EFFECTS OF LAND CLEARING METHODS ON A TROPICAL FOREST ECOSYSTEM AND THE GROWTH OF *Terminalia ivorensis* (A. Chev.)

by

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DECLARATION

This thesis has been compiled by me from my own research work. Work of and assistance by others is acknowledged. Nothing contained within has been presented for a higher degree.

December, 1989

DEDICATION

To my uncle, Yongbi chiambeng Godfrey.

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ABSTRACT

Three methods of land preparation, (i) partial clearance with hand held tools (Manual Regrowth), (ii) partial clearance with heavy machinery (Mechanical Regrowth) and (iii) total land clearance with heavy machinery (Complete Clearance), were investigated for their effects on soil physical and chemical properties, nutrient dynamics and the survival and growth of *Terminalia ivorensis* in a tropical lowland rainforest at an altitude of 650 m in Cameroon.

The soils of the study site are ultisols, with a sandy to sandy clay surface soil texture. They are highly weathered, acid, with an average topsoil (0-20 cm) pH of 4.3, and poor in nutrients. Total N and P contents of the 0-20 cm topsoil were 0.12% and 0.015% respectively, exchangeable base values were, 0.11 cmol kg^{-1} for K, 0.28 cmol kg^{-1} for Ca, and 0.20 cmol kg^{-1} for Mg. Subsoils (20-40 cm) showed low concentration of nutrient elements but a slightly elevated pH (4.4).

The small litter fraction on the forest floor was estimated at 3.8 t ha^{-1}. Three months after clearance (August, 1987), there were increased litter amounts in the Control (5.23 t ha^{-1}) and Manual Regrowth (5.89 t ha^{-1}) plots, and a reduction in the Mechanical Regrowth (2.70 t ha^{-1}) and Complete Clearance (0.95 t ha^{-1}) plots. Fifteen months later, litter amounts had increased in all the plots. The Manual Regrowth and Mechanical Regrowth plot had increased twofold to 10.6 t ha^{-1} and 5.16 t ha^{-1} respectively, while there was almost a fourfold increase in the Complete Clearance plot (3.14 t ha^{-1}).

The pattern of soil nutrient dynamics (total N, P and exchangeable bases K, Ca, Mg) and pH in the Mechanical Regrowth and Complete Clearance plots showed an initial increase at three months after clearance before dropping one year later. In contrast, the Manual Regrowth plot showed an opposite pattern for exchangeable bases.

Bulk density results showed significant and very significant soil compaction, 1.34 ± 0.19 g cm^{-3} and 1.52 ± 0.08 g cm^{-3} in the Mechanical Regrowth and Complete Clearance plots respectively, as opposed to 1.31 ± 0.06 g cm^{-3} in the Manual Regrowth plot and 1.16 ± 0.07 g cm^{-3} in the Control plot.

Total fine litter-fall over the one year study period was significantly affected by the mechanized methods, Mechanical Regrowth plot 6.93 t ha^{-1} and Complete Clearance plot 1.83 t ha^{-1} as opposed to 9.9 t ha^{-1} for the Manual Regrowth and 12.09 t ha^{-1} for the Control plots. No significant differences were observed in nutrient concentrations of these litters. However, there were significant differences in total nutrient (N, P, K, Ca, Mg) inputs in the Mechanical Regrowth and Complete Clearance plots, 240 kg ha^{-1} yr^{-1} and 63 kg ha^{-1} yr^{-1}, respectively, as against 463 kg ha^{-1} yr^{-1} in the Control and 349 kg ha^{-1} yr^{-1}in the Manual Regrowth plots.

Decomposition of leaf litter was studied using litter bags. Percentage weight remaining after six months was significantly different in the Mechanical Regrowth and Complete Clearance plots, 4% and 21% respectively. *K* values (yr^{-1}) ranged from 3.0 in the Complete Clearance plot to 6.6 in the Mechanical Regrowth plot with similar values of 4.4 and 4.6 recorded in the Control and Manual Regrowth plots respectively. There was a net accumulation of N and P, and decrease in K and Ca concentrations in the leaves over the study period. Ca showed a pattern of decline at the end of the study but its values were high, around levels of original concentration. Nutrient content followed a general pattern of decline similar to that of leaf litter weight loss.

Percentage survival of trees was similar in the Manual Regrowth (90%) and Mechanical Regrowth (89%) plots and low in the Complete Clearance (82%). However, average tree growth after 23 months was, 178 cm in height and 29.1 mm in diameter in the Manual Regrowth plot, 299 cm in height and 47,3 mm in diameter in the Mechanical Regrowth plot and 343 cm in height and 44.1 mm in diameter in the Complete Clearance plot. Other factors being equal, the growth of *Terminalia ivorensis* was favoured by high light conditions.

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CHAPTER ONE

GENERAL INTRODUCTION

1.0 Introduction

Large areas of forest are currently being cleared for development in the tropics principally for agriculture but also for a number of purposes including a relatively small proportion for silviculture (Boerma, 1975; Boer, 1977; Thijsse 1977a, 1977b). It is therefore important that there should be appropriate methods of land clearance and management aimed at conserving the soils as a resource and creating a favourable environment for the establishment of young trees (Cunningham, 1963; Synnott and Kemp, 1976; Sanchez, 1979; Lal and Cummings, 1979; Lal, 1986).

Land clearing in tropical rain-forests involves the modification of complex ecosystems by the partial or complete removal of existing vegetation so that the land may be used for purposes other than management of natural forest. Generally speaking, the issues surrounding tropical land clearance are more complex than corresponding issues in temperate regions. Higher temperatures, which accelerate degradation of soils and high rates of precipitation which are instrumental in removing soil and soil nutrients by leaching and erosion, create potentially unstable environmental conditions. Tropical rainforests are especially vulnerable, for in them the effects of a particular method of clearing can cause greater harm than in the drier forests of the tropics (Ross and Donovan, 1986) or in non-tropical forests. Land clearance, the first step in plantation establishment, can cause irreversible damage to soils and the plant environment when not properly planned. The consequences of natural forest conversion into plantations in the tropics is poorly understood. The complexity of these forests makes land clearing a dramatic ecological event with far-reaching implications on, for example, the soil conditions of the site (Lundgren, 1978).

Ecological studies in tropical rainforests have focused almost entirely on the natural ecosystem. With extensive deforestation and a growing interest in the establishment of forest plantations, it is becoming increasingly important to extend these ecosystem studies into man-made forests.

The lack of ecological research into the dynamics of these forest plantations makes it virtually impossible to make positive recommendations to foresters as to the probable environmental and silvicultural benefits or dangers of establishing plantations using different forms of site preparation (Mason et al. 1989)

The present study, lays the foundation for a long term ecological study, concerning the nature and effects of three land clearing methods used for silviculture in Cameroon . These methods (Manual Regrowth, Mechanical Regrowth and Complete Clearance abbreviated henceforward to Man. Reg., Mech. Reg., and Comp. C. respectively) were believed to have differing effects on soil physical and chemical properties and on the growth of *Terminalia ivorensis,* the major planted tree crop. An understanding of the impact of these different systems was considered at the onset of this research to be very important for the planning of future land clearance and subsequent management of plantations. The general lack of such information and data on silvicultural activities has accounted for many of the mistakes that have been made in the planning of major planting projects (Synnott, 1975).

The extent of the importance can be judged by the attention that plantations have received in tropical forest management in recent years. After briefly appraising the nature of tropical forests, this introduction will serve to review silvicultural activities and their implications with particular reference to plantation establishment. In addition, increasing concern has been shown by conservationists and soil scientists about land clearance since heavy equipment mounted on crawler tracks became available from 1945 onwards.

1.1 Appraisal of tropical rainforests

The world's tropical rainforests (TRFs), considered to lie in a belt centred on the equator and extending 23° north and south to the tropics of Cancer and Capricorn comprise one of the most diversified ecosystems found on earth, perhaps matched in complexity only by the underwater life of some coral reefs (Longman and Jenik, 1987).

The total extent of tropical moist forests, which include both tropical rainforests and tropical moist deciduous forests, is not known accurately, but was recently estimated at 1,081 million hectares over half of which is found in Latin America (Sommer, 1976; Lanly, 1979, 1982; Grainger, 1984). The relative proportions of tropical rainforest and tropical moist deciduous forests were estimated by Persson (1974) at 2:1 and upon this basis the area of tropical rainforests is estimated at between 600 and 700 million hectares (Grainger, 1988).

The importance of TRFs, enhanced by their richness and species diversity, has been extensively reviewed by many authors (such as, Poore, 1976; Myers, 1980, 1983; Evans, 1986; Kwesiga, 1984; Ramdass, 1987). Despite the importance and significant socio-economic contribution of these forests to the peoples of these regions, their rate of deforestation in the last 10-20 years has caused considerable concern (Grainger, 1980, 1983; Myers 1980b). In some countries, loss of forest has gone on steadily for over thousands of years; in others, it is a recent occurrence. But only in the last 150-200 years has net destruction of forest taken place in almost every country, and over the past 10-20 years, the rate of disappearance has increased sharply (Evans, 1986).

The reasons for TRF deforestation are abundant and have been extensively reviewed (Poore, 1976; Myers, 1979, 1980a; Caufield, 1982; Steinlin, 1982; Kwesiga, 1984; Jordan, 1985; Evans, 1986). They can be briefly summarized as:-

i) the pressures exerted by the expanding population of peasant farmers and their practice of shifting agriculture ,

ii) the need of many tropical countries for the capital gained from the export of timber and agricultural products grown in previously forested areas,

iii) logging by multinational corporations and

iv) improved means of access and communication that have opened up inaccessible areas for exploitation and land development.

In response to the great concern about TRF destruction, many suggestions and propositions for better management have been made and several other initiatives taken by both international agencies and local institutions (see the review by Kwesiga, 1984). The most obvious and on-the-spot solutions are those concerned with:-

i) increased research and development of TRF resources,

ii) increased education and public awareness about the importance of TRFs,

iii) development of alternative technologies to reduce demands on tropical products and lands and

iv) an attack on the causes of the pressures upon these forests including unemployment, food and energy deficiencies and uncontrolled population growth.

One solution for the future of TRFs which seems to be rapidly gaining ground is the establishment of artificial forest plantations to relieve pressure on the natural forest by providing timber, fuelwood and other primary products normally obtained from natural forests.

1.2 Plantation forests in the tropics

Interest in plantations in the tropics is increasing rapidly. Table 1 shows that the area of plantations increased almost three times between 1965 and 1980 and that the forecast rate of planting in the 1980s is double that of the 1970s.

Region	1965	1980	1985
Africa	1,423	2,595	3,643
Asia including southern china	4,420	10,323	15,862
Australia + Pacific Islands	70	262	384
Central America + Carribbean	218	510	759
South America	570	4,211	6,901
Estimated area between about 27 °N and S of the equator.	6,701	17,901	27,549

Table 1: Areas of plantations in the tropics by continents in thousands of hectares. (After Evans. 1986).

The reasons for the interest and rapid increase in plantation establishment are reviewed by Evans (1986) and can be summarized as:-

i) Past and continuous destruction of the natural forests,
ii) problems of access to existing forests,
iii) unsatisfactory rates of natural regeneration,
iv) land availability,
v) high productivity of plantations,
vi) plantations as a tool of development and
vii) environmental forestry.

It is naive to assume that all plantation schemes develop only for the above suggested reasons. Large regular plantations are politically impressive, they are clear evidence of development in perhaps otherwise remote areas. In the Amazon for example, 'development' signified changing the forest to more productive land use. A good number of projects have developed more from political motives than for reasons of silviculture (Evans, 1986).

Forest plantations in the tropics will clearly play a very important role in future world wood supply. Moreover, if the rate of afforestation is substantially increased, plantations can begin to relieve the pressure on the dwindling reserves of the natural forest. As recommended by the Eleventh Commonwealth Forestry Conference (1980), production of wood for industrial purposes and for fuel will have to increase in the coming decade and will increasingly rely on plantations and other intensive forestry practices.

1.2.1 Development of plantation forestry

Between 1965 and 1980 the area of forest plantations (mostly with exotic species) in the tropics has trebled. Most countries have undertaken some planting and many more are now committed to large afforestation programmes. Though some countries commenced plantation establishment earlier than others, the recent upsurge in planting has occurred nearly everywhere (Evans, 1986). The expansion in recent years, cannot be viewed in isolation since projects today draw on silvicultural information from scattered trial plots and small plantations established in the past. In addition over the last 30 years, much stimulus has come from the rising of nationhood and independence (economic as well as political) across the developing world. Also this period has seen a new internationalism in world affairs particularly in aid and development such as the United Nations Organization for Food and Agriculture (FAO), the Development Programme (UNDP), and the World Food Programme (UNWFP), the development banks, bilateral aid programmes between poor and rich countries, and direct investment by industrial nations in developing countries. All these moves have shifted the emphasis from exploitative to a more sustained spectrum of management techniques.

1.3 Silviculture in the Tropics

Because most tropical countries were once the colonies of various European powers, their present silvicultural practices have developed along lines similar to European schools of thought and principles, but the application of these principles revealed that they were inapplicable to a large extent and led to silvicultural mistakes (Stracey, 1959), primarily because tropical ecosystems are so complex and little understood. Faced with such a heterogeneous and multi-aged structure, the first reaction of foresters has been to simplify the composition of the forest by reducing the number of species to the most valuable ones. The second reaction was then to convert the forest into as regular a stand as possible for the easier treatment and management which this form permits. It was thought that these actions would simplify the problems of natural regeneration and assure its perpetuation. The silvicultural systems which have been applied to tropical rainforests belong to one of two kinds which are, the *polycyclic* and *monocyclic* systems respectively (Troup, 1952; Dawkins, 1958). A number of the most relevant systems are considered briefly below.

1.3.1 The Selection System

It is a polycyclic system based on the repeated removal of selected trees in a continuing series of felling cycles, whose length is less than the rotation age of the trees. The aim is to remove trees before they begin to stagnate and deteriorate from old age, leaving all appreciated stems to swell the future yield. Because of the very rich nature of most tropical rainforests, and the relatively small numbers of species with timber which is commercial by current standards, extraction on a polycyclic system tends to result in the formation of scattered small gaps in the forest canopy (Whitmore, 1985). This system, called the selection system, because of the selective nature of the felling has had many variants.

In Asia, this form of silviculture in the early days consisted of the removal of commercially valuable trees with little attention to possible stand degradation or regeneration. It was assumed that enough seeds were available on the forest floor for regeneration purposes. In some places, a minimum girth limit was established for exploitation, while in other places a proper selection developed as foresters gained a better perception of their actions on the structure of the forests. Some foresters express satisfaction in the proper selection system, while others have misgivings about the attention paid to the natural regeneration and the effect of increased mechanization

(Rosayro 1954).

In Africa where silvicultural activities started in 1900-1905 in Nigeria and 1925-1980 in other regions, early commercial exploitation was also similar, without much or any concern for the condition and quality of the residual stand. Aubreville (1949) and speakers at the first International Forestry Conference (Anon, 1951) both pointed out the inevitable impoverishment that can result from such a policy, in terms of degradation and loss of species.

1.3.2 The Shelterwood System

The most widely practiced monocyclic system and still in very common use in the tropics is the *shelterwood system.* In contrast to the polycyclic systems, monocyclic systems remove all saleable trees at a single operation, and the length of the cycle is more or less equal to the rotation age of the trees. Except in those cases where there are few saleable trees, damage to the forest is more drastic than under the polycyclic systems, the canopy is more extensively destroyed and bigger gaps are formed. The shelterwood system involves the establishment of young tree crops under the shelter of the old one, before final felling of the main tree crop (Troup, 1952).

In Asia, progressive coupés were introduced as in Europe. This system involved several fellings at intervals of a few years, with poisoning and girdling of unwanted stems. The main crop was harvested when regeneration was 5-10 years old, and after one or more clearing and girdling the area was passed as regenerated. This system had its problems. The first was inadequate amounts of commercial species that were available and secondly, there were technical and economic problems of extraction. But the most crucial problem was with regeneration. The commercial species had great competition with unwanted species, lianas and weeds. To avoid weeding expenses, the canopy was kept more closed to reduce light in the stand. However, because the majority of the valuable species were light demanders, canopy closure affected their growth.

In Africa in 1944, the British foresters introduced a sequence of cutting operations under the title *Tropical shelterwood system (TSS)* (Lancaster, 1961; Lowe, 1978), based on success of similar practice in India and Burma (Catinot, 1965; Lowe, 1978). The system consisted of canopy opening, by poisoning unsaleable trees to promote survival and growth of seedlings of desirable species, and also climbers and herbaceous weeds. The treatments were begun 5 years before exploitation. Originally the felling cycle was fixed at 100 years, and a final crop of 25 fully grown trees per hectare was regarded as acceptable, compared with actual removals at the time of 5 trees per hectare on average. Satisfactory regeneration was regarded as a minimum of 100 well grown seedlings per hectare. The general effect of this method was to increase the amount of regeneration (Donis, 1954; Foggie et al, 1952). Since the trees aimed at in the regeneration process in this case were shade-tolerant, the problems encountered in Asia with the light demanders were absent.

The French on the other hand, who arrived in Ivory Coast later, instituted enrichment planting in lines, bands and blocks, with natural regeneration being applied only in some special areas and forest types (Catinot, 1965). The reason for having to plant was that the forest had very few individuals of the valuable species and not enough seedlings of these species, occurring as natural regeneration. The usual practice was to cut parallel strips 5 metres wide at 20-25 metres apart and seedlings of desired species are planted at spacings of 2-5 metres apart. The problem with these techniques was the fierce competition from strong light demanders and line invasion by lianas which have to be removed constantly - an expensive operation. The system was also introduced on a trial basis in Cameroon.

The shelterwood system was also introduced in tropical America around 1930 for most of the areas where attention was paid to natural regeneration (Fanshawe, 1952). Here as in Africa, no light problem was posed to species as they were shade tolerant. In most of the tropics these systems have been abandoned or modified and new systems have been introduced.

1.3.3 Present Systems

Present silvicultural systems have evolved as a result of some of the problems summarized in section 1.2 above and have developed along different lines relating to specific conditions and structure of the forests, tree species and policies of the country. For example, in Malaya, because of increased mechanization, more species utilization and the necessity to obtain adequate returns, the shelterwood system gave way to the *Malayan Uniform System,* which involves extracting all the marketable species in a single felling (monocyclic system) (Whitmore, 1985). The canopy opening in this case favours the commercial light demanders, but it works well only when there are adequate seedlings and if advance growth is removed. However, with the prospect of exhaustion of the forest resources in Malaya in the mid-1970s, the Malayan Uniform System was incorporated into the *Selective Management System* (Mok, 1977). This involves a pre-felling inventory after which one of three procedures is chosen - thus the term selection. The areas richest in adolescent trees of commercial species are managed on a polycyclic system with an intermediate felling; the areas without these are managed by the Malayan Uniform System; and areas with poor natural regeneration of desired species are to be enriched by planting or replaced by closed 'compensatory' plantations.

In Africa, the TSS has been abandoned in most places and replaced by monoculture plantations of fast growing indigenous and exotic species. However, it is intended that after a complete inventory of the remaining natural TRFs there could be a reintroduction of a modified form of TSS (Ramdass, 1987).

1.3.4 Silvicultural Activities in Cameroon

1.3.4.1 Brief Outline of Development

Silvicultural activities in Cameroon started in the forest Reserves of Ottotomo and Makak in 1930 and 1936 respectively. They have followed a similar trend to that of most of the TRF countries in Africa, as reviewed by Catinot (1965). Many silvicultural techniques have been tried in Cameroon (Catinot, 1965; Mbandji 1985) including:-

a) *Tropical shelterwood system*

This was tried in Mbalmayo but later abandoned because of many problems and difficulties, such as insufficient and irregular plant growth as a result of inadequate light reaching the ground. This poor illumination did not favour growth of light demanders. Perhaps more important, however, was the lack of finance to ensure the expensive weeding and plant maintenance.

b) *Methodes des placeaux*

This method of natural forest enrichment was tried in Kribi (1947) and Bonepoupa (1956) using two species, Okoumé (*Okoumea klaneana)* and Ilomba (*Pycnanthus angolensis*) respectively. An inventory of these forests revealed they contained very few commercial species to enable adequate natural regeneration. Small blocks of 4x4 m were marked out at regular distances of 10 m in these forests. Lianas and herbaceous undergrowth were removed before nursery stock was planted as close together as possible. After the establishment of the plants, shrubs inside the blocks were progressively removed including some understorey trees. The trials were, however, abandoned and no results are available about the outcome of these plantations.

c) *Taungya*

This is an agro-forestry system that was first introduced in Burma in 1956. It is the practice of establishing artificial forest tree plantations using a farmer or paid labour to clear land and plant both annual food crops and forest tree nurse stocks. The farmer is then responsible for the early tending of the forest trees alongside the food crops. This system was introduced in the South West and North West Provinces of Cameroon in early 1958 (Ngeh, 1985) and later in the Littoral and Central Provinces. It is still currently practiced in the latter provinces and the North West Province though on a very small scale.

d) *Methodes des Layons (Line Planting)*

This method recommended by Aubreville and first used in Gabon between 1932 -1949, was extensively used in Cameroon but was abandoned in 1968. Initially, this method consisted of cutting 2 m wide strips at distances of 5 m apart in a N-E direction in the forest. Trees were then planted at distances of 3-5 m within these lines. The initial 5 m interbands were progressively increased to 10 m and then 20-25 m. Also the initial 2 m wide strips were later considered too narrow to allow adequate light to the soil and hence enlarged to 4 m by Catinot and renamed *Methodes des grandes layons*. This method was used mostly for mixed planting trials. Although no longer in use, results of some plantations in Ottotomo, Bonepoupa and Makak forest reserves seem satisfactory (Mbandji, 1985)

1.3.4.2 Present Silvicultural Systems

Currently, silvicultural activities in the rainforest zone of Cameroon are based on two systems, the *Methode reçru* (Manual Regrowth) and the *Mechanical Regrowth* which are infact just methods of partial land clearance. In other parts of West Africa e.g Ivory Coast, complete clearance of the plantation site is done by bulldozer. This method, still under consideration for future use in Cameroon, is investigated in this study.

1.3.4.2.1 Manual Regrowth method (Methode reçru)

This method was first introduced in Cameroon in 1968 - 1969 and declared as the official silvicultural system for regeneration in the rainforest zone in 1973. The method was first introduced in Gabon in 1958 in order to reduce plantation costs on one hand and on the other hand reduce soil baring by heavy machinery in the Methode Okoumé (see below), that favoured land invasion by Musanga (*Musanga cecropioides)* and noxious weeds. Generally this method aims at giving the plants adequate light conditions by the progressive removal of the existing forest cover. The method consists of cutting back the undergrowth with hand tools (matchets and axes) and poisoning the dominant vegetation. Depending on the light requirements of the planted species (shade-tolerant or light demanding) poisoning is done at once or progressively with plant establishment. Basically this method aims at:-

a) protecting the soil by cutting back the undergrowth and small trees (diameters ≤ 30 cm) at 40-50 cm above ground,

b) preventing the possible invasion of *Musanga* and *Eupatorium* through the rapid revegetation of the undergrowth which reduces seed input to the soil and prevents light reaching the soil for their growth,

c) enhancing plant growth by creating ambient conditions (temperature and humidity) similar to those of the natural forest (plate 1). The work procedure can be briefly summarized in five stages as illustrated in figure 1A.

i) Location and demarcation of treatment plots.

ii) Cutting of shrubs, lianas, lower canopy vegetation and small trees. The soil is left undamaged.

iii) Pegging, line opening, digging of holes for planting (pitting) (approximately 30 cm wide and 30 cm deep) and planting.

iv) Poisoning of big trees, alongside weeding and plantation maintenance.

v) Weeding, plantation maintenance and abandonment once the planted trees completely dominate the surrounding vegetation.

Plate 1: Situation of site after clearing using the Manual Regrowth method. The dry forest floor litter, not burned, together with the big trees provide soil protection and is also a source of plant nutrients. Rapid revegetation of the slashed undergrowth create around plants ambient conditions similar to those of the natural forest.

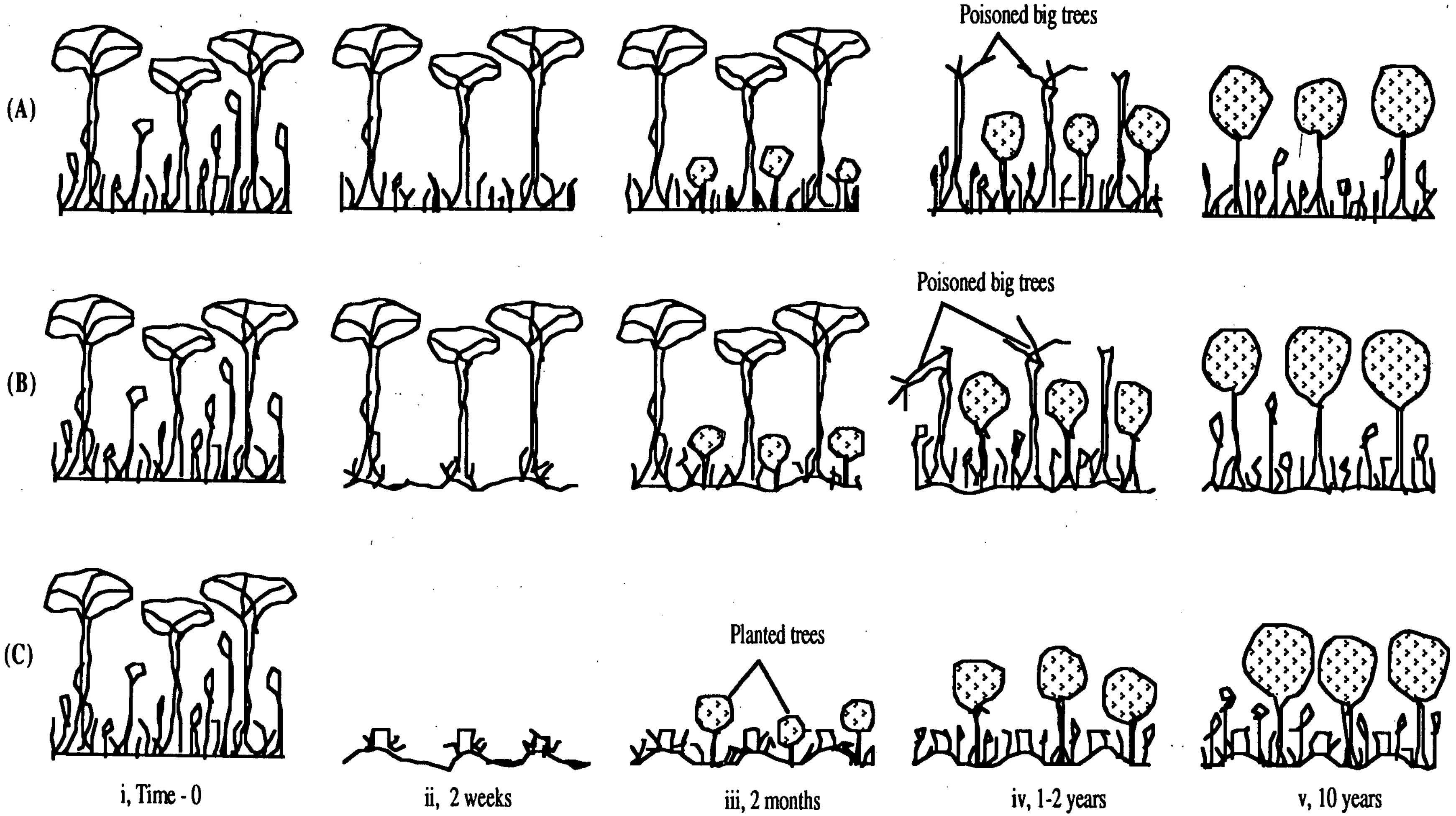

Figure 1: Diagrammatic illustration of the different methods of land clearance. (A), Manual Regrowth, (B), Mechanical Regrowth, (C), Complete Clearance. The desired result in about 10 years is a complete dominance of the surrounding vegetation by the planted Framiré trees, probably with treatment effects evident in their growth.

