le paysan. Ceci a permis de capitaliser les réactions et les modifications des paysans face à l'innovation. Cette approche a aussi permis de rapprocher les résultats obtenus en station, des réalités du milieu paysan, et ainsi améliorer l'intérêt et l'acceptabilité des résultats de la recherche. L'évaluation et l'intégration des modifications proposées par les paysans, ont permis de passer de l'agriculture en couloir à la jachère rotative, mieux adaptée au contexte de l'agriculture traditionnelle, et partant, un potentiel d'adoption plus élevé. La collaboration avec les ONGs, les organisations paysannes, et les services de vulgarisation agricole qui sont plus proches des réalités paysannes (Place et Dewees, 1999), a permis d'étendre les techniques de jachères rotatives, à un grand nombre de paysans.

Conclusions

Cette étude est une investigation spécifique des causes de dégradation des sols, dans le système de l'agriculture itinérante sur brûlis, tenant compte des pratiques paysannes et des facteurs environnementaux. Elle se base sur une méthodologie innovatrice pour quantifier l'impact de différentes pratiques agricoles sur les stocks et les transferts de nutriments ; elle implique les paysans dans le développement des stratégies de gestion appropriée. Cette étude a prouvé que les jachères plantées de *Inga edulis*, ont un grand potentiel pour la réduction de la déforestation, l'amélioration des rendements de cultures agricoles et de la qualité de l'environnement.

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CURRICULUM VITAE

Jacques Kanmegne was born in Bayangam, a city in the highlands of western Cameroon, in 1962. From 1969 to 1975, he attended primary school in Bayangam, Bandjoun and Mbouda, and obtained his *CEPE* in 1975. From 1975 to 1983, he attended secondary school at the *Lycée de Mbouda*, where he obtained his *BEPC* (1979), *Probatoire-D* (1982) and *Baccalauréat-D* (1983).

After one year in the Faculty of Sciences, Yaound*é* University, he was admitted in 1984 in the *Ecole Nationale Supérieure Agronomique (ENSA)*, and graduated in 1989 as *Ingénieur des Eaux et Forêts*. He was then staffed in the Ministry of Agriculture, and in 1990, posted at the Institute of Agricultural Research for Development (IRAD), then seconded to the IRAD/ICRAF collaborative agroforestry project, in Yaound*é*, Cameroon. He was in charge of on-farm agroforestry research.

In 1993 - 1995, he was awarded a DGIS-funded fellowship through the then DLO-Institute for Soil Fertility Research at Haren, The Netherlands, for a MSc in soil science at the Rivers State University of Science and Technology, Port Harcourt, Nigeria. Back to the IRAD/ICRAF project in1996, he was in charge of technology transfer, training of trainers, and scaling up of agroforestry technology transfer. Since 1998, he is Research Associate at IRAD.

In 2000, he was awarded a Tropenbos International fellowship for a PhD study at Wageningen University and Research Centre, The Netherlands. This doctoral thesis is the output of research activities conducted in the Campo Ma'an project, in southern Cameroon. After completion of his PhD studies in May, 2004, he will resume his post at IRAD/ICRAF.

Jacques Kanmegne is married to Michelle Solange Medjoda Mbah, and a father of four children.

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