1.3.4.2.2 Mechanical Regrowth method

The Mechanical Regrowth Method was introduced in the Mbalmayo forest reserve in 1985 as a modification of the Manual Regrowth method. It was designed to accelerate land clearance and had been long used in Gabon for the establishment of Okoumé plantations (Methode Okoumé) but later abandoned in favour of the Manual Regrowth method (Catinot, 1965) for reasons explained above. The main difference in technique with the Manual Regrowth method is that the undergrowth and smaller trees are cleared using a bulldozer (a straight rake D8 bulldozer in Mbalmayo - plate 2) and pushed to form windrows. This results in soil baring (plate 3) and, as was the case in Gabon, land invasion not only by *Musanga* but also *Eupatorium* which is causing some concern and making weeding very expensive even though it is semi-mechanized (using strimmers). This problem of weed invasion raises the question about how much the foresters knew about this method and what solutions were envisaged to counter the problem.

The work procedure is generally very similar to that of the Manual Regrowth method and can be briefly summarized as above in five main stages (Figure 1B).

i) Location and demarcation of treatment plots.

ii) Clearing of undergrowth and small trees and pushing to form windrows using heavy machinery. Big trees are left behind and subsequently poisoned. Soil is left bare with an undulating surface as a result of scraping and deposition.

iii) Pegging, 'pitting', and planting.

iv) Poisoning of big trees, alongside weeding and plantation maintenance.

v) Weeding, plantation maintenance and abandonment once the planted trees completely dominate the surrounding vegetation.

Plate 2: The 23.51 tonnes, D8 straight rake, bulldozer used in the clearance of the Mechanical Regrowth and Complete Clearance plots. Topsoil displacement was mostly by the felled slash and trees being pushed to form windrows.

Plate 3: Site situation after clearing using the Mechanical Regrowth technique. The soils are relatively disturbed, but the big trees offer some soil protection as well as providing it with nutrients. A fairly random distribution of organic litter is left behind. Slighly visible to the right of the picture is the edge of a windrow.

1.3.4.2.3 Complete Clearance method

As mentioned earlier, this method is not yet in use in the rainforest zone of Cameroon but is extensively used in Ivory Coast. However, it is under consideration for future regeneration projects, hence it is important that the implications of the technique are well understood and mastered. This method is identical to the method of conventional bulldozing commonly used in agriculture and consists of the complete removal of the vegetation with heavy machinery enabling the possible mechanization of subsequent silvicultural operations. It has drastic consequences through complete soil baring and compaction and removal of organic litter from the site (very different from previous systems) (plate 4). Land invasion by *Musanga* and *Eupatorium* is more intense as a result of the more complete exposure of the soils.

The work procedure in this method though different in many aspects to the above methods can similarly be summarized in five stages (Figure 1C).

i) Location and demarcation of treatment plots.
ii) Complete vegetation removal and pushing to form windrows with heavy machinery. This leaves a completely bare and very undulating soil surface as a result of topsoil scraping and deposition.
iii) Pegging, 'pitting' and planting.
iv) Weeding and plantation maintenance.
v) Weeding, plantation maintenance and abandonment once the planted tree crop completely dominates the surrounding vegetation.

Plate 4: Land situation after clearing using the Complete Clearance method. Soils are completely exposed to maximum climatic and environmental effects. Note the compaction resulting from the bulldozer tread lines.

Many techniques of land clearance are in use in the tropics with varying effects on the soils in particular, and the ecosystem as a whole, depending on a number of factors such as the soils, vegetation type, clearing implements, knowledge and experience of labourers. Lal (1986) has extensively reviewed the different methods used in tropical land clearance, which can be grouped by intensity of disturbance as follows:-

i) Manual Clearing without burning - causes slight physical and moderate but short term chemical and biological impact.

ii) Manual Clearing with burning - burning has greater chemical and biological impacts as a result of high temperatures and more physical disturbance due to soil baring.

iii) Semi-mechanized clearing - basically manual clearance but with a more complete canopy opening by tree felling with chain saws. Disturbance is more intense than in the manual methods and varies according to the amount of exposure and whether debris is burnt or not.

iv) Mechanized Clearance - there are various types of mechanized clearance using heavy machinery with accessory attachments such as, shear blades, straight blade, root rake, stump removers, tree pushers, tree crushers, chains etc. All these generally cause drastic disturbance to the soils.

v) Chemical Clearance - this is not very common in the moist tropics but sometimes appropriate for savannah regions with sparse trees.

Most of the various forms of mechanized clearance are more extensively used in agriculture than forestry where liming, fertilization and other expensive soil improvement measures are envisaged in subsequent management operations.

1.4 Review of effects of land clearing methods on tropical forest ecosystems

Numerous studies have reported effects of different land clearing methods on tropical forest ecosystems (Seubert et al, 1977; Lundgren, 1978; Sanchez et al, 1983, 1985; Jordan, 1985; Fölster, 1986; Lal, 1986; Lawson, 1986; Mambani, 1986; Palm et al, 1986; Ross and Donovan, 1986; Soane, 1986). These effects are summarized in Table 2 and their changes with time are summarized in Lundgren's model (section 4.0).

Land clearing procedure	Objective	Environmental impact	
		Manual methods	Mechanical methods
Underbrushing	To cut shrubs, vines and lower canopy vegetation.	Disturbs lower levels, including ground surface, of forest ecosystem	
Felling trees	To bring down trees and larger woody vegetation.	Tree stumps and roots are left in place.	Removal of tree stumps and boles with tree pushers results in large holes which must be filled, usually with surrounding topsoil Felling with blades (KG) leaves roots in place lessening soil disturbance. second compaction process begins.
Windrowing	To rake felled debris into long piles for ease of burning.	Not done, debris is left to dry where it falls.	Unless correct attachments are used, topsoil is removed with debris, subsoil is bared, soil is compacted for the third time.
Drying of vegetation	To reduce moisture content in vegetation and facilitate burning.	In situ drying of debris is most effective.	Debris at the bottom of the pile insufficiently dried thus hindering burn.
Burning	To remove as much vegetive debris as possible, also release of nutrients.	Extensive burning can remove up to 95% of debris, reduces soil micro-organisms, leaves incomplete burnt stems and stumps, evenly distributes ash over the area.	Piling results in very hot burns in small areas; concentrate ash to high levels not immediately useful to plants; subseqently leaching by erosion in the first downpour wastes potential nutrients.
		Removal of vegetation and humus bares soil to direct impact of sun's rays and heavy tropical rainfall. Heavy rains on bare soils may result in wide spread erosion.	

Table 2: Impact of various land clearing methods on soil and site conditions in tropical rainforests (After Ross and Donovan, 1986)

Some other important ecosystem effects of tropical deforestation are on climate and hydrology. The destruction of tropical forest produces the major part of carbon dioxide release to the atmosphere (Palm et al, 1986). Thornthwaite (1956) observed that climates owe their individual character to the nature of the exchange of momentum, heat and moisture between the earth's surface and the atmosphere. On the basis of these interactions between the air and the underlying surface, it may be deduced that changes in the surface properties have an inherent potential to induce changes or modifications in climate (Lawson, 1986). Drastic effects on soil hydrology can occur when forest is removed through alterations of infiltration and evaporation rates as a result of soil disturbance. The most important effect of land clearance which has been widely investigated is its effect on plant nutrient availability and dynamics.

1.4 Nutrient Cycling in tropical forests

Nutrient cycling is one of the most important topics of tropical forest ecology. The highly weathered profile of tropical soils is poor in nutrients. Thus the usual explanation for the frequent presence of tall trees, strikingly luxuriant forest communities and high production lies in the existence of very efficient mechanisms for capturing and retaining nutrients within these ecosystems. This includes both the limited resources of nutrients contained in the soil, and those entering from the atmosphere. Such efficient nutrient cycling implies rapid uptake, economic utilization and conservation against loss from the ecosystem. Efficient cycling of nutrients has been recognized as one of the most striking characteristics of mature tropical forests (Golley 1983; Jordan, 1985; Longman and Jenik, 1987; Proctor et al, 1983).

The movement of nutrient elements within the forest ecosystem is governed primarily by its biotic components or by the presence of particular producers, consumers and reducers (Longman and Jenik, 1987). Although the rates of flow of non-volatile nutrient elements through the ecosystem differ, as do their stocks in given ecosystem compartments, the pathways and storage compartments of all non-volatile nutrients are similar (Figure 2). Site preparation disrupts these flows and compartments and some methods may be more disruptive than others and the system may have only a limited capability of 'repair'. It is very difficult ,if not impossible, to study all the ecosystem compartments at any given point in time. This study is interested in investigating, and where possible quantifying, the effects of the three land clearing techniques on litter-fall and ground litter amounts, and selected properties of surface and subsoils, (compartments 1, 2 and 3, Figure 2).

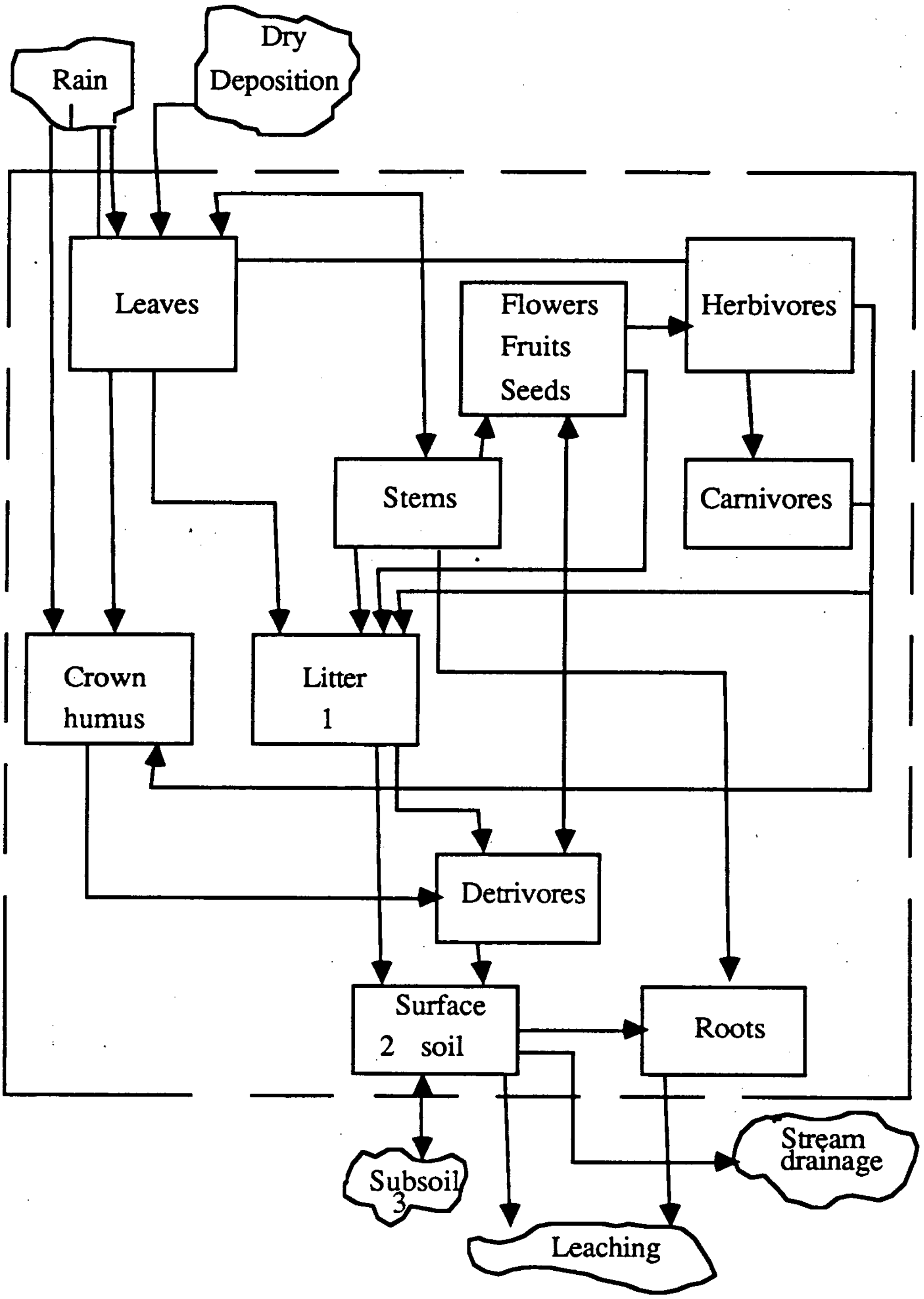

Figure 2: A diagrammatic model of the cycling of materials in an ecosystem. (After Golley, 1983). Compartments 1, 2 and 3 are investigated in this study.

1.6 Justification of the present study

Deforestation in the moist belt of the countries of West Africa (Sierra Leone to Congo), is running at 772,000 ha an^{-1} and Cameroon accounts for 10% of this area (Mason et al, 1989). In Cameroon more than 45% of the forest area is open to exploitation and the contribution of forest to the gross national product is very significant (Foaham, 1982). The rate of deforestation was recently estimated at 100,000 ha an^{-1}, with an estimated forest area of 16.5 million hectares remaining, these forests would disappear in about a century and a half if present rates continue. This has given rise to much concern and the government is taking appropriate measures to relieve the pressures on these forests. These include personnel training recycling programmes with special emphasis laid on plantation establishment under the responsibility of a government agency ONAREF (Office National des Régénerations des Fôrets) created in 1982.

Total re-afforestation in the West African belt has been only 331,000 ha in this century and over 80% of this with exotic species. Most of the indigenous hardwood plantations are small with low levels of survival and poor growth. In Cameroon, the total plantation area, since silvicultural activities began in 1930 in the forest zone was estimated in 1986 at 535,816 ha. The sixth five year plan currently under execution envisaged annual plantation creation by ONAREF at 3000 ha. It is therefore important that appropriate methods of land clearance are used and adequate management techniques envisaged in order to achieve this objective.

Land clearing methods have a strong impact on short and long term soil and nutrient dynamics of the site and its environment. Variation in the response of soil to clearing and plant establishment is related to the initial soil properties, land clearing methods, intensity of burn, rainfall distribution and post clearing management practices. The type of crop whether an annual crop, pasture or tree crop, is somewhat irrelevant at this stage. The most important factor is the rate at which plants establish a ground cover. The soil therefore is the main support for plant survival during the early stages of plantation establishment, hence the need for appropriate methods of forest clearance.

Fully-cleared sites like those of SODEFOR (Societé des Dévélopement des Fôrets) in Ivory Coast and the complete clearance (this study) are thought to be extremely damaging to soil structure and to fertility because of soil exposure to rain impact, erosion and leaching and fine root destruction. This damage may have serious effects on the growth and on the re-establishment of a balanced ecosystem, and yet this form of site preparation for forest plantation is common. By contrast, where the natural vegetation is retained in harmony with the planted crop (Manual Regrowth of ONAREF), the trees can grow well, the invasion of *Musanga* and noxious weeds like *Eupatorium* is minimized, the nutrients which might otherwise be leached out are retained in the fine root fraction and input from remaining trees continues through litter-fall. In addition the diverse ground flora may provide a source of mycorrhizal innoculum, while also forming part of the food chain within the ecosystem.

As plantation forests are increasing rapidly it is important to ensure that failures and disasters do not occur. Thus it is crucial to understand the way in which land preparation influences the fertility of the site, the extent of establishment of young trees and their growth.

1.7 Aims of the present study

The general purpose of this study is to assess the effects of the three methods of site preparation on soil physical and chemical properties, nutrient dynamics and the subsequent growth of the planted tree crop. Specifically, the study aims at:-

i) studying and where possible quantifying changes in soil physical and chemical properties when natural forest is converted into plantations using different clearing methods, (compartments 2 and 3, Figure 2)

iii) quantifying the effects of land clearing methods on the transfer and flow of materials and energy from the vegetation to the litter phase of the ecosystem, and subsequently to the other organisms and the soil, (compartment 1, Figure 2)

iv) investigating and where possible quantifying some of the causal mechanisms of the observed changes,

v) identifying changes occurring in the plantations with time and,

vi) finally, identifying the site preparation method(s) most appropriate for afforestation projects with *Terminalia ivorensis* in Cameroon and similar ecological zones. The judgement for the best method will be based on the best compromise between; achieving the highest rates of establishment and fastest growth of young planted trees, the minimum disturbance to the ecosystem (especially the physical and chemical properties of the soil) and the most economic system of site preparation.

To achieve effectively the above objectives, the study site should be relatively homogeneous. The forest should be relatively undisturbed and should have similar topography, geology, hydrology and climate. As would be expected such ideal situations are often very scarce in practice. After an initial consultation, literature review and map study, the Mbalmayo forest reserve classified in 1947 with generally uniform properties to enable a satisfactory comparative study was selected for the investigation of these clearing methods.

The study outlined in the succeeding chapters consists of four main sections. Section one focuses on the effects of the clearing methods on the soils and the subsequent changes in soil properties with time. The second section investigates the amount of disruption the clearing methods have on soil nutrient inputs through litter-fall and the extent to which turnover rates are affected by the different treatments. In section three interest is focused on the response of the planted crop to the different treatments and possible reasons for any observed differences investigated. In the last section, a synthesis of the preceding chapters is attempted and recommendations are put forward for the successful establishment of future plantation programmes.

Preceding these substantive sections, it is considered important to highlight the environmental characteristics of the study area.

CHAPTER TWO

Description of study area

2.1 Location

Cameroon is centrally located on the shoulder of Africa. It is bounded by Nigeria to the West, the Atlantic Ocean to the South West, Equatorial Guinea, Gabon and Congo to the South, Central African Republic to the East and Lake Chad to the North (Figure 3). The site of the present study is located at Ebogo in the Mbalmayo forest reserve (Figure 4) in the southern region of Cameroon at a distance of about 62 km from the capital Yaoundé (Figure 3).

The Mbalmayo area is in the Nyong-midstream catchment area, with a level to undulating and rolling plateau surface (650 m above sea level), belonging probably to the Africa 1 (Under-middle Tertiary) erosional surface (Segalen, 1967). The Mbalmayo forest reserve (Figure 4) lies between longitude 11° 25' and 11° 31' East and latitude 3° 23' and 3° 31' North of the equator. Mbalmayo pertains to the central administrative province (Figure 3).

2.2 Climate

The climate of the area is sub-equatorial (Suchel, 1972). According to the modified Köpen classification (Trewartha, 1954) the climate is AWI:-

A - stands for tropical wet climate with the mean air temperature of the coldest month higher than 18 °C.

W - indicates two rainy seasons separated by two dry seasons

I - indicates that the mean temperature differences of the warmest and coldest months is less than 5 °C.

2.2.1 Rainfall

The average annual rainfall in the Mbalmayo area (1934-1972) ranges from 1016 mm to 1990 mm with an average of 1522 mm. The rainfall pattern within the area is bimodal. The mean monthly values are given in Table 3.

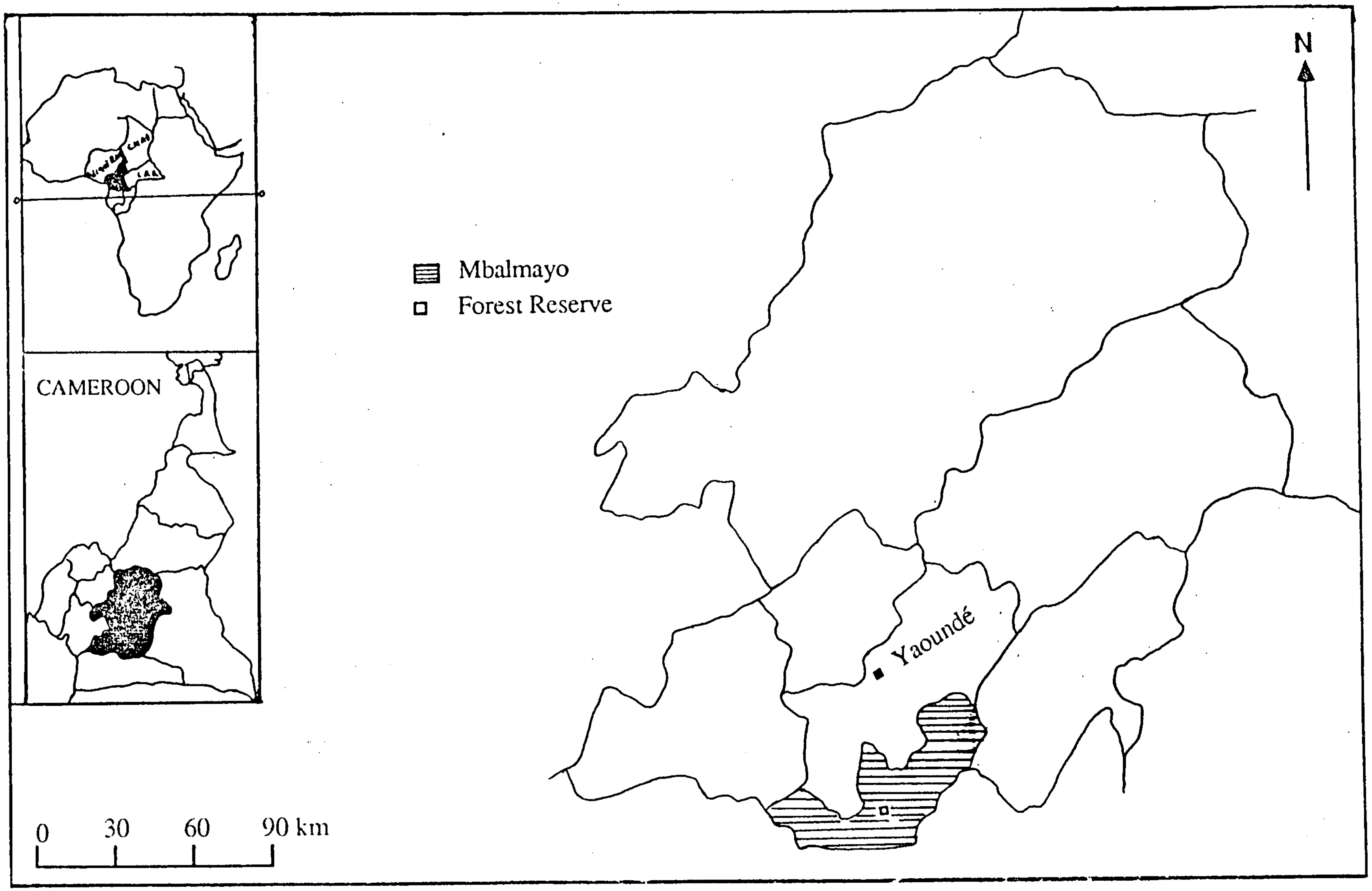

Figure 3: Map of the Central Province showing the study area

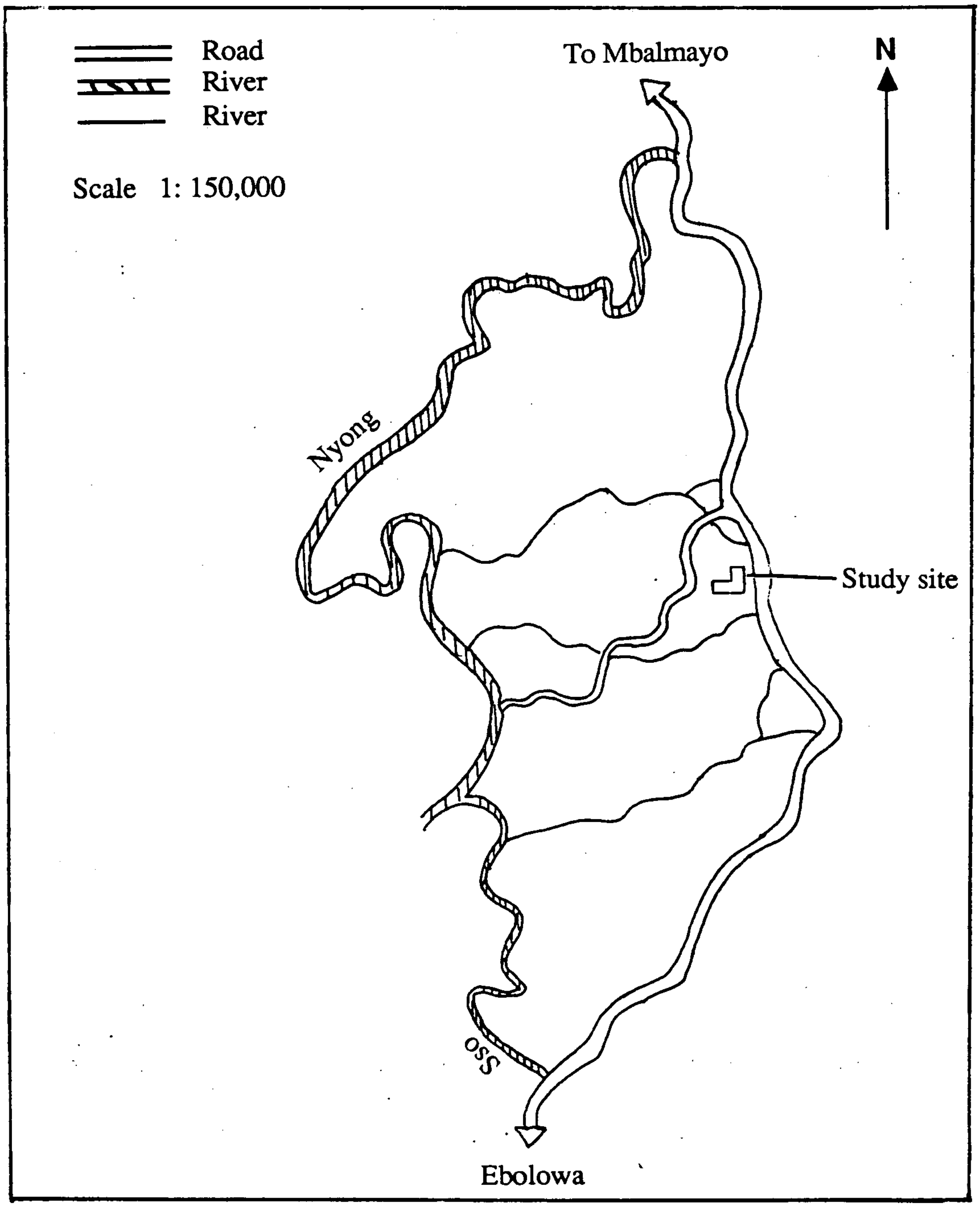

Figure 4: Map of the Mbalmayo forest reserve showing site location

Month	J	F	M	A	M	J	J	A	S	O	N	D
Pm (mm)	27.5	47.7	147.9	177.8	201.3	139.6	62.9	64.4	188.0	288.3	141.5	33.5
SD	27.9	33.4	60.3	67.4	51.2	61.9	50.5	49.3	73.0	77.9	69.2	29.3
C V%	101.6	70.0	40.7	37.9	25.4	44.3	80.3	76.5	38.8	27.0	48.9	87.6

Table 3: Average monthly rainfall for the Mbalmayo area for the period 1934-1972. (After Njib, 1987).

Pm	average monthly rainfall
SD	standard deviation
CV%	coeffocient of variation

In both the Emberger-Gaussens climatic classification and in the Birot scheme, the Yaoundé area has two dry months (In the former, the mean precipitation of the month, Pm, measured in mm, must be less than twice the temperature, measured in celsius degrees, i e Pm < 2 T; whereas in the Birot scheme a dry month is defined as Pm < 100 mm). The two dry months are December and January (Figure 5).

The first rainy season extends from March to June with the maximum in May and the second one from mid-August to November with an absolute peak in October (see figure 5).

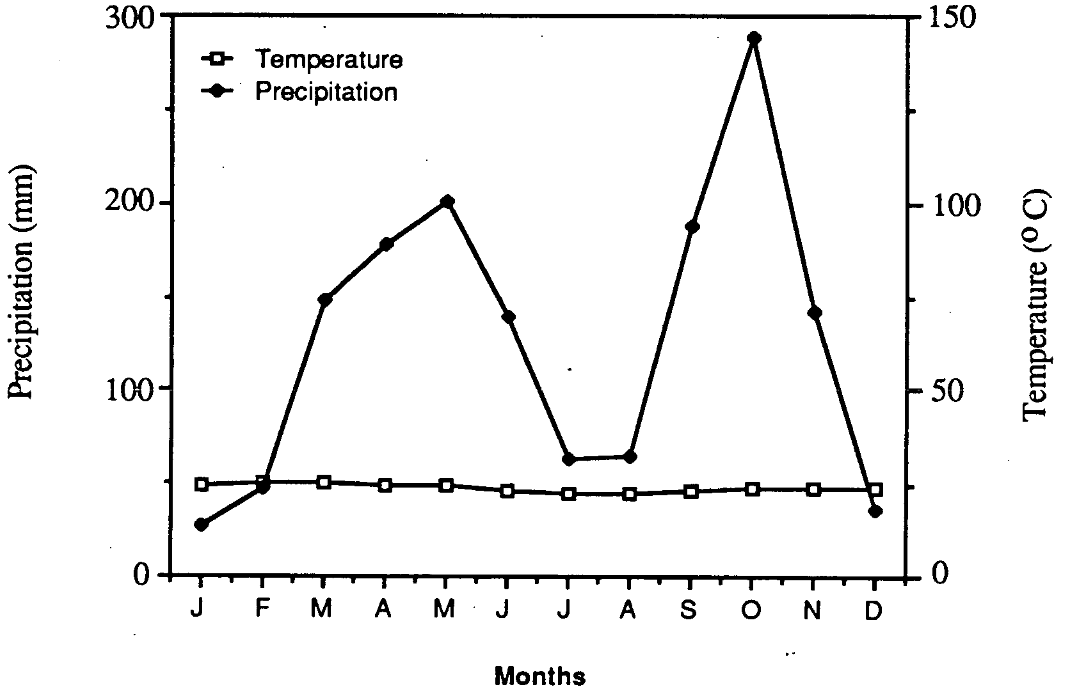

Figure 5: Mean monthly rainfall (mm) and temperatures (°C) distribution in the Mbalmayo area after Emberger - Gaussen.

2.2.2 Temperature

The variation of average atmospheric temperatures during the year are summarised in Table 3. The hottest month is February (25.5 °C) the coolest is August (22.6 °C) with an amplitude of 3 °C over the year.

2.2.3 Relative Humidity

Table 5 summarizes the mean monthly values of humidity and ranges from 73% to 84%. However daily variations masked by these averages can be relatively wide, ranging from close to 100% in mid-day and dropping to values of around 60% in the mornings. These values, recorded at the Yaoundé airport are likely to be applicable to the study area, which is 62 km south of the airport.

Month	J	F	M	A	M	J	J	A	S	O	N	D
Tm °C	24.4	25.2	25.2	24.7	24.4	23.3	22.5	22.6	23.2	23.4	23.7	23.8
S D	0.5	0.9	0.8	0.8	0.4	0.3	0.3	0.4	0.2	0.2	0.4	0.5
C V %	2.1	3.3	3.1	3.1	1.6	1.0	1.5	2.0	1.0	1.0	1.5	1.9
Max.	31.5	32.8	32.2	32.2	30.9	29.9	28.6	28.6	29.2	29.8	29.8	30.1
Min.	16.5	17.7	17.7	17.9	17.6	17.2	17.1	17.9	17.2	17.3	17.5	16.5

Table 4: Mean monthly temperatures in degrees Celcius of the Yoaundé airport located in the same geographic zone as the study area. After Njib, 1987.

Tm	average monthly temperatures
Max.	maximum temperature
Min.	minimum temperatures

Month	J	F	M	A	M	J	J	A	S	O	N	D
RL %	76.2	73.2	77.0	79.9	81.4	82.6	83.5	83.9	82.5	82.0	79.2	77.6
S D	1.8	2.2	1.8	1.0	0.9	1.2	1.3	0.9	1.2	0.9	1.7	1.4
C V %	2.3	2.9	2.3	1.2	1.1	1.4	1.5	1.1	1.5	1.1	2.1	1.7

Table 5: Mean monthly relative air humidity in percentage at the Yaoundé airport located in the same geographic zone as the study area. RL% - average monthly relative humidity. After Njib 1987.

2.3 Vegetation

The vegetation in the study area was classified by Letouzey (1985), as a climax, semi-deciduous forest which occupies an extensive area of the southern Cameroon plateau (Figure 6). Its southern limit is the atlantic forest and the Dja forest, while the north stretches right up to the foothills of the Adamawa plateau. In the North West it encounters the mountainous massifs of West Cameroon but isolated patches may be found in the valleys of the region.

The floristic composition of this forest is diverse. However on the basis of drainage condition, this forest vegetation can be subdivided into floristic units as follows:-

i) the riverine or raphiale forest of imperfectly to poorly drained valley floors. The main species are raphiale-bamboos, *Mitragyna ciliata, Uapaca paludosa,* with various shrubs (*Euphorbiaceae Spp, and Rubiaceae Spp*) and ferns.

ii) the well drained forest vegetation (selected for this study) is primarily characterized by the *Sterculiaceae* and *Ulmaceae* families represented respectively by cola (*Mansonia altissima*), Ayous (*Triplochiton scleroxylon)* and celtis (*Trema orientalis*). Also encountered in this area are ILomba (*Pycnanthus angolensis*) and Frake (*Terminalia superba*) a Combretaceae-like Framiré, the preferred species for plantations in the Mbalmayo area.

Below is a list of the families and some of the species identified in the study area at Mbalmayo (Mason et al, 1989).

Family	**Species***
Anacardiaceae	*Antrocaryon sp, Trichoscypha acuminata, Trichoscypha arborea,*
Annonaceae	*Anonidium mannii, Polyalthia suaveolens, Hexapolus crispiflorus, Xylopia aethiopica, Xylopia hypolampra, Xylopia pentassi, Xylopia quintassi.*
Apocynaceae	*Alstonia boonei, Alstonia congensis, Funtumia africana, Funtumia elastica.*
Bignoniaceae	*Markhamia lutea.*
Bombacaceae	*Bombax buonopozense.*
Boraginaceae	*Cordia aurantica, Cordia playthyrsa.*

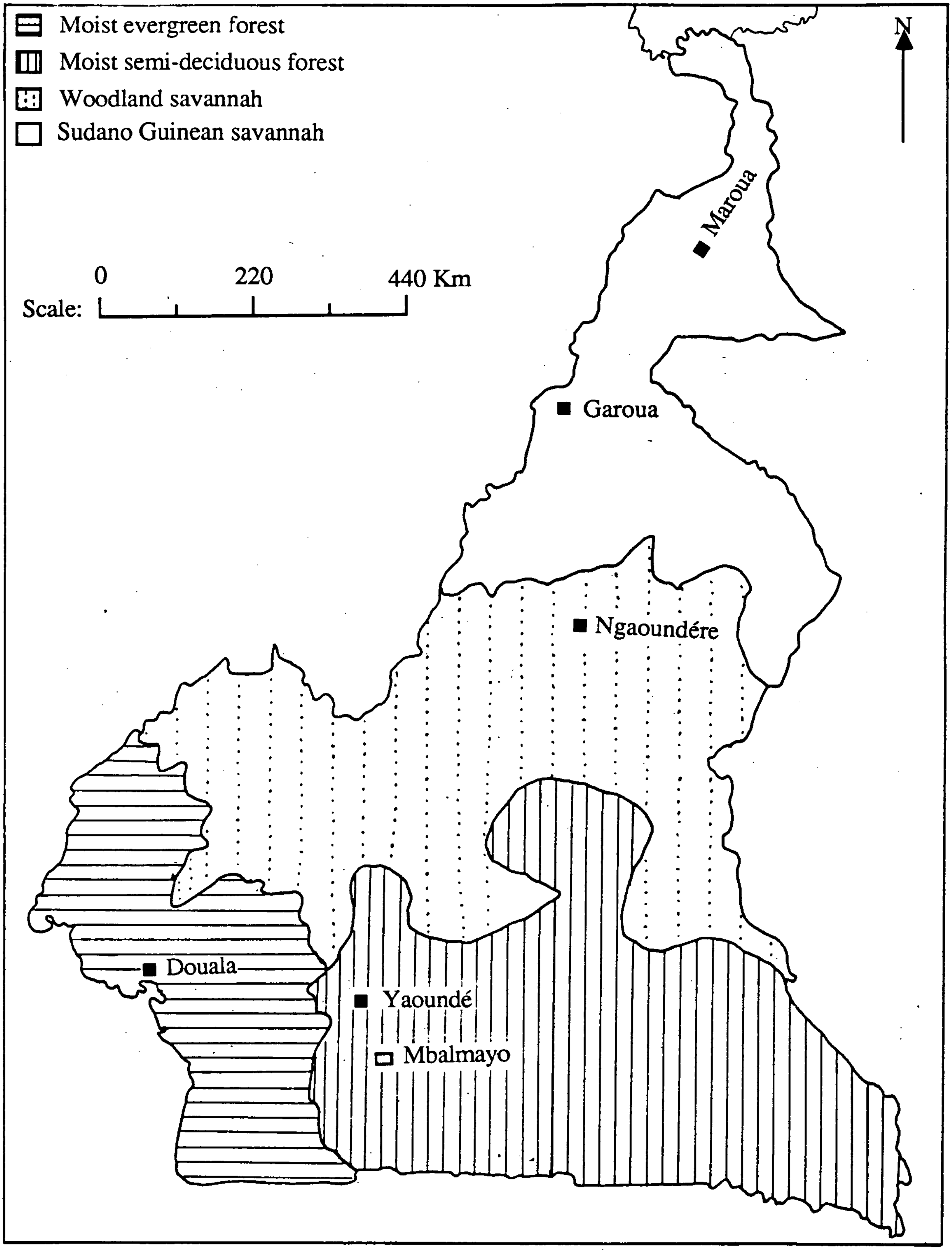

Figure 6: Map of Cameroon showing vegetation distribution. Modified after FAO, (1988).

Burseraceae	*Canarium schweinfurthii, Dacryodes igaganga, Santiria trimera*
Caesalpiniaceae	*Afzelia bipindensis, Amphimas pterocarpoides, Erythrophleum ivorense, Erythrophleum mannii, Guibourtia macrocarpa, Guibourtia tessmannii, Hylodendon gabunense .*
Chrysobalanaceae	*Maranthes gabunensis.*
Combretaceae	*Pteleopsis hylodendron, Terminalia superba.*
Ebenaceae	*Diospyros bipendensis, Diospyros crassiflora, Diospyros suaveolens*
Euphorbiaceae	*Drypetes sp, Ricinodendron heudelotii, Uapaca guineensis.*
Flacoutiaceae	*Scottelia coriacea*
Guttiferae	*Allanblackia floribunda, Allanblackia gabonensis.*
Irvingiaceae	*Desbordesia glaucescens, Desbordesia oblonga, Irvingia gabonensis, Irvingia grandifolia, Klainedoxa gabonensis, Klainedoxa microphylla.*
Lauraceae	*Beilschmiedia obscura, Beilschmiedia sp.*
Lecythiadaceae	*Petersianthus macrocarpus.*
Longaniaceae	*Anthocleista macrophylla.*
Meliaceae	*Entandrophragma candollei, Entandrophragma cylindricum, Guarea cedrata, Khaya ivorensis, Lovoa trichilioides, Trichilia rubescens, Trichilia tessmannii, Trichilia zenkeri,*
Mimosaceae	*Albizia zygia, Albizia sp, Calpocalyse denclagii, Calpocalyse heitzii, Parkia bicolor, Pentaclethra macrophylla, Pentaclethra sp, Tetrapleura tetraptera.*
Moraceae	*Chlorophora excelsa, Musanga cecropioides, Ficus mucuso.*
Myristicaceae	*Staneltia gabunensis, Staudtia, kamerunensis, Pycnanthus, angolensis.*
Myrtaceae	*Syzigium sp.*
Ochnaceae	*Lophira alata.*
Oleaceace	*Ongokea gore, Coula edulis.*
Papilionaceae	*Erythrina excelsa, Milletia excelsa, Pterocarpus mildbraedii, Pterocarpus soyauxii.*
Rqmnaceae	*Maesopsis eminii.*
Rubiaceae	*Canthium palma, Nauclea diderrichii, Pausinystalia yohimbe, Pausinystalia macroceras.*
Rutaceae	*Fagara macrophylla, Fagara tessmanii.*
Sapotaceae	*Baillonella toxisperma, Gambeya africana, Gambeya*

	lacourtiana.
Sterculiaceae	*Cola acuminata, Cola cordifolia, Cola lateritia, Eribroma oblongum, Triplochiton scleroxylon, Sterculia rhinopetala, Sterculia tragacantha.*
Ulmaceae	*Celtis aldolfi-friderici, Celtis mildbraedii, Celtis tessmanii, Celtis zenkeri, Holptelea grandis.*
Verbenaceae	*Vitex grandifolia.*

*Species nomenclature follows that of (Irvine, 1966; Letouzey, 1986).

2.4 Geology

Mbalmayo belongs to the Mbalmayo-Bengbis-Ayos series of Intermediate Precambrian Formation that extends into the Central African Republic. It is a slightly metamorphic series formed of greenish schists and micaschists some of them with garnets. Hornblend schists, amphibolites and gneiss have also been reported. An ORSTOM (Office de la Recherche Scientifique et Techniques Outre Mer) map at a scale of 1:1,000,000 locates Mbalmayo on yellow desaturated ferruginous sesquioxide soils which are likely to be Ultisols or Oxisols according to the USDA Soil Taxonomy (1975). A detailed pedological study by Sarlin (1968/69) mentioned by Foaham (1982) distinguishes four main soil types;

i) Hydromorphic soils in valleys,
ii) Intermediate (between i and iii) weathered grey soils developed in situ,
iii) Highly weathered deep red or yellow, well drained, acid soils of low base status with generally excellent soil structure, loamy or clay texture.
iv) Lateritic soils, not linked to topography. They seem to be the remains of an ancient cuirasse formed under a different climate.

Soils of the study area detailly investigated in the next chapter fall under the third category above.

2.5 Location of the study site

The ideal site for this study mentioned earlier, would be one of relative homogeneity and easy accessibility. The forest should be old and relatively undisturbed with uniform topography, geology, hydrology and climate.

An initial map study of the Mbalmayo forest reserve (Figure 4) enabled the selection of possible study sites for investigations. Field investigations of the selected sites revealed the reserve was littered with patches of peasant farmlands and that the general land form was undulating with many streams and swampy areas. Faced with these difficulties some modifications of the ideal conditions were made but keeping them as close as possible to the ideal case. The site was to be well drained and located on level land or mid-slope (avoiding valley bottoms), the forest was to be relatively undisturbed (absence of big gaps, many footpaths and major animal disturbances), and old (determined from date of classification and floristic composition). The site had to be easily accessible , but must be located at least 100 m away from any main access roads into the reserve to minimize site invasion by *Eupatorium*. All peasant cultivations were to be avoided.

Guided by the above criteria an L-shaped four hectare forest area (figure 4 and 7), was demarcated for treatment and subsequent studies. One hectare plots were considered very appropriate scientifically as treatment units, but the disposition of the treatments was governed by technical considerations. From the parking ground (figure 7), access to the mechanized plots by the heavy machinery was easy without disturbance to either the manual plot or the undisturbed natural forest.

It was considered necessary, prior to land treatment , to carry out a pilot study of the selected site in order to obtain base line data of the original situation of some selected properties of the natural forest.

CHAPTER THREE

PILOT STUDIES

3.1 Introduction.

Synnott (1975) studying the physical environment and biological effects of logging and silvicultural operations of tropical moist forests concluded that repeated mistakes in the management, and in the conversion from forest to other forms of land use, were caused by the lack of quantitative information on (i) floristic changes (ii) processes of growth and (iii) short term changes in soil properties.

The succeeding chapters of this thesis will be examining the effects of land clearing methods on soil physical and chemical properties, nutrient dynamics and the growth of the planted tree crop *Terminalia ivorensis*. It was therefore considered important for a better appreciation of any resulting changes, to establish a baseline for future comparison and reference through the investigation of these properties in the natural forest prior to clearing.

The tropical rainforest is a complex ecosystem, poor in nutrients with the lushness of its vegetation widely attributed to nutrient storage in the above ground biomass and an efficient recycling within a tight nutrient cycle. These forests have been found to possess many nutrient conserving mechanisms which are integral parts of the natural forest (Jordan, 1985). Land clearing and other less severe kinds of disturbance may have the effect of disrupting these mechanisms with varying consequences on the ecosystem, thus directly affecting any attempts to establish a tree crop.

Tropical forest soils are reputed for their acidity, fragility and low nutrient contents. They have been shown to deteriorate rapidly when denuded of vegetation cover. In this study, emphasis was placed on soil chemical and physical properties and the surface litter amounts particularly affected by land clearing methods. Beside these investigations, this chapter reports some of the inherent characteristics of the soils which may determine vulnerability to degradation. Basically this study aims at:-

i) documenting those processes which are generally assumed responsible for the rapid degradation and decreasing productivity of tropical soils shortly after land clearance,
ii) investigating the forest floor, a very important nutrient pathway and reservoir by

quantifying the fine litter amounts on the soil and their nutrient content,

iii) studying and where possible, quantifying soil physical and chemical properties which are often drastically affected especially after mechanized clearing,

iv) investigating soil fertility, in a bioassay experiment with soils from the study site planted with *Terminalia ivorensis*.

3.1 Characteristics of tropical soils

Our knowledge of soil properties and distribution in the humid and sub-humid tropics has increased substantially during the last decade (Drosdoff, 1972; Sanchez and Buol, 1975; Lundgren, 1978; IRRI, 1980; Cochrane and Sanchez, 1981; Lal, 1986) and considerable advances have also been made in understanding the soil processes involved in sustained management systems for the production of annual crops, pasture and perennial crops in the tropics (Sanchez, 1976; Pushparajah and Amin, 1977; Alvim, 1981; Greenland, 1981; Sanchez et. al, 1983)

The soils of the tropics are not uniquely different from those of the more temperate regions (Lathwell and Grove, 1986), but the processes which are at work in humid areas affect the rate and nature of pedogenesis in unique ways. Soil scientists traditionally have recognized the importance of climatic factors in the formation of soils. Although the soils of the equatorial regions vary greatly, climate indeed controls most of the key properties.

At low and intermediate elevations within the tropics, temperatures are high throughout the year, and there are no substantial seasonal variations. In these high isothermic regions, soil forming processes occur faster than in the temperate regions, particularly leading to advanced weathering stages of parent materials (Aubert and Tavernier, 1972). High temperatures also accelerate the turnover of organic matter in the tropical soils, this process may build up humic complexes, the composition of which largely depend on the extent of the dry season. At high elevations, where the mean temperature drops to below 22 °C, considerable organic matter may accumulate within the solum. Soils vary in their properties throughout the humid tropics at least as widely as those soils found in other regions and, as elsewhere, are often site dependent (Richards, 1952; Ahn, 1970; Lundgren, 1978; Evans, 1986). Many but by no means all, fit the old concept of being highly weathered and strongly leached and often very old (Sanchez, 1980; Kang and Juo, 1986). Age is a significant variable that determines many attributes of soils in the tropics and generally sets them apart from the temperate soils. The largest land areas of the tropics belong to continental shields and table lands, which have not been subject to recent folding. Soil erosion has not been strong enough to remove the products of weathering on the relatively smooth, stable areas, and no moving ice have scraped the waste mantles away, almost all soils have developed from deeply weathered materials (Aubert and Tavernier, 1972). Parent materials may range in age from very recent volcanic ash or alluvial/colluvial accumulation, to the oldest land surfaces on earth, and in composition from ultra-basic to very felsic rocks, and in genesis from vast alluvial deposition to deep sedimentary soils (Aubert and Tavernier, 1972; Lundgren, 1978; Sanchez, 1980).

Though varied in many of their properties, the majority of the soils in areas with sufficient rainfall for sustained agriculture and forest production share certain important common characteristics; they are bright red and yellow in colour, generally have loamy or clay texture but often sandy in the superficial layers, they are frequently deficient in bases and other plant nutrients in general, they are almost invariably acid, their humus contents tends to be low and confined to the uppermost horizons, they are highly weathered and their clay fraction is relatively rich in aluminium and poor in silica (Richards, 1952; Sanchez and Buol, 1975; Sanchez, 1983; Kamprath, 1979; Kang and Juo, 1986).

Three of these properties, considered to be fundamental in the rapid deterioration of tropical soils after clearance, are reviewed in sections 3.2.2 and 3.2.3, while in section 3.2.1 the forest floor and its properties is examined.

3.2.1 Forest floor

The term 'forest floor' is generally used to designate all organic matter, including litter and decomposing organic layers, resting on the mineral soil surface. These organic layers and their characteristic micro fauna and flora, are perhaps the most dynamic biological arena of the forest environment. They also form the most important criterion for distinguishing forest soils from agricultural soils (Pritchett, 1979). The litter of the ecosystem is made up of fractions at various stages of decay. Two categories of forest floor litter are usually distinguished. 'Coarse litter', consisting of fallen branches and boles is very heterogeneous in both space and in time. This fraction constitutes the largest percentage of total forest floor litter - 60% in a lowland rainforest at Kerigoma, New Guinea and 90% in another rainforest in Pasoh, Malaya, (Whitmore, 1985). 'Fine litter', the other fraction , is composed of small twigs, leaves, flowers, fruits and frass from invertebrate herbivores. It is more uniformly distributed than the coarse fraction.

As earlier mentioned, the forest floor is an important nutrient reservoir and pathway in nutrient cycling. In the tropics, the forest floor layer is often very thin compared to that of temperate forests as a result of more rapid rates of litter decomposition favoured by all-year-round warm and humid conditions. Most land clearing methods in the tropics have the effect of removing debris and reducing forest floor micro-organisms either through burning in the typical slash and burn method or by displacement and compaction in mechanized methods. Removal of vegetation and debris exposes the soil to direct irradiation and heavy tropical rainfall. Heavy rains on bare soils may result in leaching and erosional losses of nutrients in the run-off water. These effects are closely related to the organic surface and the immediate mineral subsurface properties of tropical soils.

3.2.2 Soil fragility and acidity

The fragility of tropical forest ecosystems is well documented (Aubert and Tavernier 1972; May, 1976, 1979). Most of the studies indicate that the high complexity of the ecosystem makes for dynamic fragility rather than robustness. By virtue of this complexity and fragility, these forests may rapidly degrade when disturbed. The surface properties of Oxisols and Ultisols (main soil types in the humid tropics) supporting this luxurious forest have been seen to deteriorate rapidly when the vegetation is cleared and the soils are subjected to mechanized agriculture or silviculture. There is often a rapid decline in soil physical and chemical properties in the A horizon; erosion, fertility and tilth problems usually increase quickly and so in this sense, the soils are described as being fragile (Lal, 1986).

The acidity of tropical soils is as a result of continuous release of organic acids during the decomposition of the litter layer and the subsequent leaching of bases from the surface soil, two processes favoured by the warm and wet conditions of the tropics. Land clearing is often seen to reduce soil acidity temporary through the buffering effect of released nutrients, but the accompanying leaching losses render this effect short lived.

3.2.3 Soil fertility

Tropical rainforests have great stature and the appearance of unbridled growth. This led colonists and colonial entrepreneurs from the temperate world to believe that such mighty rainforest must be a sign of great soil fertility, but almost everywhere yields of agricultural crops after clearing soon became very low (Whitmore, 1985). The idea grew up, and is still widely accepted, that this is because most of the plant nutrients are held in the forest, not the soil and are dissipated when it is felled and burned for cultivation (Hardy, 1936; Richards, 1952; Barney, 1980; Gradwohl and Greenberg, 1988). However, it has been shown that this is not always the case and that some soils (Inceptisols and Entisols) are sufficiently young to retain their primary minerals, and in some cases parent materials exert a dominant influence on base saturation (Alfisols).

There is an abundant literature on the low fertility of tropical soils (Cunningham, 1963; Ahn, 1970; Young, 1976; Pritchett, 1979; Sanchez, 1980). Most tropical soils, at least those in the wet regions, lie on top of ancient parent material that has undergone millions of years of weathering (Gradwohl and Greenberg, 1988). The all-year round warm and wet conditions of well drained tropical soils favour processes that have the potential to contribute to the continuous cation leaching and phosphorus immobilization (Jordan, 1985).

The complete weathering of all common minerals except quartz, to kaolinitic clay and oxides and hydroxides of iron and aluminium, leads to soils richer in clay with low silt/clay ratio. Kaolinite has low cation exchange capacity, especially at low pH. The role of clay in the cation exchange capacity can be significant where the clay proportion rises, but this can also lead to impermeability and anaerobism. In soils of the humid tropics, nutrient holding capacity is mainly a function of humus content and is low where humus content is low, as is usual in the subsoils. In many cases, more than half of the adsorbed bases in the soils is found in the top 25 cm (Nye and Greenland, 1960; van Baren, 1961; Lathwell and Grove, 1986). Deep, intense weathering and leaching combined with low nutrient retention are the main contributing factors to the low soil fertility of tropical humid soils on stable landscapes.

Not all tropical soils fit the above pattern. Relatively nutrient rich soils covering about 18% of the tropics, have become densely populated major agricultural centres where no significant expansion of forestry is likely to occur. They include recently formed (Inceptisols and Entisols) volcanic rock and floodplain soils whose nutrients are still replenished through annual floods, like the alluvial soils (Fluvents) mainly in India; 'padi' soils, S. E. Asia; vertisolic soils, Sudan and India; floodplains of the great Amazon, Mekong and Congo rivers and many volcanic soils (Andepts) in Java, Philipines, Sumatra, Papua New Guinea as well as parts of Central America, the Caribbean and the highlands of Cameroon and Central Africa around the lake region, and some old soils developed on basic rocks in moist seasonal climates (Nigeria, Ghana, S. Brazil) (Lundgren, 1978; Gradwohl and Greenberg, 1988; Sanchez, 1980). Low base status soils cover by far the largest area of the tropics (51%) (Lundgren, 1978) and, include areas in which man-made forests have been implanted and on which forests will continue to be established at a significant scale.

Climatic factors of tropical regions (high temperatures and moisture) have been indicated above as very important in the poor nutrient status of tropical soils. Removal of the forest canopy further exposes soil to these climatic effects resulting in rapid deterioration usually observed shortly after land clearance.

The work carried out in the subsequent sections of this chapter aimed at obtaining background information for later studies on the effects of the three land clearing methods under examination.

3.3 Materials and Methods

The four hectares delimited for subsequent treatment (Figure 7) were considered here as a single entity and sampled to represent the natural forest from which treatment results will be later compared. Sampling procedure for the studying of the selected properties was carried out as described in sections 3.3.1 to 3.3.3 below.

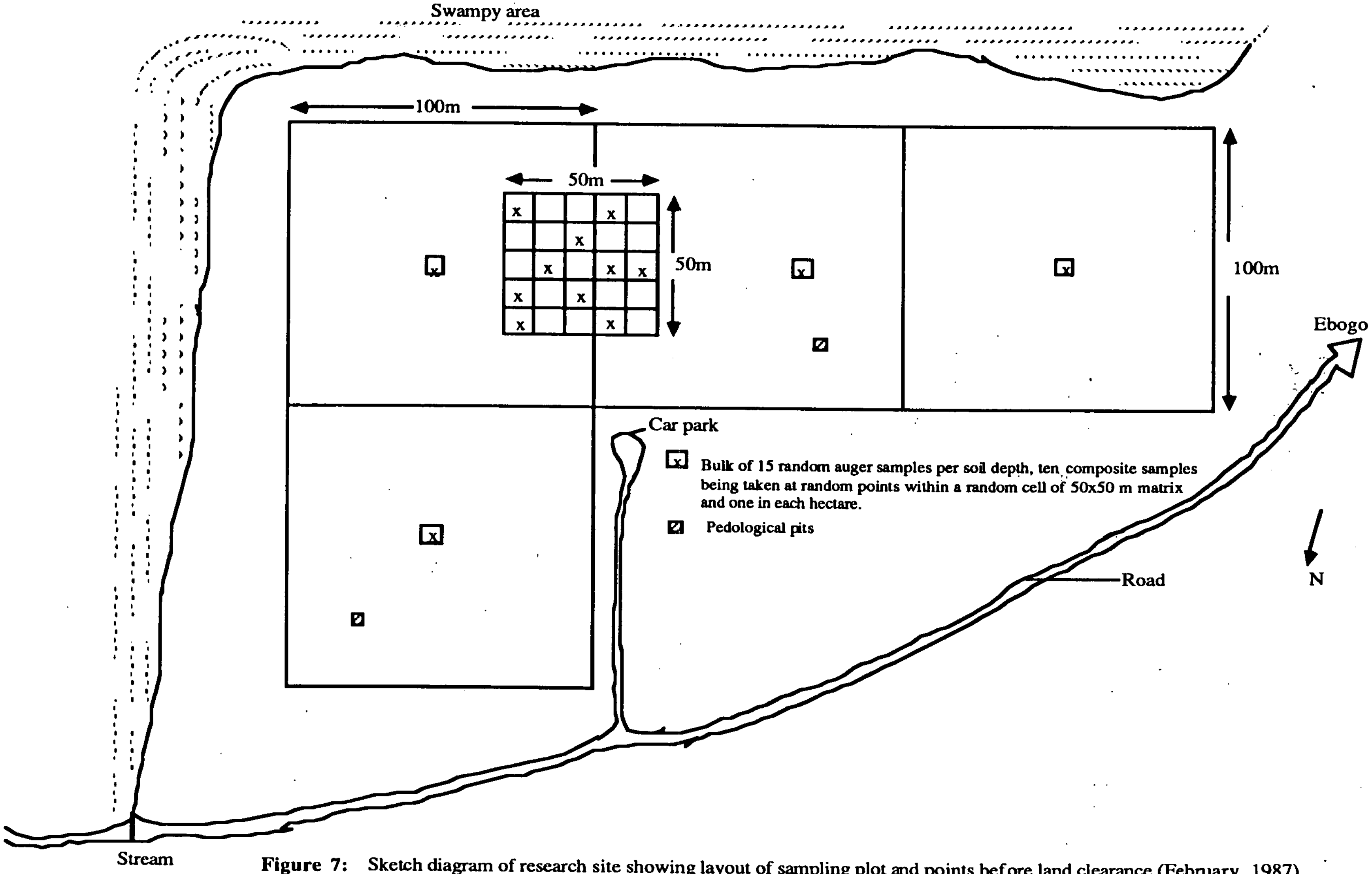

Figure 7: Sketch diagram of research site showing layout of sampling plot and points before land clearance (February, 1987) The details of the plots subsequently studied in greater details is given in chapter 4.

3.3.1 Fine litter fraction on the forest floor

On randomly selected areas in each of the four uncleared plots (Figure 7), three replicate samples of the litter layer were collected (February 1987) using a 100 x 100 cm wooden quadrat. After land clearance (March 1987), five replicate samples were collected (August 1987) using a 50x50 cm wooden quadrat as each plot was now treated individually. Litter sampling was carried out three times during the study period, before land clearance and at three and fifteen months after clearing. At each period, all loose material of recognizable identity was collected within the quadrat. Finely fragmented unidentifiable material was judged to be a component of the soil organic matter fraction rather than litter and was not collected. Material from each quadrat was oven-dried at 105 °C overnight, separated into two fractions, leaves and the rest (woody material ≤ 2 cm in diameter and reproductive organs) and weighed. Samples were then ground to fine powder and subsamples collected for chemical analysis after thorough mixing.

3.3.2 Fresh Leaves

In order to obtain a rough estimate of nutrient concentration of fresh leaves, to better appreciate the flow of nutrients in the ecosystem, a quick sampling of litter in and around the forest floor litter sampling points was carried out. At each of the these points, fresh leaves were randomly harvested from the surrounding vegetation. Leaves from bigger trees were sampled by throwing sticks into the canopy. After oven-drying at 105 °C overnight, samples were ground to fine powder and subsamples collected for analysis.

3.3.3 Soils

In each of the four hectares (Figure 7), 15 auger samples were randomly collected at two depths 0-20 and 20-40 cm. These were then bulked for each depth per hectare. In addition, a 50 x 50 m plot was randomly selected well inside the hectare plots and marked out for intensive sampling. It was further subdivided into 25, 10 x 10 m subplots; then ten of these were randomly sampled (Figure 7) and bulked as described above for the two depths. Soil sampling was carried out simultaneously with litter.

After thoroughly mixing the composite samples using two large plastic bins, two subsamples were collected, one for pH analysis at the 'Institute de Recherches Agronomique' (IRA) at Yaounde (Cameroon) and the other air-dried for nutrient analysis. The air-dried samples were further sieved to pass through a 2 mm mesh and subsamples collected in self-sealing polythene bags for transportation and analysis in Edinburgh (see appendix 1 for laboratory methods).

Soil profile description was made from two pedological pits measuring 1.5 m x 1.5 m and 1.75 m deep, dug at randomly selected points over the four hectares (Figure7). At four depths in each of the pits (0, 50, 100, 150 cm) soil samples were collected from the four sides and bulked for pH and granulometric analysis.

3.3.4 Bioassay of Soils

After collecting the two subsamples for analysis, the remaining soil was put in polythene film pots, 15 cm internal diameter and 30 cm high, for a replicated bioassay for fertility in which *Terminalia ivorensis* seeds were sown and germinated. In another bioassay experiment using well mixed soils collected from depths 0-15 cm in the forest, two treatments were investigated - addition of compound fertilizer and decomposing litter plus humus collected from the forest floor.

A total of 84 soil samples were potted for the two depths, 42 replicates per depth. The second experiment had a total of 23 pots. To seven of them, chosen at random, was spread 5 g of granulated compound fertilizer (N, P, K (20: 10:10)), eight others also randomly selected were covered with 25 g of decomposing litter and humus, the remaining eight with no treatment, served as a control. In each of the 107 pots was sown two seeds of *Terminalia ivorensis* collected under a single matured tree and immersed in water for three days to accelerate germination. The pots were laid out randomly on relatively flat ground under a temporary shade-screen at a nursery site at Mbalmayo on the 14th of March 1987. Weekly assessment of height and leaf production was carried out when germination started and continued for twelve weeks. At the end of the twelfth week, plants were harvested, oven-dried at 105 °C overnight, separated into three fractions (leaves, stems, roots) and ground into fine powder before subsamples were collected for nutrient analysis.

NB: Potted plants were watered with tap water. This might have effected results of the fertilized treatment.

3.4 Results and Discussions

3.4.1 Fine litter amounts on the forest floor

The result for the total fine litter fraction on the forest floor for the Mbalmayo area plus the standard error was estimated at 3.77 ± 0.48 t ha^{-1}. This result lieswell within the range of values for tropical lowland rainforests, of 0.61 t ha^{-1} in the Banco valley in the Ivory Coast (Bernhard, 1970) to 14.8 t ha^{-1} for a riverine forest in Lamto in the Ivory Coast (Devineau, 1976), reviewed by Devineau (1976) and Proctor et al (1983). The great variation in these values is a direct consequence of the variation in the vegetation formation of this ecosystem and are generally linked to latitude, altitude, precipitation and turnover rates. John (1973), reported values of 4.86 t ha^{-1} and 2.99 t ha^{-1} for total fine litter and leaf litter, similar to the 3.77 t ha^{-1} and 2.54 t ha^{-1} for this study, in Kade (Ghana) with a turnover rate of 0.7 and 2.5 respectively. Bernhard-Reversat (1976), found values of 3 t ha^{-1} to 4 t ha^{-1} for total fine litter amounts on the forest floor in a rainforest in the Ivory Coast with decomposition constants 3.3 and 4.2 respectively. In his experimental plots in a semi-deciduous forest also in the Ivory Coast, Devineau (1976), found that total floor litter varied between 9.3 t ha^{-1} and 14.8 t ha^{-1} with plots at different sampling periods. Proctor et al (1983) working in four contrasting lowland rainforests in Sarawak, observed some seasonal and between plot changes in the fine litter standing crop ranging from 4.7 t ha^{-1} in an alluvial forest in March to 7.5 t ha^{-1} in a limestone forest in February. Spain (1984) also found seasonal, annual and between site variation in the standing crop of litter in four Australian rainforests with a minimum of 3.0 t ha $^{-1}$ and a maximum of 10.5 t ha $^{-1}$. Maldague (1970), reported a very high value of 20.7 t ha^{-1} for the total fine litter amounts on the forest floor of a transitional semi-deciduous forest with an evergreen forest, characterized by *Scrodophleus zenkeri*, with a decomposition constant of 0.7.

3.4.2 Nutrient composition of litter and fresh organic tissue

Results of nutrient concentration and content of fine litter on the forest floor, and fresh leaves from the vegetation are summarized in Table 6.

Fraction		N	P	K	Ca	Mg
Fresh leaves		2.31 ± 0.11	0.17 ± 0.07	0.92 ± 0.12	1.14 ± 0.06	0.65 ± 0.12
Forest floor litter	Leaf litter	1.86 ± 0.07	0.08 ± 0.004	0.16 ± 0.02	1.15 ± 0.05	0.38 ± 0.01
	Rest	1.16 ± 0.06	0.04 ± 0.006	0.20 ± 0.06	1.04 ± 0.09	0.26 ± 0.03
	Nutrient content	56.9 ± 2.27	2.3 ± 0.19	6.79 ± 0.51	41.09 ± 2.64	12.06 ± 0.75

Table 6: Nutrient concentration (%dry weight) of fresh leaves and fine litter fractions and, on the final line, elemental content (kg ha^{-1}) of total fine litter amounts on the forest floor before land clearance. Results are means ± standard errors.

The results for the fresh leaves fall within the range for tropical forests reviewed by Dommerques (1963) and Vitousek and Sanford (1986). They are very similar to those reported by Bartholomew et al (1953) in Yangambi (Ivory Coast), Greenland and Kowal (1960) in Kade (Ghana), and Hase and Fölster (1982) in Venezuela. The observed differences in all nutrient elements (except Ca) in fresh leaves and leaf litter of the fine litter fraction is probably due to resorption of nutrients from the leaves prior to abscission. It is well known that elements may be transported from leaves to other tissues at different rates depending on their mobility. Mature leaves are more likely to lose elements than are young leaves, probably because of the high demand for cations in the growing tissues and the lower concentrations in the translocation stream (Golley, 1983). Bray and Gorham (1964) working on two different species in a greenhouse, found that the dry weight of leaf just before abscission was about 81% of the normal dry weight and inferred that one-fifth of the weight of the leaf is translocated out of the leaf before leaf fall. Studies in New Guinea rainforest on leaf weight before and after abscission, showed that loss of weight before and after leaf fall varied with species but in general was about 10%. This difference was thought to be probably the result of nutrient resorption (Edwards, 1977). Primary consumers were estimated by Bray and Gorham (1964) to account for about 7.5% of leaf area loss. In addition to these losses are leaching losses of the very mobile elements at the initial stages of decomposition.

Calcium, a structural component in plant tissue, is very immobile. Burges (1956) and Tew (1970) found that the amount of Ca in leaves increased throughout the growing season and the element is retained until major structural breakdown of leaves occurred. This might account for its immobility in the leaves (Table 6).

Most studies of litter on the forest floor report generally on their amounts with little or no information on their nutrient contents. The results obtained for this study are similar to those reported by Proctor et al (1983) for a limestone forest in Sarawak, except for the very high calcium value (270 kg ha^{-1}) which is expected of such soils.

Land clearance in which this ecosystem compartment is removed will lead to an important loss of nutrients from the system while at the same time exposing the mineral soils to other direct environmental effects.

3.4.3 Soils

Previous work on the soils of the Mbalmayo area by Njib (1987) with a view to evaluating the dominant soil forming processes under the influence of soil forming factors (climate, parent material, topography, drainage and time), suggested an apparent homogeneity in both physical and chemical properties. However, differences existed in soil colour and texture especially for the soils in the valley bottoms. The investigation over the 4 ha area of this study site revealed small scale variations in some selected soil properties.

3.4.3.1 Physical properties

Soils of the study area are generally dark brown to dark yellow brown in colour. They have a sandy clay texture with a decrease in sand and an increase in clay as depth increases. The silt fraction is low and almost constant down the profile (Table 7). The silt/clay ratio is also low 0.13 - 0.24:1.

Depth (cm)	pH	% Clay	% Silt	% Sand
0	4.4	36.9	9.5	53.6
50	4.7	54.4	10.2	35.4
100	4.9	55.1	9.2	35.7
150	4.9	55.5	8.2	36.3

Table 7: Average soil pH and particle size distribution down two pedological pits in the undisturbed forest before land clearance.

The trend of particle size distribution down pedological pits falls well within the range found by Njib (1987), for eighteen pedological pits over an area of 100,00 ha in the Mbalmayo region. The soils are well drained, highly weathered and generally with a sandy to sandy loam topsoil texture on flat and mid-slope. They present a high porosity with a good structure that does not impede permeability at least on the flat and mid-slopes. This might not be true for the steep and hydromorphous valley bottoms soils avoided during site selection for this study. A morphological description (colour structure, texture and porosity) of two soil profiles in the study area prior to clearance are summarized in Appendix 2, i and ii. The descriptions are typical of the well drained soils of the Mbalmayo region reported by Njib (1987) and Tchienkoua (1987).

3.4.3.2 Chemical Properties

3.4.3.2.1 Acidity and Organic Carbon

The soils of the study area, like most humid tropical soils are acidic. Average topsoil pH is 4.3 (Table 8). Samples from the soil pits showed that acidity declined with increasing depth (Table 7). Soils of the Mbalmayo area have a wide range of acidity. Tchienkoua (1987), evaluating an area of 100,000 ha in Mbalmayo, measured pH values of 4.1- 6.7 (topsoil) between the well drained soils of the slopes and flat lands and the hydromorphous valley soils.

The organic carbon percentage of the soils is low (Table 8). The C/N ratio is also low, 9.2:1 and 8.8:1 for depths 0-20 cm and 20-40 cm respectively. Low C/N ratios generally indicate higher microbial population and more rapid mineralization. Njib (1987) and Tchienkoua (1987) estimated topsoil organic carbon ranges of 1.02 to 2.88 and C/N ratios of 10-16:1 for the Mbalmayo area. In West African rainforests the topsoil C/N ratio usually stabilizes at about 10 to 12:1 (Ahn, 1970). The low organic matter of the study area and of most tropical soils result from rapid mineralization favoured by all year round high temperatures and humidity permitting continuous microbial activity.

3.4.3.2.2 Nutrients

Soils of the study area are poor in nutrients with highest concentration in the topsoil, presumably enriched with bases as a result of biotic cycles (Table 8). The results are similar to other tropical studies (Sanchez et al, 1985; Alegre et al, 1986; Kang and Juo, 1986; Lathwell and Grover, 1986). These soils have developed from deeply weathered materials and therefore possess very low mineral reserves for plant nutrition. Their low cation adsorption capacities, have made them susceptible to leaching. The reported cation exchange capacity values for the Mbalmayo region are low (Table 9).

The exchangeable aluminium content of the soils is high 5.8 cmol kg-1 and 5.6 cmol kg^{-1} for the two soil depths indicating the soils to be very toxic with respect to aluminium saturation (about 70% Al saturation from Table 10). During the 1950s considerable research established that acid soils were toxic as a result of exchangeable Al rather than hydrogen ion (Coleman and Thomas, 1967 mentioned by Kamprath, 1979). Toxic levels of aluminium in acid soils, therefore are an important factor in poor plant growth. Kamprath (1979) compiled values for exchangeable Al and Al saturation of soils in the tropics and subtropics (Table 10). The average exchangeable Al content was greater than 1 cmol kg-1 for soils with pH < 5. For all soils except those from South West Africa (Table 10) the average percentage Al saturation of the effective CEC was > 50. When Al saturation is > 60%, the concentration of soil solution Al generally exceeds 1 μg g^{-1}, a level detrimental to many crop species (Kamprath, 1979).

Soils of the study site and Mbalmayo area are characterized by strong weathering - high clay content > 50%, low ratio values of silt/clay and intense leaching of bases and silica [low base saturation and low CEC (pH 7) values Njib (1987)]. The above properties are similar to those of the soils classified as Oxisols (U S D A soil Taxonomy, 1975) and are as a result of ferralization processes (Njib, 1987).

Depth (cm)	Extractable nutrients					Total nutrients (%)			
	mg/100g		cmol kg^{-1}						
	N	P	K	Ca	Mg	N	P	C	pH
0-20	1.79 ±0.18	0.02 ±0.007	0.11±0.06	0.28± 0.32	0.2 ±0.18	0.12 ±0.012	0.015 ±0.0008	1.1 ± 0.06	4.3 ± 0.04
20-40	1.15 ±0.07	0.02 ±0.003	0.09±0.09	0.24± 0.23	0.17±0.15	0.10 ±0.007	0.016±0.0006	0.88± 0.07	4.4 ± 0.04

Table 8 : Selected soil properties of the natural forest before land clearance (February 1987). Standard errors are for means of fourteen samples

Soil property	Depth(cm)	
	0-25	25-40
pH	4.1-6.7	4.5-6.4
% Moisture	1.3-11.9	1.1-3.9
% Organic carbon	1.02-2.88	1.58-1.78
% Nitrogen	0.05-0.23	0.04-0.13
P (available) mg/100g.	0.2-1.1	0.1-0.7
K (exchangeable) cmol kg $^{-1}$	0.09-0.64	0.01-0.11
Ca " "	0.31-16.16	0.25-7.21
Mg " "	0.3-49	0-1.96
Na " "	0.05-0.19	0.01-0.15
Al " "	0-5.14	0-3.35
C E C (effective) cmol kg $^{-1}$	1.65-20.26	1.4-12.9

Table 9: Range of selected soil properties over 100,000 ha in the Mbalmayo region surveyed and evaluated by Njib (1987) and Tchienkoua (1987), respectively. Range values are for a total of sixteen pedological pits.

Region	Soils	pH range	Exchangeable Al cmol kg^{-1}		Al saturation %	
			range	average	range	average
Brazil	R. Y. latosol	4.0-4.6	1.8-3.2	1.7	38-90	74
	Red latosol.	4.1-4.2	0.7-1.9	1.2	83-90	88
Colombia	Oxisols	4.2-5.1	0.6-5.8	3.1	26-86	68
Malaysia	Oxisols	3.6-4.2	0.7-12.4	3.4	34-86	61
Panama	Latosol	4.8-5.2	0.3-5.8		44-68	
Puerto Rico	Ultisols	3.9-4.6	4.5-9.9	6.6	36-70	57
Southwest Africa	Ultisols and Alfisols	5.1-5.4	0-2.0	0.5	0-43	13
		4.5-5.0	0.1-3.7	1.3	2-69	41
		4.4-4.4	0.1-2.8	1.2	1-67	35
		4.5-4.7	0.9-4.2	2.1	54-82	72

Table 10: Exchangeable Al and Al saturation of soils in tropical and sub-tropical regions . After Kampratth (1970). (R.Y.=red yellow).

3.4.3.3 Bioassay of Soils

3.4.3.3.1 Germination and Growth

Generally, the germination of *Terminalia ivorensis* was poor, only 53%. However, compared to the general results of < 40% reported for *Terminalia ivorensis* germination (Voorhoeve, 1965), this result was relative good. A supply of seedlings from seeds sown in the nursery bed was used to ensure that every pot contained a seedling. Progressive plant mortality with diminishing replication (Table 11), was the reason why the experiment was terminated after only three months of growth , with a total mortality of 43%.

Treatment	Total planted	Total survived	Percentage mortality
0 - 20 cm	42	23	45
20 - 40 cm	42	20	52
Litter	8	6	25
Fertilized	7	4	43
Control	7	4	50

Table 11: Plant survival after three months of growth in soils from two depths (0-20 and 20-40 cm) from the natural forest, and soils treated with fertilizer and decomposing leaf litter

Plant growth (height and leaf production) was better on soils from the 0-20 cm depth (Figure 8a & b). This may be expected from the nutrient results in Table 8 which show higher concentration in this layer than in the 20-40 cm depth. The initial small differences in growth gradually increased with time as nutrients of the subsoil rapidly depleted through plant uptake and leaching loses (Figure 8a).

The litter-treated plants performed slightly better than the other treatments (Figure 8c & d). The leaf litter added as a source of nutrients, had the additional advantage of reducing evaporation rates and protecting the soil against direct solar irradiation and rainfall impaction - at least as long as it lasted. Plant response to fertilizer was only slightly evident after seven weeks of growth. It is thought initial soil watering compounded with rainfall dissolved and leached fertilizer nutrients to lower regions of the pot. Plants therefore, had to develop sufficient root systems to attain and absorb these nutrients which may account for the observed delay in response.

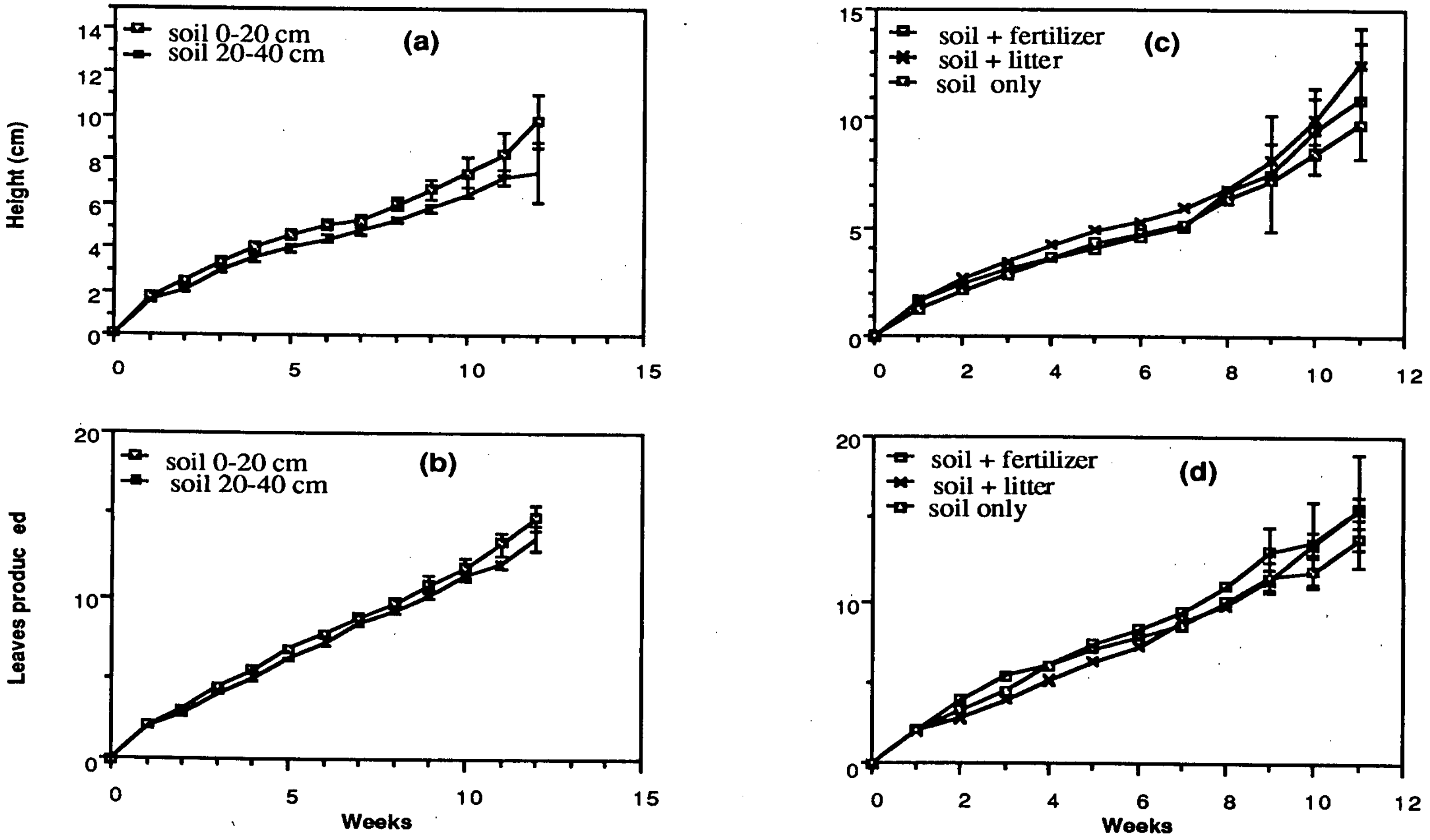

Figure 8: (a and b) Mean effects on plant height and leaf production of soils taken at two depths (0-20 cm and 20-40 cm) from the natural forest before land clearance.

(c and d) Mean effects on plant height and leaf production of added (i) fertilizer and (ii) leaf litter to soils taken at depth 0-15 cm from the natural forest before land clearance. Data points are means± SE.

3.4.3.3.2 Nutrient concentration of plants

Nitrogen and phosphorus concentrations in plants grown in soil from the top 0-20 cm soils of the profile were higher than those grown in soil from 20-40 cm (Table 12). High nitrogen concentrations are expected since the topsoil contained higher values of available and total nitrogen (Table 8) as well as organic matter, the primary component of soil nitrogen. Available and total phosphorus contents of both soil depths are identical (Table 8), therefore, the high P content of topsoil plants must result from the breakdown and release from organic matter contained in larger amounts in the topsoil. The similarities in cation concentration of plants from both depths (Table 12) indicates the ability of plants to absorb and concentrate some elements even though they maybe in short supply in the soils.

Litter-treated plants contained higher nutrient concentrations than the fertilized plants which had identical concentrations (except for K and Mg) with the control (Table 12). As mentioned above, the added litter did not only serve as a nutrient source but is likely to have offered soil protection against direct sunlight and rainfall impaction and reduced evaporation rates from the soil, factors which might help reduces volatization and leaching losses of nutrients. The similarity in the fertilized and controlled plant nutrient concentrations could be as in section 3.4.2.3.1 caused by a slow response to the applied fertilizer or as above by the ability of plants to absorb and concentrate nutrients, respectively. Nutrient concentration in the various plant parts (leaves, stem and roots) are given in appendix 3.

Treatment	N	P	K	Ca	Mg
Depth 0 - 20 cm	1.83	0.18	1.55	0.63	0.20
Depth 20 - 40 cm	1.23	0.13	1.52	0.65	0.23
Litter	1.80	0.22	1.71	0.70	0.29
Fertilized	1.78	0.16	1.64	0.51	0.17
Control	1.77	0.17	1.39	0.61	0.25

Table 12: Nutrient concentration (% dry weight) of plants from the bioassay. Nutrient concentration of plant parts (Leaves, stems, and roots) are given in appendix 3.

3.5 Conclusion

The well drained soils of the study site are likely to be Oxisols or Ultisols. Previous work in this region showed that the soils exhibited properties of Oxisols (low CEC, acidity, low base saturation, excellent granular structure with little contrast between horizons and the presence of an argillic horizon in the subsoil). The results of the investigation, over the 4 ha study area, agree with most of these findings but for the fact that the soils showed a marked clay increase with depth a property exhibited by Ultisols. Therefore, although Oxisols may be the dominant soil type, as revealed by the extensive study by Njib (1987) and Tchienkoua (1987), detailed small scale studies might reveal interesting and important differences.

The sandy soils of the study site are acidic with a surface soil pH range of 4.3 - 4.4, and poor in nutrients with high levels of aluminium. These results are quite typical of the well drained soils of the Mbalmayo region reported by Njib (1987) and Tchienkoua (1987).

The precarious conditions of the soils revealed by this study are very important for future land use and management. The results indicate that much care should be taken in the conversion of these forests, to other land use purposes, to avoid losses of the already low nutrient amounts tied up mostly in the surface soils.

The bioassay experiment showed that, *Terminalia ivorensis* grew well in the forest soils from the 0 - 20 cm depth and that growth was stimulated by adding litter and fertilizer to the pots.

Fine litter amounts on the forest floor had significant amounts of nutrients and hence play an important role in the nutrient cycling chain in tropical forests. However, this ecosystem compartment, together with the relatively high base topsoil, are shown to suffer particularly when forest is opened for cultivation to tree crops using mechanized clearance. This is discussed in the next chapter.

CHAPTER FOUR

EFFECTS OF LAND CLEARING METHODS ON SOIL PHYSICAL AND CHEMICAL PROPERTIES

4.0 Introduction

After a thorough review of the effects of fast-growing tree plantations on soil dynamics in tropical and sub-tropical highland regions, Lundgren (1978) proposed a conceptual model (Figure 9) of the dynamics of soil organic matter, nutrients and bulk density during seven different stages of plantation development. According to the model, soil organic matter content decreases after clearing, burning and plantation establishment. After canopy closure - the fallow enrichment phase - organic matter increases but then decreases during the maximum production phase, which terminates with the harvest of the first rotation. Organic matter further decreases after felling, logging, burning, and the start of the second rotation. Bulk density follows a pattern opposite to that of organic matter. Mineral nutrients increase after clearing, but then decrease throughout the three stages of the first rotation. Following harvest and burning, prior to the second rotation nutrient levels increase again. Lundgren (1978) considered this model to be a working hypothesis and urged researchers to develop hypotheses about the quality and direction of soil changes under man-made forests for specific ecosystems, soils, tree species and management practices.

The present study, which could be considered to some extent as a response to Lundgren's appeal was only able, due to limited observation period,to examine three stages of this model. Stage one was investigated as part of the pilot studies and stages two and three are presented in sections 4.1 and 4.2.

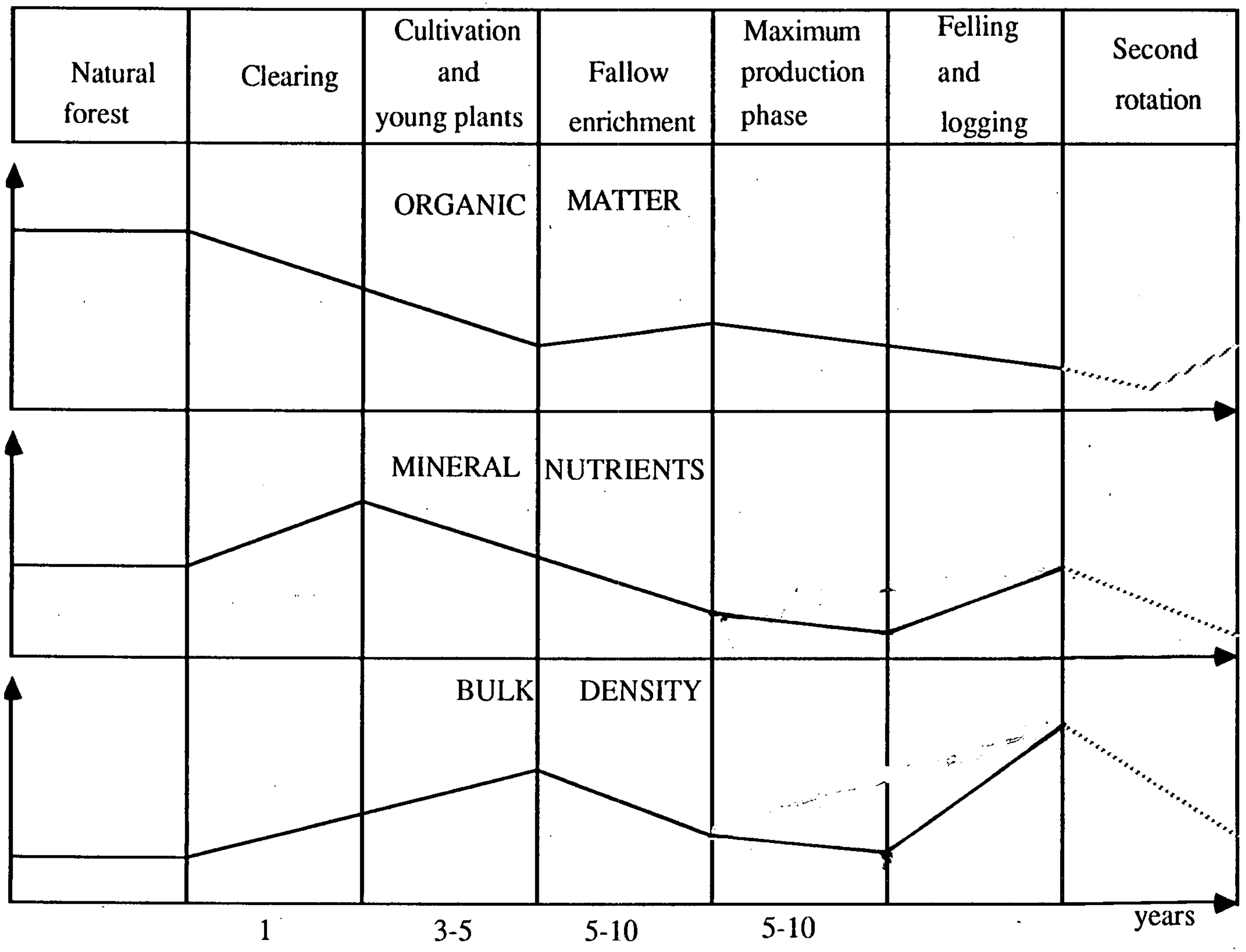

Figure 9: Effects of clearing natural forest and growing fast-growing tree species on selected soil properties in the tropics. After Lundgren (1978).

4.1 Physical Properties

4.1.1 Introduction

Forest soil investigators have long recognized the profound influence of soil physical properties on the growth and distribution of trees (Watanabe et al.,1960; Barber, 1964; Pritchett, 1979). Recently, much attention has been directed toward the equally important influence of chemical and biological properties and the interaction of all three groups of properties on each other and on site production. Soil physical properties such as texture and structure and soil colour have more indirect than direct effects on plant growth. Their influence on soil moisture, temperature, aeration and nutrient availability affects the growth and survival of trees (Pritchett, 1979).

The proportion of rain water that can be stored in the root zone for plant use is greatly influenced by the soil particle size distribution (Peters, 1957; Robins, 1957; Gardner, 1960, 1964; Denmead and Shaw, 1962; Miller, 1973), organic matter content (Biswas and Ali, 1967; Lal and Kang, 1982) and mineralogical composition (Opara-Nadi et al., 1986). Soil structure and texture play an important role in water availability through their influence on infiltration and evaporation rates . Closely related to soil water retention capacity, are soil water transmission characteristics, two properties that determine soil water behaviour in the rooting zone of most plant habitats and therefore the supply of water and nutrients to plant roots (Opara-Nadi et al., 1986). Surface horizons of sandy texture are known to have most rapid infiltration rates during rainfall of high intensity, once a continuous water column has been established (Herbel and Gile, 1973). Conversely, low infiltration rates significantly affect soil detachment and the velocity and sediment carrying capacity of run-off water (Lal , 1981).

Drastic alterations in soil physical properties can occur when the forest is removed, and the effects vary according to the nature and intensity of clearance. The direct effects of disturbance are on the soil air-water system and on soil strength properties affecting root penetration. The physical properties affected by disturbance also affect the chemical and microbial soil conditions indirectly and, thus, they can be said to directly affect soil fertility and productivity (Pritchett, 1979; Sanchez, 1985).

4.1.2 Materials and methods

Three months after land clearance (August, 1987), 50 x 50 m plots were subdivided into 25, 10 x 10 m subplots to form a sampling matrix in the centres of each of the treatment areas (Figure 10). Pedological pits each measuring 1.5 x 1.5 m and 1.75 m deep were dug per treatment plot for soil morphological description and particle size analysis. The soil physical properties investigated were colour, texture, structure, particle size distribution and bulk density.

4.1.2.1 Soil profile study

Particle size distribution was determined by the pipette method (appendix 1) on samples taken at four depths (0, 50, 100, 150 cm) from the pits . Profile samples were taken at horizons distinguished by soil colour and all the field observations were made at these depths.

4.1.2.2. Bulk density

Bulk density was measured on undisturbed cores (6 cm long and 6 cm internal diameter). Soil-core samples for bulk density determination were taken at randomly selected points in fifteen of the 25, 10 x 10 m subplots. Four replicated soil-core samples were also taken at four depths (0, 25, 50, 100 cm) from the pedological pits for bulk density determination. After carefully cutting clean the soil-core edges and cleaning the sides of the corer free of soils, the soil-cores were put in paper bags and oven-dried for forty-eight hours at 105 °C. Samples were weighed after cooling and bulk density calculated (Black, 1965). A small scale experiment was set up to study the effects of repeated passes of a heavy machinery on soil compaction, using a D8 bulldozer equipped with a straight rake, exerting a pressure, on the soil, of 66 k Pa at each pass.

NB: Plots were cleared in the month of May corresponding to the short rainy season. However, clearance wth heavy machinery actually took place only after long rainless periods.

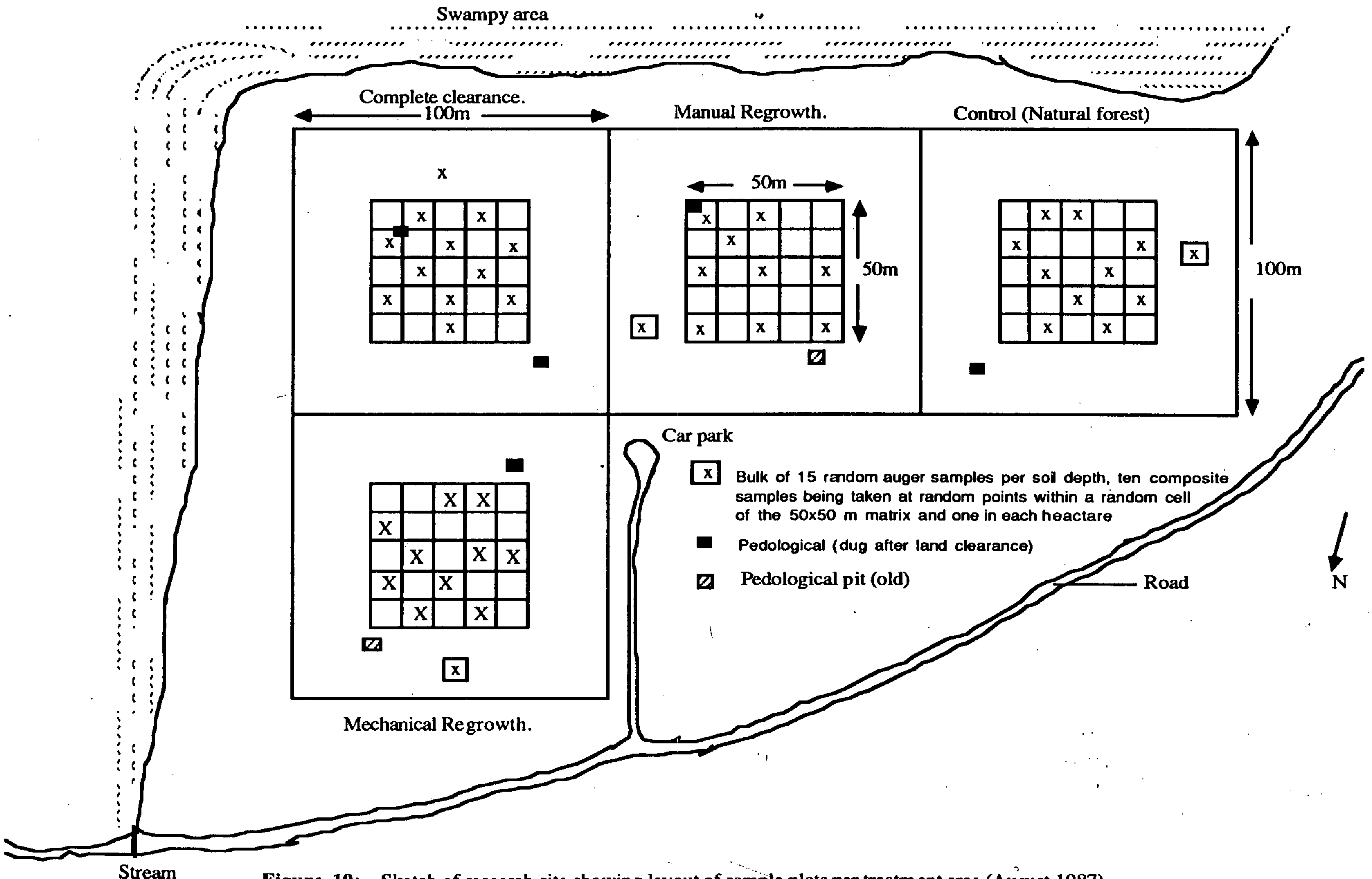

Figure 10: Sketch of research site showing layout of sample plots per treatment area (August 1987)

4.1.3 Results

4.1.3.1 Site preparation

The most apparent effect of the treatments was gross soil disturbance on the Mechanical Regrowth and Complete Clearance plots. Almost all the topsoil on the Complete Clearance plot and most of that on the Mechanical Regrowth plot was displaced, not by the the bulldozer rake which was kept above the soil, but, by the pushing and dragging of uprooted trees and logs. There was further exposure of the soil surface on these two plots to the direct action of sun and rain. Topsoil scraping in high places and accumulation in low spots and root holes, and mixing of topsoil with lower layers as a result of track spin was commonly observed.

Topsoil scraping and displacement on these two plots exposed the subsoil with a high clay content (Table 13). Marked increases in the clay fraction with depth in the Control, Manual Regrowth and Complete Clearance plots (Table 13), indicate the presence of an argillic subsurface horizon suggesting the soils are Ultisols.

Depth (cm)	Soil property	Treatment			
		Control	Man. Reg.	Mech Reg	Comp. C.
0	pH	4.3	4.5	4.6	4.5
	% Clay	29.1	36.1	44.6	41.6
	% Silt	15.8	15.6	10.9	11.6
	% Sand	55.1	48.3	44.5	46.8
50	pH	4.9	4.8	4.8	4.6
	% Clay	53.7	45.3	43.2	52.3
	% Silt	11.6	14.1	15.7	11.6
	% Sand	34.7	40.5	41.1	36.1
100	pH	5.2	5.3	4.8	4.9
	% Clay	50.6	43.6	40.4	54.4
	% Silt	11.6	12.6	16.6	11.6
	% Sand	37.8	43.8	43.0	34.0
150	pH	_	5.4	5.2	5.0
	% Clay	_	21.0	47.8	53.2
	% Silt	_	14.5	13.2	12.5
	% Sand	_	64.5	39.0	34.3

Table 13: Average soil pH and particle size distribution down pedological pits in the different treatment plots three months after land clearance (see also Figure 10),

4.1.3.2 Soil compaction

Conventional bulldozing of the complete clearance plot resulted in drastic effects on soil compaction. Analysis of variance of data from the surface layer showed highly significant (p=0.01) differences in bulk density between the Complete Clearance and the Manual Regrowth plot. The bulk density of the Mechanical Regrowth plot was not significantly different from that of the Manual Regrowth plot but was significantly different from the Control plot. The observed differences in bulk density of the Control and Manual plots could have possibly resulted from soil compaction by the felled trees or it is simply a result of soil variability. Table 14, shows that significant effects of soil compaction occurred in the Mechanical Regrowth and Complete Clearance plots to the depths of 50 cm.

Depth (cm)	Bulk density g cm^{-3}				LSD
	Control	Man. Reg.	Mech Reg.	Comp. C.	
0-10	1.16	** 1.30	** 1.38	** 1.53	0.094
20-30	1.30	1.34	* 1.43	* 1.48	0.35
45-55	1.34	1.38	* 1.44	* 1.42	0.041
95-105	+ 1.76	1.39	1.40	1.40	0.071

Table 14: Effects of land clearing methods on soil compaction in the treatment plots. Means of 0-10 cm are for nine samples and those of lower depths for four.

+ high bulk density may be as a result of parent material. Digging was very difficult beyond this depth due to the presence of a hard lateritic crust (probably a buried palaeosol).

* significant at $p<0.05$

** significant at $p<0.01$

Morphological description of soil profiles, given in appendix 2, iii - iv, show that compaction eliminated voids and visible pores and left the soils (top compacted areas) structureless.

The selective nature of the Mechanical Regrowth technique of land clearance resulted in a high coefficient of variation for the bulk density of the 0 - 10 cm depth (CV=14%). The CVs for the other plots were low, Control - 6%, Manual Regrowth - 5%, and Complete Clearance - 5%. The similarity in the variation coefficient of the Manual Regrowth and the Control plot is an indication of the mild effect of this technique on the ecosystem. In the contrary, the low value recorded in the Complete Clearance plot indicates the extensive and even distribution of the compaction effect over the plot.

The results of the effects of different passes of heavy machinery on soil compaction (figure 11) can be divided into three main phases. As the number of passes increased, there was an initial sharp rise in bulk density, followed by a gradual increase and finally reaching an asymptote where there was little or no further compaction with increased passes. Only four passes of the D8 bulldozer were sufficient to cause severe damage to the soils of the study area.

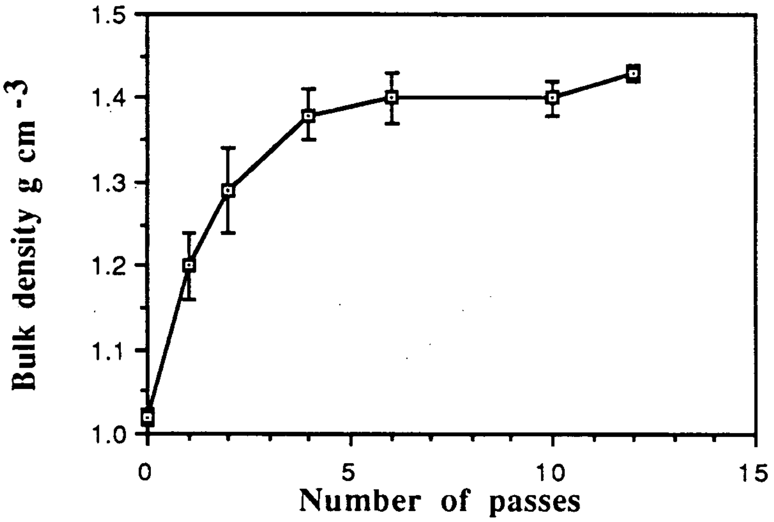

Figure 11: Effects of number of passes of a D8 straight rake bulldozer, weighing 23.51 tonnes (plate 2), on soil compaction in the Mbalmayo forest reserve. Bars are standard errors of means.

4.1.4 Discussion

4.1.4.1 Site preparation

Most forest soils concentrate nutrients in a shallow topsoil layer and their removal can significantly affect production. In Nigeria, Lal et al. (1975), observed that corn yields decreased by 50% when the top 2.5 cm of an Alfisol was removed.

4.1.4.2 Soil compaction

Only rarely are measurements of soil physical responses to machinery in land clearing operations extended to sufficient depth and with sufficient replication to allow a full description of the responses obtained (Soane, 1986). Studies by van der Weert and Lenselink (1972) showed that changes in bulk density attributable to clearing may extend to a depth of about 70 cm.

The observed pattern of soil compaction as a result of different passes of heavy machinery could be explained by variation in soil porosity (macropores). The initial sharp increase in bulk density could presumably have resulted from a rapid reduction in macropores and voids. As the number of pores decreased, the rise became gradual finally attaining a platform when almost all compactible pores were eliminated. Soil water conditions are also very critical in soil compaction analysis. In some soils of very high compactability (Soane, 1986) a single pass may be as damaging as many passes.

A common effect of land clearance (especially with heavy machinery) is increased soil heterogeneity. This was evident from the CV values for the four plots. In contrast to the low soil compaction of the Control and Manual Regrowth plots, the low CV of the Complete Clearance plot depicts the drastic effects of the method of conventional bulldozing resulting in almost all topsoil removal and complete plot compaction from the numerous and repeated passes of the machinery.

Land clearing with heavy machinery is rapid and results in an increased heterogeneity of substrate for plant growth (Alegre et al., 1986a, 1986b; Alegre and Cassel, 1986), but evidence from several locations in the tropics confirm that it can result in severe compaction with concomitant reduction in macroporosity, infiltration rate and available moisture and soil aeration (Seubert,1977; Lal and Cummings, 1979; Sanchez and Salinas, 1981; Gent et al., 1983,1984; Alegre et al. 1986b; Soane, 1986). In Surinam,mechanized clearing resulted in increases of bulk density to a depth of 80 cm at two sites and 60 cm at another with macroporosity (>80 μm) totally eliminated to depths 15 and 25 cm respectively (van der Weert and Lenselink, 1972; van der Weert, 1974). These changes were accompanied by a large reduction in basic infiltration rate and in rooting depth of the crop.

Soil compaction by heavy machinery in the Mechanized plots probably resulted because of the action of the machinery tracks, including back and forth movement (occasionally up to 20 times) in the process of stump and tree removal, the removal of the highly porous root mass and the exposure of bare soil to the impaction of high intensity rains. In contrast, the Manual Regrowth plot retained its root mass and was protected from the rain by the mass of leaves, twigs, branches and logs from the unburnt and unremoved slash.

The effects of compaction can persist for long periods on some soils as evidenced by stunted growth of trees on skid trials, machinery tracks and log landings (Pritchett, 1979; Mason et al.,1989). Clearly the risks of compaction in mechanized land clearing are so high that every possible means of avoiding the problem must be explored. The detrimental effects of mechanical land clearance can be and have been lessened to a great extent by choosing correct accessory implements on the machinery. In a study conducted in an Alfisol in Nigeria, bulldozing with a shear blade followed by zero tillage caused less run-off and erosional losses, than bulldozing with a combined tree pusher and root rake (Sanchez, 1980; Sanchez et al, 1985). Soil compaction can also be minimized by careful supervision of operations; by working in the drier seasons or on dry days and by the early establishment of beneficial cover crops.

4.1.5 Conclusion

i) The effects of the clearing methods on the soils were proportionate to the intensity of disturbance caused during clearance.

ii) The Manual Regrowth method caused the least disturbance and consequently had the least effects on the soils as depicted by the similarities in results with the Control plot.

iii) The most drastic effects on the soils were recorded in the Complete Clearance plot. This resulted mainly from the repeated passage of heavy machinery hence compacting the soils and exposing them to rain impaction and erosion.

iv) The Mechanical Regrowth method caused intermediate effects to the two extremes above, through the selective nature of vegetation removal. The big trees provided the soils with some protection against direct solar irradiance and direct rain fall impaction. However, some soil damage (compaction and soil disturbance) was caused in the process of clearing and windrow creation.

The effects of land clearance on soil physical properties indirectly affect plant growth through the influence on soil moisture, temperature, aeration and, nutrient availability often reported to be loss in great quantities after clearing.

4.2 Chemical Properties

4.2.1 Introduction

Human interference with the natural forest causes a series of long- or short-term changes most of which are detrimental to secondary land use (Fölster, 1986). In many environments, the preparation of land for agriculture and silviculture by means of clearing will, of necessity, modify the existing balance between soil, climate and vegetation. Agricultural and silvicultural activity creates a new physico-chemical status of the soil, which may be grossly different from its initial state and may deteriorate very rapidly under the influence of unstable cultivation and management techniques (Martin, 1986).

One of these changes is the unavoidable loss of nutrients caused by disturbance. Such losses occur whether the disturbance consists only of partial extraction or of more radical transformation of forest into plantations, shifting cultivation or permanent fields or pastures. One can recognize two overlapping and interconnected steps; one being the cutting and disposal of the forest biomass and its important nutrient store and the second, the gradual adaptations of the chemical soil properties to the dynamics of the land use system adopted (Fölster, 1986). These losses are generally rapid in Oxisols and Ultisols in humid tropical climates because the surface horizon is generally shallow and contains most of the nutrient reserves (Sanchez, 1980; Martin, 1986). The problem is also aggravated by harsh climatic factors. For example, frequent high intensity rain that destroys surface soil structure, and which may cause erosion and accelerate leaching of the clay and nutrient elements.

The potential fertility of tropical forests is often overestimated because of the apparent lush vegetation. In fact, the forest 'feeds' on its own debris and reuses the nutrients which are concentrated on the soils surface for various biological activities

(Whitmore, 1985; Jordan, 1985; Roose, 1986). Once the organic matter store has been mineralized, the ferrallitic soil cover is no more than a weathered skeleton devoid of nutrient reserves (Roose, 1986). As soon as the forest disappears, the carbon content in soils decreases, nutrients weakly held by 1:1 layer kaolinitic clays are leached, biological activities are reduced, macroporosity declines and soil structure is degraded (Nye and Greenland, 1964; Fauk et al, 1969; Charreau and Fauk 1970; Roose, 1979-1980).

The measurement of inorganic nutrients in the soil involves the problem that the amounts estimated by chemical analyses are not necessarily a measure of the amounts available to plants. The total amount is generally an overestimate and the 'available' or 'exchangeable' amounts are underestimates of what is available to plants in the long term. Roots may possess surface phosphatases that release phosphate from organic matter. In highly organic soils much of the N may not be available, especially under acid conditions (Whitmore, 1985). Different analytic procedures give different results even when supposedly measuring the same component and this can invalidate detailed comparisons between different studies. One way to make biologically meaningful measures of plant-available nutrients in a range of soil is to compare the growth in them of a standard plant (a 'phytometer' or bioassay). This has seldom been attempted for rainforest soils (Whitmore, 1985). Here this idea was exploited in the bioassay experiment described in chapter three.

In the part of the work described in sections 4.2.2 the hypothesis under examination is that site preparation causes sufficient disturbance to the soil to influence the chemical properties in the rooting zone. To test this hypothesis, chemical analysis were carried out three and fifteen months after the sites had been prepared and planted with young *Terminalia ivorensis*.

4.2.2 Materials and Methods

Soil sampling three months after land clearance was carried out in the centrally marked out and subdivided 50 x 50 m plots (Fig. 10) as described in section (3.4.4). Although auger samples were obtained for the two depths before and three months after clearance to try and eliminate effects of soil scraping and deposition in the Mechanical Regrowth and Complete Clearance plots, nevertheless great differences exist in surface soil and subsoil nutrients. After fifteen months from clearance and with the soil surface looking relatively leveled out in the Mechanical Regrowth and Complete Clearance plots, a detailed examination of the soils was carried out in small rectangular pits measuring 100 x 50 cm and 40 cm deep. Fifteen of these rectangular pits were dug at randomly selected points in fifteen of the 25, 10 x 10 m subplots per treatment area (Figure 10). Soils were collected at three depths from each pit; below the litter layer, and at 15 and 30 cm from the pit. The samples were thoroughly mixed and subsamples collected for analyses. Pre-treatment and sample analysis for chemical properties was carried out as described in section (3.4.4).

4.2.3 Results

4.2.3.1 Chemical properties three months after clearance

The chemical properties of the two soil depths sampled at three months after clearance are summarized in Table fifteen. The topsoil (0-20 cm) contained higher nutrient concentration than the subsoil (20-40 cm) and is the layer largely discussed here. All treatment plots showed increases in inorganic nitrogen but only the Mechanical Regrowth and Complete Clearance plots showed significant increases in exchangeable K and Ca. On the contrary, the Manual Regrowth plot showed significant decreases in exchangeable Ca and Mg. Available P increased only in the Mechanical Regrowth plot. There was no clear pattern for total P in all treatment plots, but there was a reduction in total nitrogen and organic carbon and an increase in pH in the Mechanical Regrowth and the Complete Clearance plots.

Treatment	Extractable Nutrients					Total Nutrients (%)			pH
	N	P	K	Ca	Mg	N	P	C	
	mg/100g		cmol kg -1						
	Depth 0 - 20 cm								
Control	1.54 ±0.01	0.04 ±0.012	0.10 ±0.005	0.21 ±0.025	0.26 ±0.018	0.13 ±0.006	0.017 ±0.0006	1.3±0.07	4.4 ±0.06
Man. Reg.	1.86 ±0.13	0.02 ±0.004	0.01 ±0.009	0.11 ±0.011	0.13 ±0.011	0.13 ±0.006	0.016 ±0.0005	1.3 ±0.06	4.4 ±0.05
Mech Reg	2.25 ±0.16	0.04 ±0.014	0.16 ±0.031	0.41 ±0.018	0.22 ±0.018	0.10 ±0.005	0.015 ±0.0007	1.0±0.11	4.8 ±0.06
Comp. C.	2.03 ±0.15	0.02 ±0.008	0.18 ±0.026	0.36 ±0.011	0.18 ±0.011	0.11 ±0.013	0.016 ±0.0005	1.1±0.11	4.7 ±0.05
	Depth 20 - 40 cm								
Control	0.95 ±0.09	0.01 ±0.003	0.08 ±0.005	0.19 ±0.03	0.21 ±0.030	0.11 ±0.006	0.016 ±0.0006	0.91 ±0.06	4.8 ±0.06
Man. Reg	1.18 ±0.08	0.02 ±0.006	0.08 ±0.005	0.09 ±0.009	0.09 ±0.009	0.11 ±0.005	0.015 ±0.0004	0.97 ±0.01	4.6 ±0.04
Mech Reg	2.00 ±0.15	0.04 ±0.010	0.10 ±0.008	0.27 ±0.024	0.27 ±0.024	0.10 ±0.004	0.017 ±0.0004	0.78 ±0.07	4.8 ±0.04
Comp. C.	1.61 ±0.10	0.05 ±0.015	0.13 ±0.009	0.26 ±0.03	0.26 ±0.030	0.11 ±0.005	0.014 ±0.0011	1.20 ±0.06	4.6 ±0.05

Table 15: Selectecd soil properties of the different treatment plots three months after land clearance (August 1987). Standard errors are for means of eleven samples.

4.2.3.2 Chemical properties fifteen months after clearance

There was a striking similarity in topsoil nutrient concentration of the control and the Manual Regrowth plots (Table 16). Topsoil nutrient concentration of the Mechanical Regrowth and Complete Clearance plots were lower than those for the Manual Regrowth and Control plots.

Topsoil organic carbon was highest in the Manual Regrowth plot and decreased with depth for all the treatment plots. Soil acidity in the Mechanical Regrowth and Complete Clearance plots was still lower than in the Manual Regrowth plot. There was a slight increase in subsoil total P in all the treatment plots.

Depth (cm)	Treament	Extractable nutrients					Total nutrients (%)			
		mg/100g		cmol kg^{-1}						
		N	P	K	Ca	Mg	N	P	C	pH
0	Control	4.90 ±0.27	0.122 ±0.009	0.22±0.012	0.56±0.055	0.40±0.04	0.19 ±0.02	0.012 ± 0.0004	1.3 ±0.14	4.3±0.25
	Man. reg.	3.49 ±0.75	0.121 ±0.011	0.23±0.014	0.61±0.075	0.42±0.06	0.14 ±0.02	0.011 ± 0.0002	1.3 ±0.11	4.4±0.06
	Mech. Reg	4.40 ±1.09	0.034 ±0.013	0.11±0.017	0.39±0.091	0.29±0.04	0.17 ±0.07	0.011 ± 0.0004	0.82 ±0.4	4.7±0.04
	Comp. C.	2.73 ±0.47	0.025 ±0.006	0.15±0.018	0.42 ±0.070	0.27±0.04	0.39 ±0.11	0.011 ± 0.0002	0.81 ±0.11	4.7±0.05
15	Control	3.40 ±0.27	0.014 ±0.002	0.07±0.004	0.03±0.003	0.11±0.02	0.13 ±0.06	0.012 ± 0.0002	0.59 ±0.06	4.3±0.23
	Man. Reg.	1.27 ±0.18	0.021 ±0.003	0.08±0.004	0.05±0.012	0.11±0.02	0.05 ±0.01	0.010 ± 0.0003	0.87 ±0.16	4.4±0.04
	Mech. Reg.	4.00 ±1.22	0.043 ±0.011	0.11±0.024	0.41±0.108	0.29±0.06	0.25 ±0.07	0.011 ± 0.0001	0.68 ±0.19	4.5±0.04
	Comp. C	1.04 ±0.08	0.031 ±0.015	0.07±0.004	0.08±0.019	0.09±0.01	0.32 ±0.12	0.010 ± 0.0002	0.64 ±0.09	4.5±0.03
30	Control	2.14 ±0.29	0.013 ±0.004	0.07±0.007	0.03±0.004	0.11±0.01	0.05 ±0.001	0.011 ± 0.0002	0.51 ±0.13	4.4±0.14
	Man. Reg.	1.12 ±0.19	0.033 ±0.005	0.07±0.017	0.03±0.010	0.09±0.01	0.07 ±0.02	0.013 ± 0.0002	0.48 ±0.08	4.7±0.05
	Mech. Reg.	4.28 ±1.08	0.064 ±0.017	0.13±0.021	0.32±0.070	0.25±0.04	0.24 ±0.06	0.012 ± 0.0004	0.58 ±0.21	4.6±0.04
	Comp. C.	1.06 ±0.06	0.027 ±0.012	0.06±0.004	0.07±0.018	0.07±0.01	0.36 ±0.12	0.012 ± 0.0002	0.45 ±0.06	4.6±0.05

Table 16: Selected soil properties at three depths (0, 15, 30 cm) in the different treatment plots fifteen months after land clearance (August 1988). Standard errors are for means of fifteen samples.

4.2.3.3 Nutrient dynamics

In order to establish a time series and compare results of topsoils in the different treatment plots (although in fact samples are not strictly comparable due to the difference in sampling techniques) the average nutrient concentration of the 0 cm and fifteen cm depths at fifteen months after clearance was calculated and compared with those of the 0-20 cm depth before and three months after clearance (Fig. 12a and 12b)

1) *Inorganic nitrogen*

   The Mechanical Regrowth and Complete Clearance plots showed increased nitrogen concentration at three months after clearance, but this decreased slightly at fifteen months for the Complete Clearance plot. On the other hand, the Manual Regrowth plot showed no change at three months but increased slightly one year later.

2) *Base status*

   Exchangeable Ca and Mg decreased at three months in the Manual Regrowth plot before rising rapidly at fifteen months. Exchangeable K, Ca and Mg in the Mechanical Regrowth plot increased at three months but K decreased one year later, while in the Complete Clearance plot K and Ca rose at three months before declining to levels in the natural forest at fifteen months but magnesium decreased at three months and remained unchanged at fifteen months.

3) *Available phosphorus*

   The Manual Regrowth plot showed no change in 'available' P at three months but increased rapidly twelve months later. In the Mechanical Regrowth plot 'available' P increased at three months and was unchanged one year later. There was no change in 'available' P in the Complete Clearance plot at three months and only a slight increase was recorded at fifteen months.

4) *pH*

   The pH of the Mechanical Regrowth and Complete Clearance plots increased by an average of 0.3 units as against 0.1 for the Manual Regrowth plot. There was little or no influence of the Manual Regrowth Clearance on soil acidity.

5) *Organic Carbon*

   The general trend of organic carbon in all the treatment plots was in decline with time, except for a temporary increase in the Manual Regrowth plot at three months after clearance.

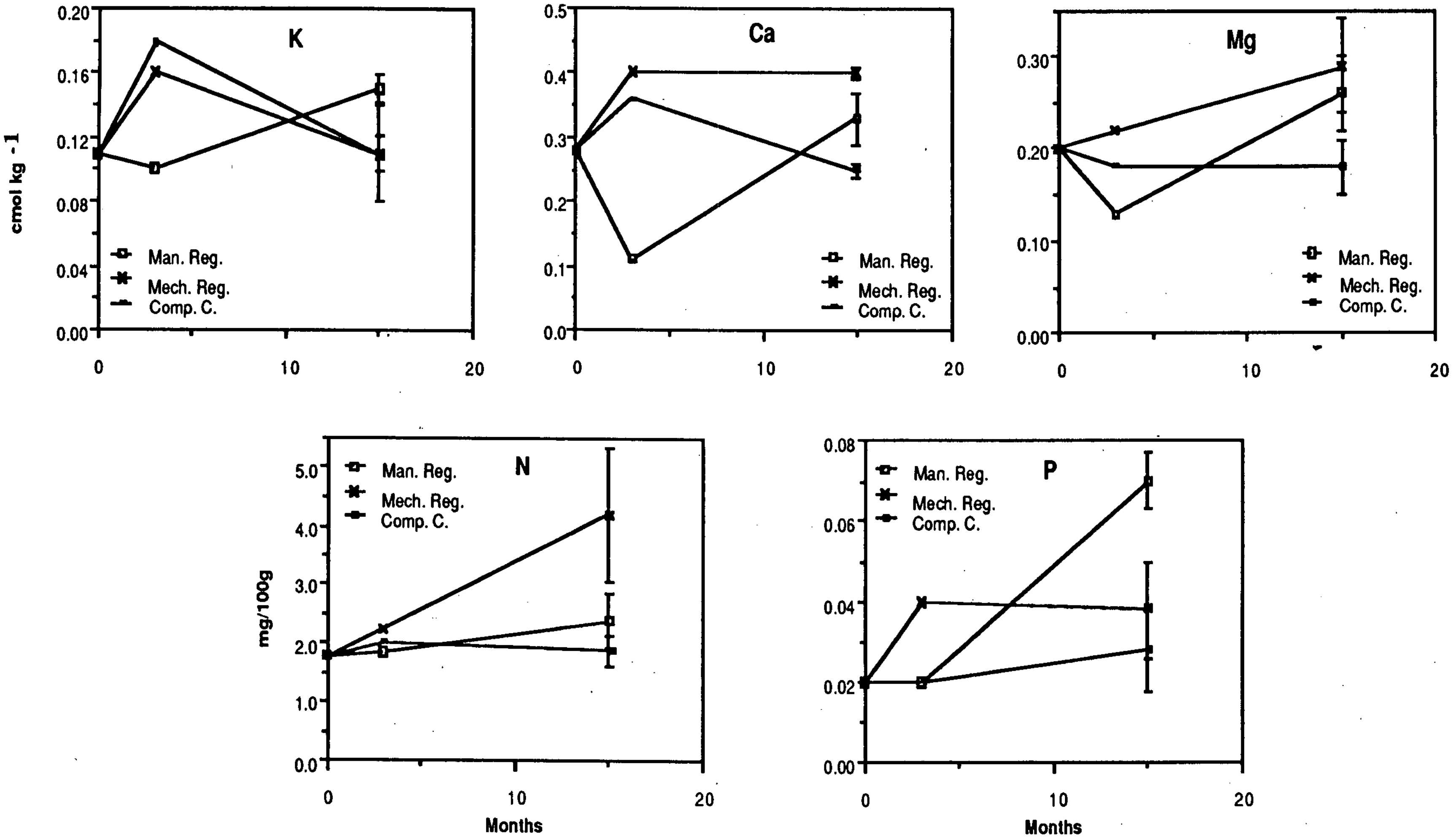

Figure 12a: Effects of land clearing methods on topsoil (0 - 20 cm) nutrients (N, P, K, Ca, Mg), at three and fifteen months after land clearance. Data points are means ± SE.

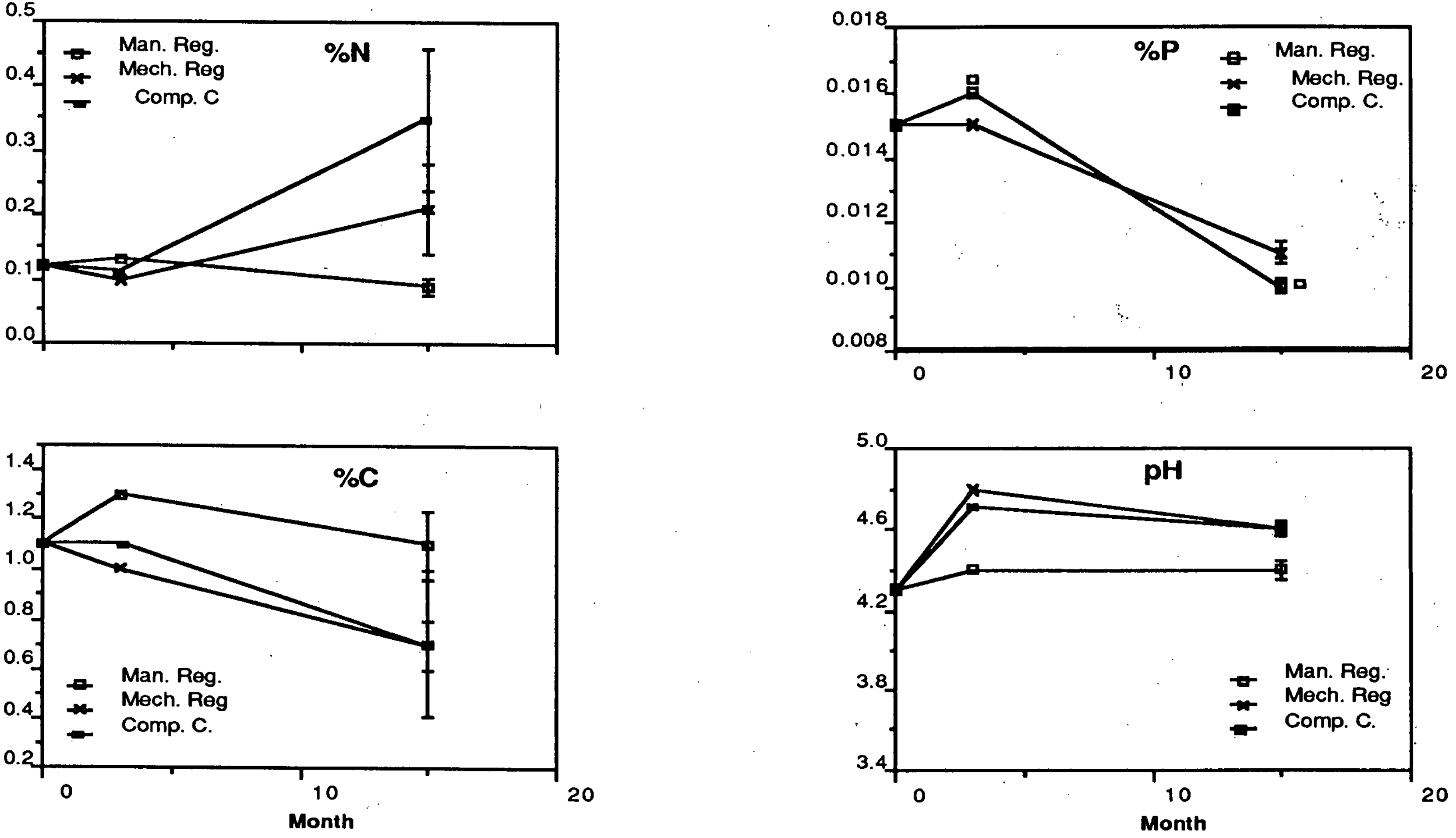

Figure 12b: Effects of land clearing methods on topsoil (0 - 20 cm) total N and P, organic carbon, and pH at three and fifteen months after land clearance. Data points are means ±SE. (P values for Man. Reg. and Comp. C. are identical).

4.2.4 Discussion

4.2.4.1 Chemical properties at three and fifteen months after clearance

High nutrient concentration in the topsoil 0-20 cm at three months after clearance (Table 15) was expected since tropical soils have been shown to concentrate nutrients in the surface soils. Increases in bases in the Complete Clearance and Mechanical Regrowth plots may be attributed to the increases in soil temperature and moisture conditions as a result of the complete and partial removal of the canopy in these plots respectively, thus giving rise to rapid mineralization.

The high and similar nutrient concentrations of topsoil nutrients in the Control and Manual Regrowth plots (Table 16) at fifteen months after clearance indicates the mildness of the Manual method of land clearance. As explained above, most nutrients in tropical forest soils are contained in the surface layer with a dense root mass considered as an adaptive mechanism for nutrient conservation, and this remains intact in the Manual Regrowth plot.

Lower topsoil nutrient concentration of the Mechanical Regrowth and Complete Clearance plots at fifteen months may be attributed to the partial and complete removal of the canopy and substrata in these plots respectively, and the destruction of the protective root mass probably increasing leaching and erosional losses of elements. The high subsoil nutrient content of the Mechanical Regrowth plot may indicate probable leaching losses of topsoil elements to lower depths, but the high bulk density values of the Complete Clearance plot (Table 14) and the low subsoil nutrients suggest losses could most probably have occurred through erosion rather than leaching. Field observations showed the Complete Clearance plot had the greatest soil erosion perhaps aggravated by a relatively steep slope of 7% in part of the plot. One could see channels and mini-anastomosed streams systems with sediment banks where water had run down the slope during rain storms.

The increased subsoil total nitrogen of the Mechanical Regrowth and Complete Clearance plots may have resulted from increased mineralization and nitrification and subsequent losses through leaching. This could also have accounted for increased subsoil values for P.

4.2.4.2 Nutrient dynamics

4.2.4.2.1 Inorganic nitrogen

The release of ammonium from decomposing organic material provides the major source of biologically available nitrogen in forest soils, and ammonium and nitrate uptake by micro-organisms and plants are the largest sinks of this element. Other processes, including atmospheric inputs, leaching and denitrification, also add or remove available nitrogen, but they are generally a small fraction (<10%) of annual mineralization and uptake in intact-forests (Rosswall, 1976). Biological uptake of available nitrogen is relatively rapid in most intact forests and consequently the pool sizes of ammonium and nitrate are small and turnovers are rapid (Vitousek and Matson, 1985). Numerous studies have reported increased nitrogen mineralization and nitrification and nitrate loss during forest disturbances and several reasons have been suggested for this rise:-

i) Increases in soil temperature and soil moisture availability caused by forest clearance is often suggested to cause increased decomposition, nitrogen mineralization and nitrification (Dominiski, 1971; Stone, 1973; Bormann et al, 1974; Aber et al 1978; Likens et al, 1979; Vitousek and Melillo, 1979; Vitousek, 1980). The direct effect of temperature and moisture on rates of both mineralization and nitrification are well documented (Föcht and Verstraete, 1977).

ii) Changes in substrate availability and quality following clearing could also cause increased mineralization and thus increase potential nitrification.

iii) A reduction in plant uptake of mineral nitrogen following clearing could cause increased nitrate availability and loss even where rates of mineralization are unaltered by the clearing. The reduced uptake of nitrogen by roots and mycorrhizae and decreased competition with decomposers for nutrients could also cause an increase in decomposition and nitrogen mineralization by increasing nitrogen availability to heterotrophs (Gadgil and Gadgil, 1978)

iv) The removal of sources of potential inhibitors of nitrifying bacteria produced by the natural forest vegetation could also increase nitrification in the cleared plots.

These reasons are not mutually exclusive, any combination of them could be important in the treatment plots.

The decrease of nitrogen in the Complete Clearance plot at fifteen months could be attributed to leaching and erosional losses and to the uptake and use by the new vegetation. Boring et al (1979) found the vegetation produced in the first year after cutting a deciduous forest in the Appalachain mountains distinguished especially by the increased concentration of nitrogen and potassium, indicating that this process minimizes hydrological losses of nutrients and is the initial phase of their new cycling.

4.2.4.2.2 Base status

The observed initial decrease in Ca and Mg in the Manual Regrowth plot may have resulted from the temporary accumulation in this plot of large amounts of unburnt logs and slash, which has the effect of reducing the amounts of rains as well as solar irradiation reaching the soil surface. It was observed that very little or no water got to the soils of this plot after light rains. These means therefore, that the soils were deprived of nutrient inputs from rain, throughfall and possible stemflow. Considerable amounts of elements, especially potassium, have been found to exist in throughfall (Fassbender and Grimm, 1981; Edwards, 1982). In addition, a reduction in these vital factors (moisture and sunlight-temperature) for microbial activity could probably reduce decomposition rates accounting for the observed decrease in nutrients. The gradual decomposition of the slash with time coupled with silvicultural activities like line opening, 'pitting', planting, and weeding, probably opened the soils to more moisture and solar irradiation, consequently increasing decomposition activities thus accounting for the subsequent nutrient increases at fifteen months.

The recorded base increases in the Mechanical Regrowth and Complete Clearance plots may be attributed as in section (4.2.4.2.1) to increases in decomposition rates and mineralization as a result of increases in soil moisture content and temperatures. The later decrease in K may be as a result of losses through leaching enhance by its high mobility and erosion but most likely as in section (4.2.4.2.1), and especially for the Complete Clearance plot, to uptake and use by the revegetation.

4.2.4.2.3 Available phosphorus

The rapid rise in P at fifteen months after stability for three months in the Manual Regrowth plot following clearance may be as a result of mineralization of organic phosphorus from leaves of the felled vegetation. The observed increase in the Mechanical Regrowth plot could be explained as above and also by increased soil pH which has been found to improve P availability in acid soils (Jordan, 1985).

The relative stability of P in the Complete Clearance plot over the study period may be as a result of the removal of most organic debris from this plot, an important store of organic phosphorus.

4.2.4.4 pH and organic carbon

The decrease in soil acidity of the Mechanical Regrowth and Complete Clearance plots may have resulted from the neutralizing effect of added nutrients from increased mineralization and decomposition processes. Many studies on land clearing especially in the slash and burn technique report pH increases as a result of ash incorporation into the soils (Sanchez, 1979; Sanchez et al, 1983; Jordan, 1985).

The temporary increase in organic carbon in the Manual Regrowth plot at three months may be explained as in section 4.2.4.2.2 by a reduction in decomposition rate by the accumulated slash but the general decline in organic carbon on all plots may be attributed in part to accelerated rate of decomposition. The dynamics of forest floor organic matter are controlled by a complex interaction of factors; decomposition rates, leaf litter input; wood litter input and decomposability (Covington, 1981). Any alteration to these factors would indirectly affect the organic carbon percentage of the site.

4.2.5 Conclusion

Land clearance inevitably affected soil nutrient concentration and dynamics in all the treatment plots, and differences were detected between treatments.

The general pattern of nutrient change in the Mechanical Regrowth and Complete Clearance plots was similar to that reported for most land clearing methods elsewhere. This consists of an initial rise immediately after clearance, attaining a peak at about six months and then declining. However, the concentration of nutrients in the Mechanical Regrowth plot were generally higher than those of the Complete Clearance plot as a result of the less drastic effects of the former method on the ecosystem..

At fifteen months, topsoil nutrient concentrations in the Mechanical Regrowth and Complete Clearance plots, where the root mass had been destroyed, were lower than those for the Manual Regrowth and Control plots with intact root mass. The higher subsoil nutrient concentrations in the Mechanical Regrowth and Complete Clearance plots might have resulted from leaching losses probably due to the abscence of the root mass, which has been shown to be an efficient nutrient conserving mechanism of tropical forests.

The most striking effect of the methods was the decrease in bases at three months in the mild Manual Regrowth method as opposed to the increases in the other two plots. The pattern of change, in topsoil nutrient concentration, shown in the Manual Regrowth plot is advantageous to tree crops where growth is slow and plants take a long time to be established. In such a situation a late release of nutrients as in the Manual Regrowth method, rather than the early and abundant releases in the mechanized methods often followed by heavy losses, is preferable.

The fact that a high proportion of nutrients are contained in the vegetation necessitates not only a consideration of the nutrient status of the soil under forest during plantation creation but also underline the need for a cautious operation with the vegetational nutrient store. On poor sites, like most of the tropical soils, the nutrient store of the vegetation is 'capital', the loss of which should be avoided in site preparation. Regrettably, there has been a shortage of data in published reports on how site factors like precipitation, slope, soil properties and vegetation as well as operational methods of clearance act to influence the nutrient capital of the ecosystem.

The results of the soils studies have highlighted the effects of the three clearing methods on soil physical and chemical properties and their changes with time. Many factors are responsible for the observed changes such as, nutrient input through litter-fall, and the rate of decomposition of organic matter discussed in chapter five.

CHAPTER FIVE

EFFECTS OF CLEARING METHODS ON NUTRIENT DYNAMICS

5.0 Introduction

Through the work of many scientists such as Nye and Greenland, (1960); Cunningham, (1963); it is widely recognized by soil scientists and ecologists that the luxuriant and tall tropical forests may grow on relatively nutrient poor, highly weathered substrates. In these conditions tropical forests have evolved mechanisms to utilize the nutrients in the soil solution efficiently as well as those entering the forest from the atmosphere and to recycle nutrients (Golley and Clement, 1978; Golley, 1983). Adaptations to nutrient poor environments occur in any region where soils are infertile and would vary with the nature of nutrient stress. Since poor soils are common in the tropical regions, nutrient conserving mechanisms are commonly associated with tropical species (Jordan, 1985). Among the many adaptive and nutrient conserving mechanisms to nutrient poor soils are; mycorrhizae, long lived resistant leaves, thick bark and most conspicuously the production of a relatively large root mass (Hermann, 1977) and the concentration of this mass on or near the soil surface (Golley and Clement, 1978; Jordan and Harrera, 1981; Golley, 1983).

All the nutrient conserving and cycling mechanisms are integral parts of undisturbed, native forests. When such forests are cleared and the site used for agriculture, silviculture, pasture or other reasons, these mechanisms are affected proportionately to the intensity and extent of the disturbance. Changes in nutrient cycles due to different types of disturbances can be classified using three criteria (Jordan, 1985).

i) *Intensity*

The intensity of disturbance can be light, moderate or severe. A light disturbance is considered as one which does not disrupt the basic structure of the ecosystem. For example, a tree gap created by the fall of a large tree. A moderate disturbance is one in which the structure of the forest is destroyed, but the soil is not degraded. For example the cutting of primary forest, retaining a proportion of the trees and preserving the organic surface, and planting with tree crops.

A severe disturbance is one in which forest structure is destroyed and the soil is severely degraded. An example is the clearing of land with heavy machinery and scraping off the surface organic matter.

ii) *Size*

The factor used to classify disturbance here is the ease with which seeds that initiate the recovery can enter the disturbed site. In small disturbances (tree-fall gaps), seeds from surrounding trees fall directly into the gaps or were already in the soil before gap formation.

In intermediate size disturbances, seed dispersing animals can freely traverse the disturbed area (usually one to a few hectares).

In large disturbances, the distance from undisturbed forest to the middle of the disturbed area is beyond the normal range of the animals which carry seeds and mycorrhizal spores. Revegetation may be by windborne seeds.

iii) *Duration*

A short duration is a single discrete occurrence, such as a logging operation, which is over in a matter of days or less and after which recovery begins immediately.

Disturbance of intermediate duration can be a series of events such as planting, weeding and harvesting during shifting cultivation. When the disturbance ceases, as when an agricultural or plantation plot is abandoned, recovery occurs without interruption.

A long-term disturbance is one in which disruptive effects continue long beyond the cessation of the original disturbance event. For example, soil compaction by heavy machinery or nutrient depletion beyond a rapid recovery level or soil erosion out of the area can persist for a long time.

Changes during the various types of disturbances revealed several patterns of nutrient cycling and vegetation dynamics in different regions and under different circumstances. Changes range from virtually undetectable (in small, short and non intense disturbances such as natural tree-falls) to almost total (in areas denuded by landslides or volcanic activity). Most of the disturbances caused by man fall somewhere in between the two extremes.

In this chapter we will consider changes in fine litter-fall, the fine litter fraction of the forest floor and decomposition rates of leaf litter and their nutrient contents as affected by three types of disturbances; low intensity, intermediate size and short duration (Manual Regrowth); moderate intensity, intermediate size and intermediate duration (Mechanical Regrowth), severe intensity, intermediate size and long duration (Complete Clearance).

5.1 Fine litter-fall

Litter-fall, the organic debris shed by forest vegetation upon the surface of the soil, has long engaged the attention of ecologists (Bray and Gorham, 1964). The study of the quantitative aspects of litter-fall continues to be an important part of forest ecology (Proctor, 1983, 1984). The study of litter aspects of an ecosystem is essential, in any study of productivity and dynamics of the ecosystem, as litter production represents the major pathway in the transfer of energy and materials within the system (Tsai, 1978). It is also the principal source of energy for the saprobiota of the forest floor and soil (Spain, 1984). This transfer of material and energy is especially important in the tropical rainforest ecosystem where the soils are generally poor and it is mainly through litter-fall that not only the vegetation can benefit from the nutrient elements released but also other organisms which contribute to the diversity that the tropical rainforest ecosystem is well known for (Tsai, 1978). Much has been and can be said about the usefulness of the study of litter production , however, some of the more relevant purposes for studying it are:-

i) To give a gross estimate of primary productivity (Bray and Gorham, 1964; John, 1973; Klinge, 1978; Ogawa, 1978; Proctor et al, 1983; Singh et al, 1984; Songwe et al, 1988).

ii) To quantify the transfer or flux of materials and energy from the vegetative phase of the ecosystem to the litter phase (Bray and Gorham, 1964; Bernhard, 1970; Klinge, 1978; Ogawa, 1978; Proctor et al, 1983; Dantas and Philipson, 1989).

iii) To identify ecosystems and plant communities. As different ecosystems have different litter-fall, it could be used as an attribute in the description of plant communities (see review Bray and Gorham, 1964; Devineau, 1976; Klinge, 1978; Spain, 1984).

iv) To give information (when combined with forest floor litter measurements) on decomposition rates (Olson, 1963; Bernhard, 1970; UNESCO/UNEP/FAO, 1978; Proctor et al, 1983).

Because litter-fall is an important component of net primary production (Chapman, 1986), authors have often attempted to compare litter-fall at their study sites with that in other regions (Tanner, 1980; Lam and Dudgeon, 1985) but this study compares the amount of litter-fall of plots in the same area cleared using different techniques.

5.1.1 Materials and methods

Fine litter-fall measurements were carried out by catching litter in 50 x 50 cm wooden frame traps with 15 cm deep sides and a plastic mesh attached at the bottom. These traps stood on wooden frames at approximately 75 cm above the ground. Fifteen traps were randomly located at permanent positions in fifteen randomly selected subplots of the 50 x 50 m areas (Figure 10). Litter was collected at two and four weekly intervals depending on the season. After each collection, samples were oven-dried at 105 °C for 12 hours and sorted into three fractions, leaves, woody materials (twigs ≤ 2 cm in diameter and barks ≤ 2 cm thick), and others which included reproductive parts and unrecognizable particles. The subsamples were bulked on monthly bases before grinding and subsamples collected for analysis.

5.1.2 Results

5.1.2.1 Fine litter-fall amounts

The mean monthly fine litter-fall amounts in the different plots over the one year study period (June 1988 - May 1989), are shown in Figure 13. All plots showed similar seasonal litter-fall trends with two peaks more visible in the Control plot than the three cleared plots. The highest peak occurred between the months of February and April which is the period of first rains and the smaller peak between August and October corresponding to the period of second rains.

An analysis of variance (ANOVA) of litter-fall data over the study period, showed a significant difference ($p = 0.05$) between the Control and Mechanical Regrowth plots and a very significant difference ($p = 0.01$) with the Complete Clearance plot. No significant difference was observed with the Manual Regrowth plot. It was noted that there was a significant difference between the Mechanical Regrowth and Complete Clearance plots.

Total annual fine litter-fall summarized in Table 17, show clear treatment effects. The Complete Clearance plot had the lowest amount of litter-fall, only one sixth of the amount caught in the Control plot, depicting the drastic effects of this method of clearance. The Manual Regrowth plot on the other hand was 2 tonnes short of the Control plot's value as a result of the mild effects of the method on the ecosystem. There was a big difference of 5 tonnes between the Mechanical Regrowth and the Control plot.

In all the plots, leaves accounted for the highest percentage of total litter-fall (Table 17). In the Control plot, 58% of total litter-fall was leaves, 72% for the Manual Regrowth , 70% for the Mechanical Regrowth and 82% for the Complete Clearance plot.

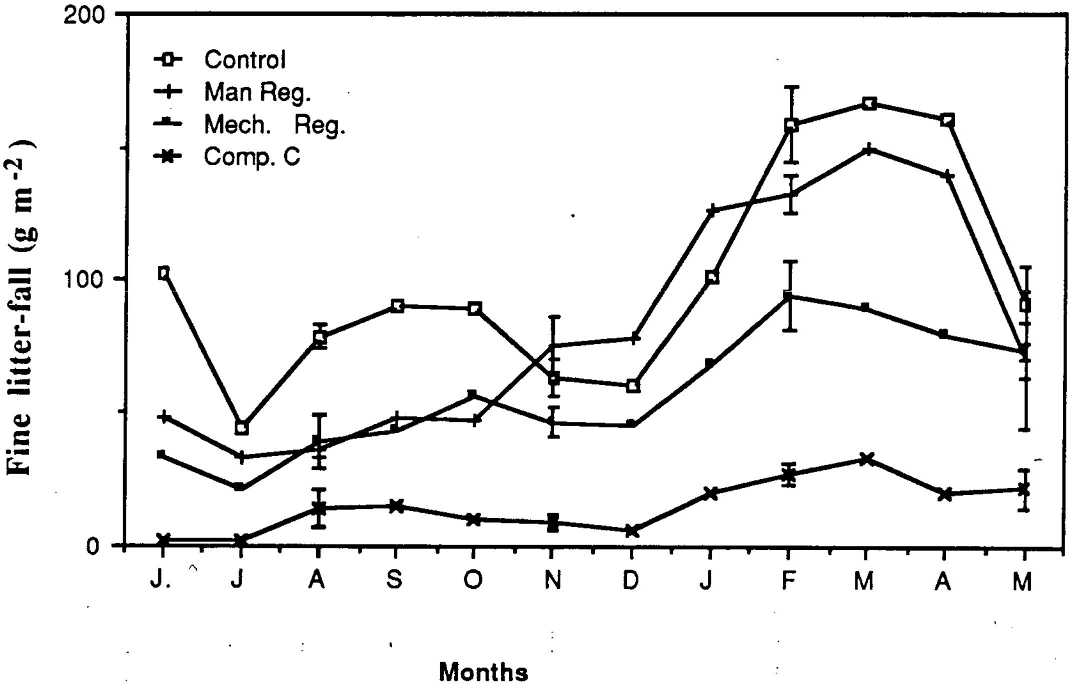

Figure 13: Effects of land clearing methods on fine litter-fall in the Mbalmayo forest reserve (June 1988 - May 1989). Bars are standard errors of means of fifteen samples. Litter-fall studies started 14 months after land clearance.

Fine litterfall fraction	Treatment			
	Control	Man. Reg.	Mech. Reg.	Comp. C.
Leaves	7.05 (58)	7.12 (72)	4.85 (70)	1.51 (83)
Woody material	3.08 (25)	1.70 (17)	1.14 (16)	0.08 (4)
Others	1.96 (16)	1.08 (11)	0.94 (9)	0.23 (12)
Total	12.09	9.9	6.93	1.83

Table 17: Annual fine litter-fall fractions (t ha^{-1}) and their percentages (in brackets) in the different plots (June 1988 - May 1989). Mean monthly litter-fall fractions are given in appendix 4.

5.1.2.2 Nutrient composition of fine litter-fall

Nutrient concentrations of fine litter-fall during the observation period of one year, revealed no fundamental differences between the treatment plots (Figure 14). Nitrogen and calcium concentrations were variable throughout the year in all the plots with no seasonal tendency. The concentration of phosphorus and to a lesser extent magnesium, showed some seasonal pattern with peaks in the dry season and the lowest values in the raining season. The only consistent seasonal trend was in potassium concentration, which showed two peaks corresponding to the two dry seasons.

The nutrient content of litter-fall calculated by multiplying each nutrient concentration by the corresponding litter-fall mass is given in Table 18. The mean annual nutrient concentrations are similar in all the plots, hence the differences in nutrient content resulted from differences in the litter-fall amounts.

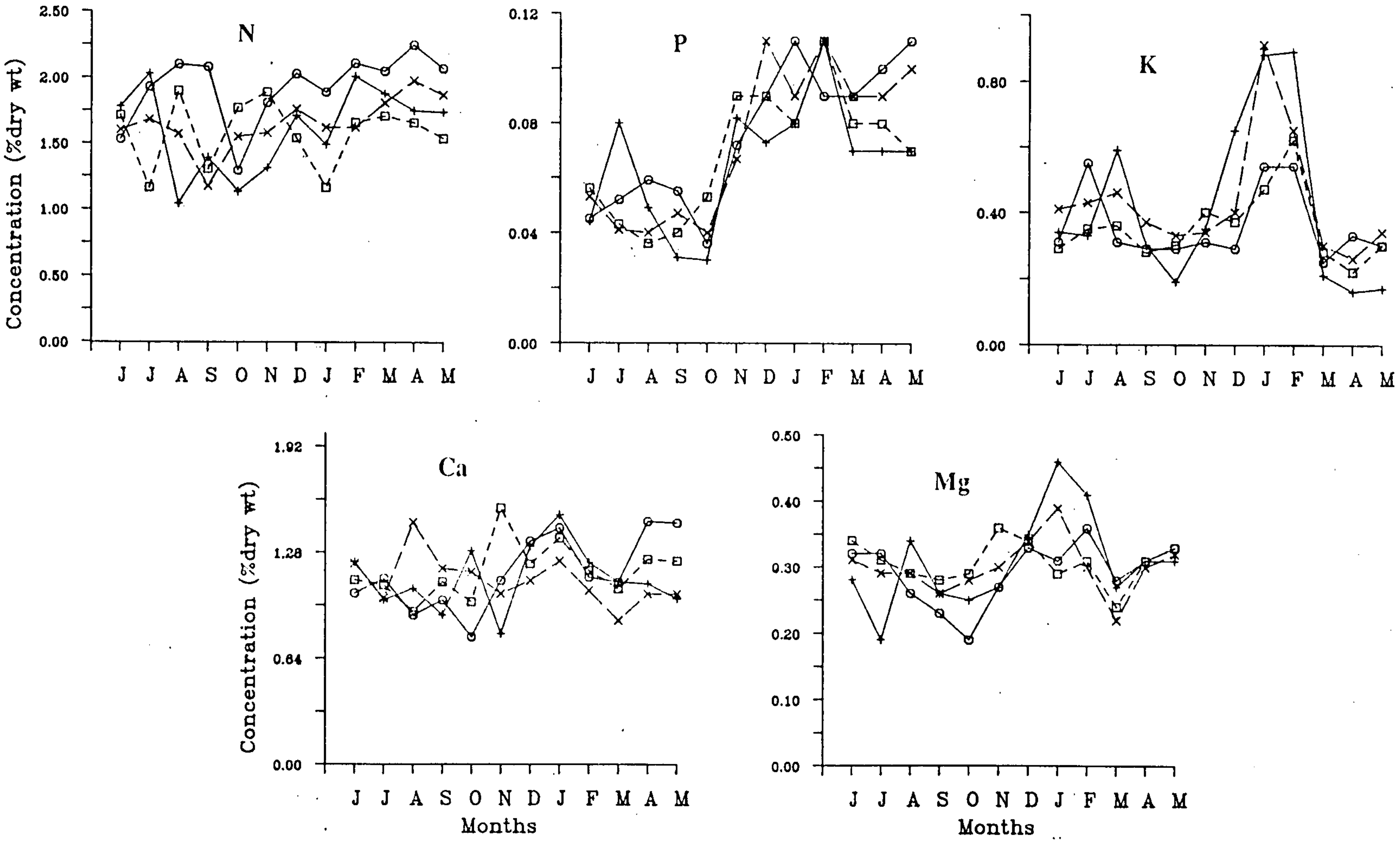

Figure 14: Effects of land clearing methods on nutrient concentrations (%dry weight) of fine litter-fall in the Mbalmayo forest reserve (June 1988 - May 1989). o——o Control, x— — — x Man. Reg ☐- - - -☐ Mech. Reg., +——+ Comp. C. Litter-fall studies started 14 months after land clearance. Nutrient concentration of monthly litter-fall fractions can be seen in appendix 5.

Treatment	Concentration					Weight	Content					
	N	P	K	Ca	Mg		N	P	K	Ca	Mg	Total
Control	1.93	0.07	0.36	1.18	0.29	12.1	233	8	44	143	35	463
Man. Reg.	1.65	0.07	0.43	1.11	0.30	9.9	163	7	42	110	30	352
Mech. Reg	1.58	0.07	0.35	1.17	0.31	6.9	109	5	24	81	21	240
Comp. C.	1.60	0.06	0.42	1.12	0.29	1.8	29	1	8	20	5	63

Table 18: Average nutrient concentration of fine litter-fall (%dry wt.), annual fine litter-fall amounts (t ha^{-1} yr^{-1}), and annual nutrient content of fine litter-fall (kg ha^{-1}) in the different plots over the 12 months study period (June 1988 - May 1989). Results of monthly fine litter-fall fractions and monthly nutrient concentrations of fine litter-fall are given in appendix 4 and Figure 12 respectively.

5.1.3 Discussion

5.1.3.1 Litter-fall amounts

The annual fine litter-fall amount for the study area (considering the Control plot), lie within the range of values for other tropical forests reviewed and studied by; UNESCO/UNEP/FAO (1978), Proctor et al (1983), Spain (1984), Vitousek (1984), Songwe et al (1988), Dantas and Philipson (1989). In many of these studies, peak litter-fall has been related to period of water stress with the maximum occurring during the dry season. However, results in Figure 13 show peak litter-fall in the wet season in the Mbalmayo area. The occurrence of exceptional high winds often observed prior to rainfall in this area might have partially contributed to the litter-fall peaks. Hopkins (1966) and John (1973) associated litter-fall rates with wind activity. A few studies have also reported maximum litter-fall during the wet season in the tropics, Cornforth (1970) in Trinidad, Edwards (1977) in New Guinea, Jackson (1978) in Brazil, Enright (1979) in New Guinea, Proctor et al, (1983) in Sarawak. Hopkins (1966) working in the tropical forest and Proctor (1983) after examining a large number of tropical forest litter-fall values, concluded that there was no simple relationship between litter-fall and a single environmental factor.

The low litter-fall amount observed in the Complete Clearance plot was expected since all the original vegetation had been removed in the clearing process. All litter input therefore, came from the new vegetation (still very young) and possibly from wind transport from the surrounding vegetation. In addition to input from the new vegetation, the Manual Regrowth and Mechanical Regrowth plots benefited from continuous input from the big trees. A total of 95 and 122 trees remained in the Manual Regrowth and Mechanical Regrowth plots respectively, after clearance. From field observations, trees in the Manual Regrowth plot had larger crowns than those in the Mechanical Regrowth plot. This probably accounted for the lower light reaching the soils in this plot (Leakey, 1987) and could explain the higher litter-fall amounts observed, in spite of the fewer trees.

5.1.3.2 Nutrients

The concentration of nitrogen and calcium in the litter-fall was found to be fairly constant throughout the year. Similar studies by Bernhard (1970), Cornforth (1970) and Brassel et al, (1980) found no seasonal variation in nutrient concentration of tropical rainforest litter-fall. However, the concentrations of potassium, phosphorus and to a lesser extent magnesium, showed some seasonal tendency. The decrease in the concentration of these elements during the wet season might have resulted from leaching from the canopy before litter-fall and leaching from the litter in the collection traps. This is particularly true for potassium, a great deal of which has been shown to be leached by rain from the living crown (Nye and Greenland, 1960; Bernhard-Reversat, 1976; Fassbender and Grimm, 1981; Edwards, 1982). The increase observed in the dry season is likely to have resulted from the accumulation of the elements on the litter surfaces.

A comparative analysis of Table 18 and 19, show that the total litter-fall amounts in the Control and Manual Regrowth plots lie within the range for tropical forests in Africa. The litter-fall amounts of the other two plots, lie below this range as a result of the significant disturbance caused to the ecosystem during their clearance.

The nitrogen content of the Control plot is slightly higher than the range for the Africa tropical forests. This may be as a result of the high nitrogen concentration of this flora. However while the nutrient contents of litter in the Mechanical Regrowth plot are just slightly below the ranges for Africa tropical forests, those for the Complete Clearance plot lie far below these ranges, reflecting the intensity of the disturbance caused to the ecosystem by this technique of land clearance.

Continent		Litterfall	N	P	K	Ca	Mg
Africa	mean	11.7	165.0	7.4	60.1	105.0	40.7
	range	8.0-15.3	104-224	4.0-14.0	26-104	61-206	22-53
Asia	mean	7.8	87.7	4.4	24.9	100.7	17.9
	range	3.9-11.5	44-110	1.2-7.0	17-33	13-290	9-24
Central and south America	mean	7.2	71.4	3.0	27.3	69.5	18.5
	range	4.4-13.0	28-169	0.8-8.6	8-130	8.0-240	5-64

Table 19: Annual litter-fall ($t\ ha^{-1}\ yr^{-1}$) and nutrient content ($kg\ ha^{-1}$) from different tropical rainforests (After Dantas and Philipson, 1989)

5.2 Effects of clearing methods on the fine litter fraction of the forest floor

The definition and importance of the forest floor compartment of the ecosystem was briefly reviewed in section 3.2.1. The materials and methods used in its investigation are outlined in section 3.4.1. In section 3.5.1.1, the results of the investigation in the natural forest before land clearance are given and discussed. In this section, results of the investigation carried out at three and fifteen months after land clearance (six and nineteen months after first sampling) are presented and discussed.

5.2.1 Results

5.2.1.1 Fine litter amounts

The results of fine litter amounts on the forest floor in the various plots measured before clearance (February 1987), at three months (August 1987) and at fifteen months (August 1988) after clearance, are summarized in Table 20. An ANOVA of these data showed significant ($p = 0.05$) and very significant ($p = 0.01$) effects of the Mechanical Regrowth and the Complete Clearance methods respectively, on this ecosystem compartment three months after clearance.

The amount of litter in the Complete Clearance plot at three months was only one fifth that of the control plot, but at fifteen months, it was just one tonne short of the Control plot value. In the Mechanical Regrowth plot, the amount at three months was one half that in the Control plot but at fifteen months, it had exceeded this value. The Manual Regrowth plot on the contrary, showed increased litter amounts at three months, and at fifteen months was more than double the amount in the Control plot.

Treatment	Febuary 1987	August 1987	August 1988
Control	3.77 ±0.48	5.23 ±0.29	4.31 ±0.40
Man. Reg.	3.77 ±0.48	5.89 ±0.64	10.6 ±2.30
Mech. Reg.	3.77 ±0.48	2.70 ±0.53	5.16 ±1.36
Comp. C.	3.77 ±0.48	0.95 ±0.50	3.14 ±1.15

Table 20: Amount of fine litter fraction (t ha $^{-1}$) on the floor in the treatment plots before and after land clearance. The value for the natural forest (before clearance, February 1987) is the average of 12 samples and values after clearance are results of 5 samples each ± SE.

5.2.1.2 Nutrient composition

The nutrient concentration of the fine litter fraction on the forest floor 1 summarized in Table 21, shows low concentrations of potassium, calcium and magnesium in the Mechanical Regrowth and Complete Clearance plots at three months after clearance (August, 1987). At fifteen months after clearance (August, 1988), the Complete Clearance plot still showed low potassium, calcium and magnesium concentrations, but only potassium concentration in the Mechanical Regrowth plot was still low. The Control and Manual Regrowth plots showed similar nutrient concentrations. The nutrient content also shown in Table 21 illustrates a similar trend to that of litter weight at the different sampling times.

5.2.2 Discussion

5.2.2.1 Fine litter mass

The fine litter fraction of the forest floor measured in the study area before clearance (February 1987) was discussed in section 3.5.1.1. The high litter amount observed in August (1987) for the Control (natural forest) plot is as a result of increased litter-fall in this area during this period (this study).

The decrease in litter amounts in the Mechanical Regrowth and Complete Clearance plots (August 1987) resulted from the partial and total removal of the vegetation during clearing. The increase later observed in the Complete Clearance plot (August 1988) came mainly from the weeds of the dominant pioneer species, particularly *Musanga* and *Eupatorium*, which invaded this plot. The Mechanical Regrowth plot, other than the input from weeding operations, benefited from additional input from the big trees still to be poisoned. The large amount of litter in the Manual Regrowth plot in August (1988), came from weeding operations, the big trees still to be poisoned and the gradual dropping off of dead leaves and twigs from the felled, slashed and unburnt trees. This plot contains a large amount of logs and branches that were not measured in this study. The eventual decomposition of these larger litter fraction is an important long term aspect of this method. This would assure gradual but continuous nutrient supply, very important for plant growth and sustainability.

5.2.2.2 Nutrient composition

Low potassium, calcium and magnesium concentrations at three months resulted probably from leaching losses as a result of increased moisture reaching the soils due to the partial and total destruction of the protective vegetation cover. Fifteen months after clearance, the new vegetation in the Mechanical Regrowth plot coupled with the shade from the big trees reduced rain input into the forest floor hence reducing leaching activity. This probably accounted for the increase in concentrations of calcium and magnesium. The persistent low concentration of potassium is most likely a consequent of its high mobility. In the Complete Clearance plot, rainfall input was still important after fifteen months since the only forest floor protection was from the young vegetation frequently weeded. Therefore, there was continuous nutrient loss through leaching though at a reduced rate than at three months, which explains the low concentrations of potassium, calcium and magnesium still observed at this period.

The similarity in the amount of litter and its nutrient concentration and content in the Control and Manual Regrowth plots once again, is evidence of the moderate disturbance caused by this method on the ecosystem.

Treatment	Nutrient concentration (August 1987)					Nutrient content (August 1987)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Control	1.42	0.06	0.15	0.87	0.25	74.3	3.14	7.8	45.5	13.1
Man. Reg.	1.42	0.05	0.15	0.91	0.23	83.6	2.90	8.8	53.6	13.5
Mech. Reg	1.18	0.05	0.13	0.55	0.14	31.9	1.30	4.0	14.8	3.8
Comp. C.	1.50	0.05	0.06	0.50	0.13	14.9	0.47	0.57	4.7	1.2
	(August 1988)					(August 1988)				
Control	1.34	0.04	0.23	0.90	0.19	57.7	1.7	9.9	38.8	8.2
Man. Reg.	1.02	0.03	0.38	0.86	0.18	108	3.2	40.1	90.8	19.0
Mech. Reg.	0.95	0.03	0.18	0.90	0.18	49	1.5	9.3	46.4	9.3
Comp. C.	1.0	0.04	0.18	0.55	0.12	31.4	1.2	5.6	17.3	3.8

Table 21: Nutrient concentration (% dry weight) and nutrient content (kg ha^{-1}) of fine litter on the floor at three and fifteen months after land clearance in the different treatment plots.

5.3 Leaf litter decomposition

5.3.1 Introduction

Decomposition is the complex process through which plant and animal remains are broken down into their constituent parts. In forest ecosystems, litter decomposition represents the major pathway for the supply of plant nutrients to soil. Particularly for tropical rainforests growing in nutrient poor soils with relatively low external inputs, the turnover of bioelements is an important step (Staaf and Berg, 1982). The energy and nutrients released in this recycling process are utilized by flora and fauna which make up food webs on which ultimately most living organisms depend, and thus the decomposition system forms a dynamic interface between the abiotic and biotic components of the ecosystem (see review by Swift et al, 1979). The breakdown of organic materials occurs through leaching, catabolism and comminution. This leads to a reduction in weight of the original substrate and reduction in total nutrient content (in the absence of fixation) although not necessarily to a reduction in percent nutrient concentration. Overall, these three processes lead to substrate weight reduction and changes in quality of the substrate with time. The rate of weight loss provides a useful index of the rate of decomposition once an initial leaching phase is past.

Litter decomposition rates and concomitant mobilization of nutrients are determined by a variety of interelated variables such as moisture, temperature, activity of micro-organisms and substrate quality (Witkamp, 1971; Meentemeyer, 1978; Melillo et al, 1982). Substrate quality includes not only the concentration and availability of nutrients and of carbon and energy sources but also modifiers, such as tannins which affect the activity of heterotroph. Clear-felling causes changes in the soil environment by increasing the water table and soil moisture content (Lundin, 1979). Loss of canopy protection leads to loss of interception of precipitation (Gash et al 1980) and increased temperature extremes (Bjor, 1972; Cochran, 1975).

Decomposition processes accelerate with increasing soil moisture (Sommers et al, 1980) and temperature (Theodorou and Bowen, 1983; Clark and Gilmour, 1983), and increased leaching of nutrients from tree litter in laboratory studies has been observed with increasing temperature (Witkamp, 1969; Buldgen and Remacle, 1981). While fungal populations have been observed to decrease and bacterial populations to increase on clearfelling (Bååth, 1980; Hendrickson et al, 1982), overall community biomass and respiration can increase (Niemela and Sundman, 1977, Sundman et al, 1978). It has also been suggested that the loss of mycorrhizae can increase litter decomposition (Gadgil and Gadgil, 1971; Berg and Lindberg, 1980). Substrate quality also changes on felling with the large input of green material rather than senescent or abscinded tissue.

All the above observations suggest that decompostion processes increase on felling, and that litter weight loss and nutrient mobilization is more rapid from leaves on clearfelled sites than from leaves in the natural forest. At Mbalmayo, interest was not simply on rates of decomposition as affected by clearing but on how these rates are affected by different types of clearing methods.

Although an increasing amount of information on litter decomposition and nutrient cycling in tropical rainforest ecosystems has been made available during the past few years (Olson, 1963; Jordan and Jerry, 1972; Edwards, 1982; Edwards and Grubb, 1982; Klinge, 1978; Aber et al, 1978; Aber and Melillo, 1980; Irmler and Firch, 1980; Tanner, 1980; Krause, 1982; Anderson and Swift, 1983; Anderson et al, 1983; Golley, 1983; Gong and Ong, 1983; Proctor et al, 1983; Adedeji, 1984; Binkley, 1984; kirmise and Malechek, 1987), comparative studies on decomposition between disturbed and undisturbed rainforests, are relatively few (Jordan et al, 1983; Maheswaran and Gunatilleke, 1988). No studies have yet been reported on effects of different types of disturbances on decomposition processes and turnover rates.

The extent of disruption of decomposition in modified sites may have implications for the regrowth and establishment of forest tree crops and seedlings. Therefore studies of the effects of disturbance on turnover rates and on soil biological processes are important for better forest management and soil nutrient conservation.

Several techniques have been used in studying litter decomposition, and can be broadly classified as direct methods (e.g. litter bags, tethered leaves, radioisotope tagging) where known quantities of litter are placed in the field and retrieved after set time intervals, or indirect methods (e.g. harvest data, paired-plot, decomposition constants) where balance sheets of organic remains on two different collection dates estimate assumed losses through decomposition (see reviews by Singh and Gupta, 1977; Woods and Raison, 1982). The litterbag technique is the one that has been most widely used in forest decomposition study, despite several drawbacks (Witkamp and Olson, 1963; Wiegert and Evans, 1964; St John, 1980), and objections that it creates an artificial environment within the bag where the rate of decomposition will differ from that of the surrounding litter. Although this method may under- or overestimate actual decomposition, results from litter bag studies are assumed to reflect trends characteristic of unconfined decompositing litter and, as such, allow for comparisons among species, sites and experimental manipulations (Wieder and Lang, 1982). However, various reviews have examined comparisons of different mesh sizes, tethered litter versus enclosed litter and litterbag results versus indirect method results (e.g. Singh and Gupta, 1977; Woods and Raison, 1982; Wessen, 1983) and generally conclude that the evidence for objections to the use of litterbags for field incubations is contradictory. On balance, the choice of method must depend on the nature of the litter and particular ecosystem in question as well as the objectives and duration of the study (Titus, 1985).

5.3.2 Materials and Methods

Treatment effects on rates of decomposition were investigated using mixed leaf litter enclosed in bags measuring 30 cm x 25 cm constructed with 2 mm nylon screen. Freshly fallen leaves were collected from the forest floor in the natural forest and air-dried in the laboratory for two weeks to approximately constant weight. Approximately 10 g of the air-dried leaves were weighed into each bag. Three of the bags were selected at random for subsequent determination of initial percentage dry weight and mineral nutrient content. The remainder were assigned at random locations within the 50 x 50 m areas marked out in each plot. To fifteen of the subplots chosen at random in these areas was assigned 15 bags. The bags were placed so that the lower surface was in contact with the soil and the upper surface approximately level with the surrounding natural litter, (except for the complete clearance plot with very little litter) then anchored in position with small sharp sticks inserted obliquely through the outer sections, of the stitched margins, into the soil.

The bags were collected after decomposition had proceeded for three periods of time, two months, four months and six months. At each collection time, five bags were randomly harvested, put into plastic bags and transported to the laboratory where they were carefully transferred into paper bags and oven-dried at 105 °C for 12 hours. The oven-dried samples were carefully separated from soils and other foreign organs before they were weighed, ground and subsamples collected after thorough mixing for chemical analysis as described in Appendix I.

NB: Litter bags were put out in the field in the month of June corresponding to the short rainy season. Results would have probably been different if studies took place during the dry season.

5.3.3 Results

5.3.3.1 Litterbag weight loss and decomposition rates

Litterbags from each of the treatment plots lost weight from an initial oven dry weight of 8.74 g. The simplest model that describes the weight loss over time of litter that does not readily decompose is that of a constant fraction loss of the type e^{-x}. However, this model assumes that the material being decomposed contains only one substrate, and that no product of decomposition is inhibiting to further decomposition of the substrate. This model does not take into account either the complexity of the composition of the litter or of decomposition processes, but can still serve as a good useful 'first approximation' of decomposition weight loss (Swift et al, 1979).

Olson (1963), describes this model as follows:

$$\ln x/x_o = -Kt$$

Where x = the fraction remaining after time (t).

x_o = original weight

K = decay parameter

t = time (in years)

Solving the equation for K indicates that:

K = slope of a regression of ln (fraction remaining) with time.

$$\ln x = \ln x_o - Kt$$

$$= a - Kt \quad \text{where } a \text{ is a constant}$$

A plot of the mean percent dry weight remaining with time and ln (mean percent weight remaining) is given in figures 15a and 15b. The regression of ln (percent weight remaining) over time for the treatment plots are given in Table 22.

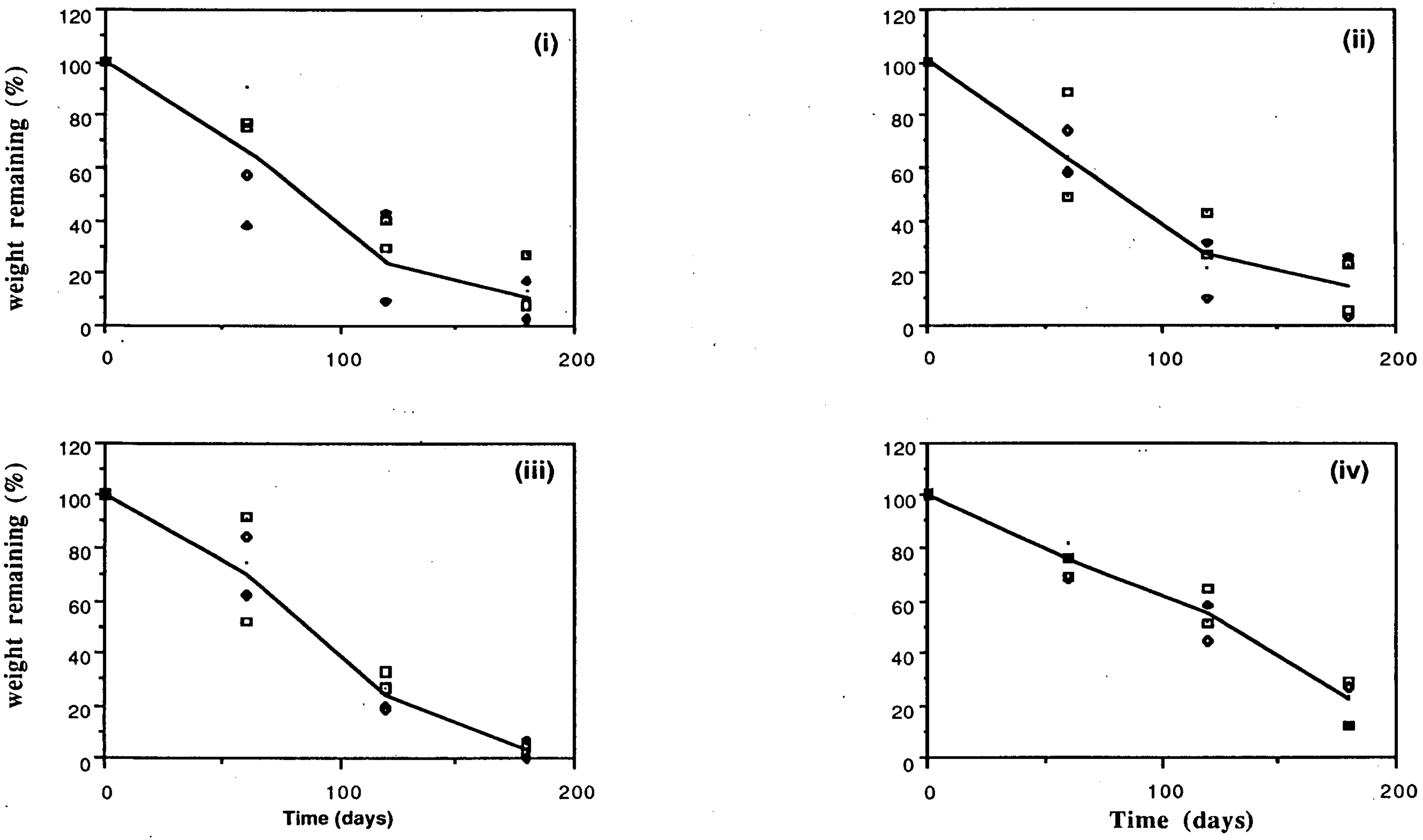

Figure 15a: Percent weight remaining over time of decomposing leaf litter in the treatment plots. Control plot (i) Manual Regrowth plot (ii), Mechanical Regrowth plot (iii), Complete Clearance plot (iv).

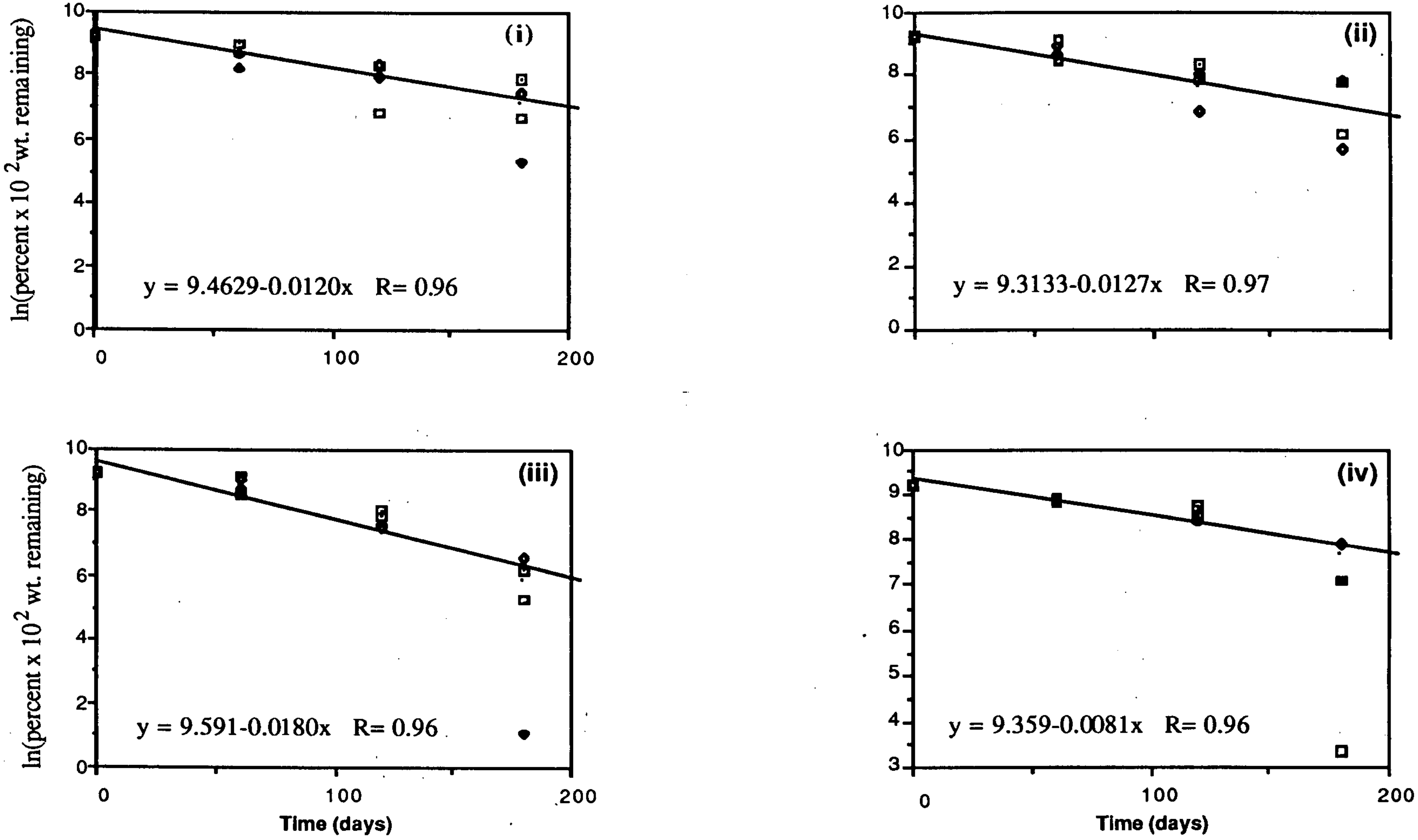

Figure 15b: ln(percent x 10^2 weight remaining) over time of decomposing leaf litter in the treatment plots. Control plot (i) Manual regrowth plot (ii), Mechanical Regrowth plot (iii), Complete Clearance plot (iv).

Treatment	*a*	*b*	*r*	*n*	*K* (yr^{-1})
Control	9.46	-0.012	-0.96	15	4.4
Man.Reg.	9.31	-0.013	-0.97	15	4.6
Mech. Reg.	9.59	-0.018	-0.96	16	6.6
Comp.C.	9.36	-0.008	-0.96	16	3.0

Table 22: Statistics and *K* values for regressions of ln (mean percent x 10^2 litter bag weight remaining) over time (days) for each of the treatment plots. *K* is obtained by multiplying *b* by 365.

The pattern of weight loss was very similar in the Control and Manual Regrowth plots throughout the study period (Figure 15a i and ii). Differences with the Mechanical Regrowth plot (Figure 15a iii) were observed only after six months. However, an ANOVA showed significant (p = 0.05) differences between the Complete Clearance plot (Figure 15a iv) and all the other plots at four months but only with the Mechanical Regrowth plot at the end of the study (after 6 months).

At the end of the study, the highest percent weight loss was observed in the Mechanical Regrowth plot (96%), and the lowest in the Complete Clearance plot (79%). The Control and Manual Regrowth plots lost the same percent weights (86%)

Relative rates of decomposition at each harvest time were calculated and are shown graphically in figure 16. The rates for the Control and Manual Regrowth plots showed a more or less constant decomposition pattern throughout the study period. The Mechanical Regrowth plot showed a remarkable linear increasing decomposition rate throughout the same period. The Complete Clearance plots, beside having the lowest rates, showed no clear pattern during the observation period. These results suggest that the Manual Regrowth method does not have significant effects on ecosystem processes. On the other hand the differences observed between the Control plot and the Mechanical Regrowth and Complete Clearance plots, are evidence of the effects of these methods on ecosystem functions.

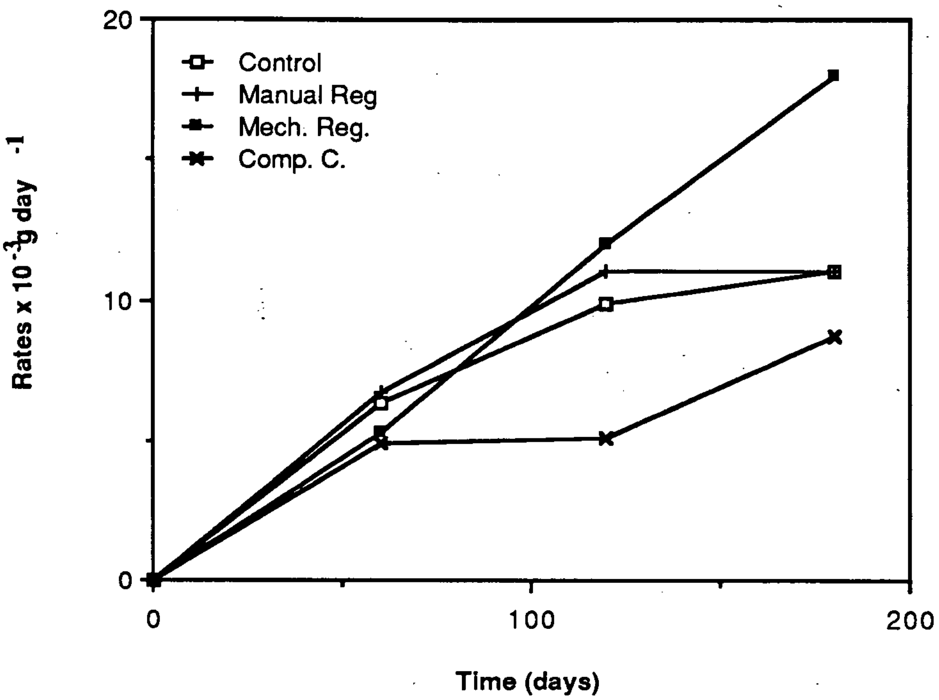

Figure16: Relative rates of decomposition of leaf litter in the treatment plots at each harvest time.

5.3.3.2 Nutrient composition of decomposing litter in bags

Mean nutrient concentration data (percent initial concentration) and nutrient content for all collection dates over the study period were calculated for all the treatment plots and are shown graphically in figures 17 and 18.

a) *Nitrogen*

Nitrogen concentration of decomposing leaf litter showed a general increased pattern over the study period in all the treatment plots. At the end of six months, increases recorded ranged from 58% for the Mechanical Regrowth plot to 103 % for the Control plot with increases of 62% and 67% observed in the Manual Regrowth and Complete Clearance plots respectively. No significant differences were determined between the various treatments.

Nitrogen content showed a pattern opposite to that of its concentration. Once again there was close similarity in leaf litter contents of the Control and Manual Regrowth plots. An ANOVA of these data showed significant (p = 0.05) treatment

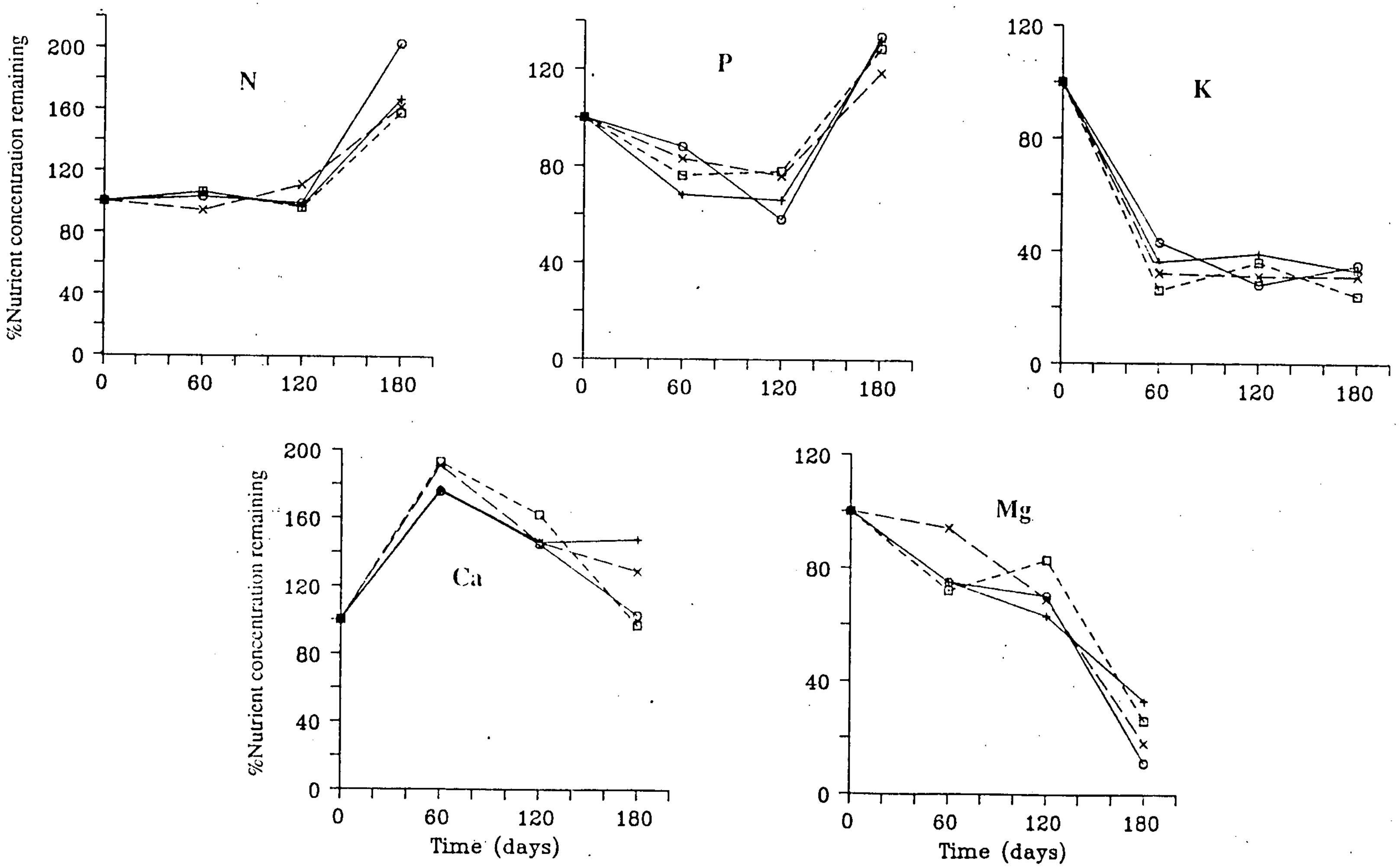

Figure 17: Percentage of initial concentration of elements (N, P, K, Ca, Mg) remaining with time in decomposing leaf litter in the different plots. o———o Control, x— — — —x Man. Reg., □– – – –□ Mech. Reg., +———+ Comp. C.

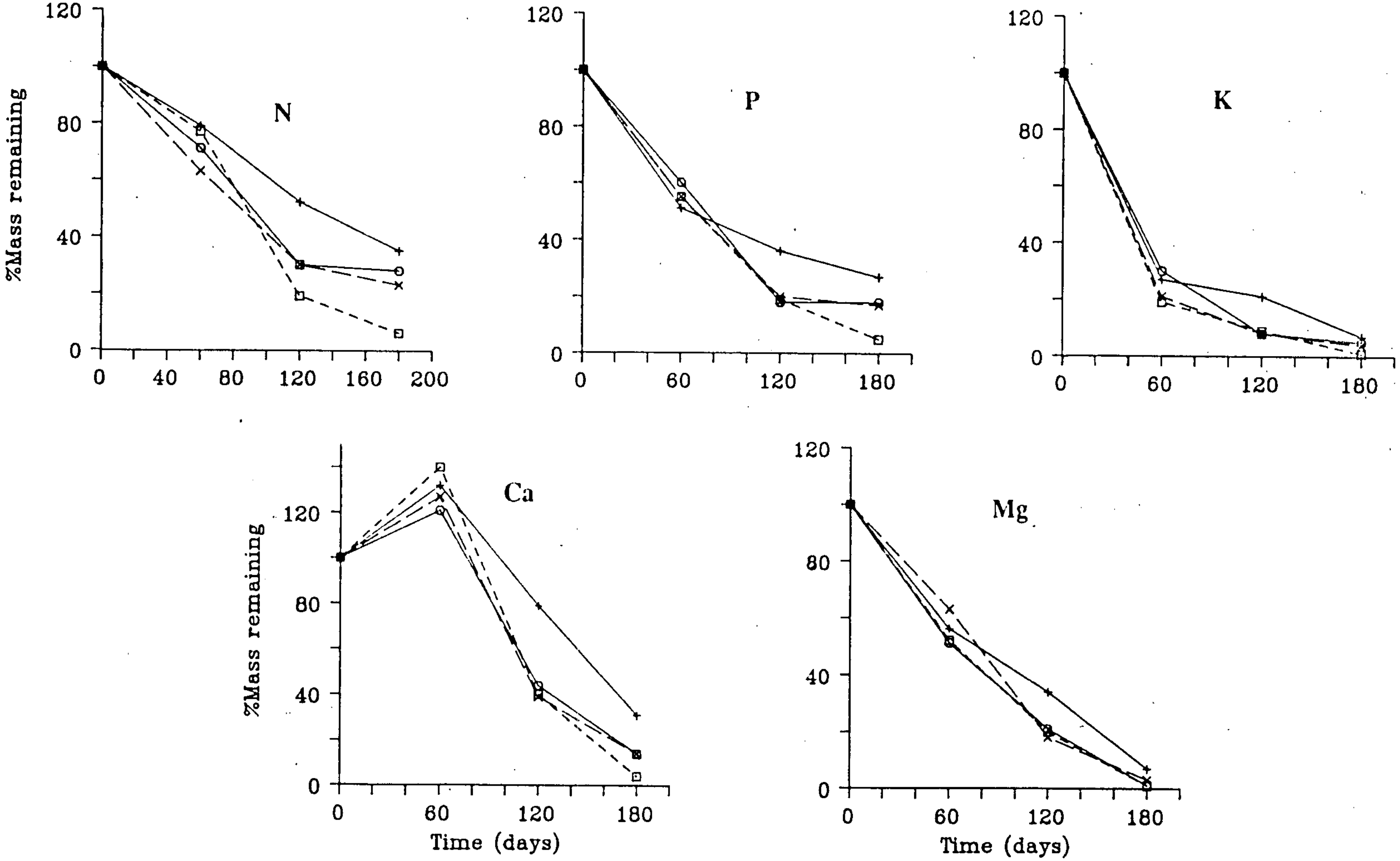

Figure 18: Percentage of initial mass of elements (N, P, K, Ca, Mg) remaining with time in decomposing leaf litter in the different plots. o——o Control, x— — —x Man. Reg. □- - - -□ Mech. Reg., +——+ Comp. C.

effects at four months between the Complete Clearance plot and all the other treatments, but at six months significant differences were only recorded between the Complete Clearance and Mechanical Regrowth plots.

b) *Phosphorus*

Phosphorus concentration showed a similar pattern in all the treatment plots and was similar to that of nitrogen. There was a more significant drop in the first four months compared to the almost constant situation shown by nitrogen. Final increases at the end of the study period were far lower than those for nitrogen. The leaf litter in the Control plot had the highest concentration of 34%, Complete Clearance 32%, Mechanical Regrowth 29% and Manual Regrowth 19%.

Phosphorus content also showed a pattern similar to that of nitrogen over the study period but with smaller differences between treatments. As with nitrogen, ANOVA results showed significant ($p = 0.05$) differences between the Complete Clearance plot and all the other treatments at four months, but at six months significant differences were recorded only with the Mechanical Regrowth plot.

c) *Potassium*

Like nitrogen and phosphorus, the pattern for potassium concentration was similar in all the treatment plots but unlike them, it declined throughout the study period. There was a very sharp uniform drop in the first two months during which time about three quarters of the total potassium was lost. In the last four months plots showed slightly variable concentration patterns. The concentrations of leaves in the Mechanical and Complete Clearance plots increased at four months before declining correspondingly at six months. The concentrations of those in the Control plot declined further at four months then rose almost to the level at two months. On the other hand, the concentration of leaves in the Manual Regrowth plot was more or less constant over this period. Unlike nitrogen and phosphorus, potassium concentration was positively correlated (not strongly) with weight loss in all the plots; Control r = 0.87; Manual Regrowth r = 0.82; Mechanical Regrowth r = 0.74; Complete Clearance r = 0.78.

Potassium content showed a decline pattern over the study period very similar to that of its concentration. At the end of the study period, all the decomposing leaf litter in the plots had lost more than 90% of their original potassium content. The highest loss was recorded in the Mechanical Regrowth plot of 99%, Manual Regrowth, 96%, Control , 95% and Complete Clearance, 93%.

d) *Calcium*

Calcium concentration also showed a similar pattern in all treatment plots throughout the study period. There was an initial very sharp increase in the first two months of decomposition followed by a sharp decline (to almost initial levels), in the Control and Mechanical Regrowth plots, in the sixth month. The Manual Regrowth and Complete Clearance plots showed a corresponding sharp decline in the fourth month then remained almost constant (at levels above initial concentration) in the sixth month. Considerable differences were observed between treatments at the end of the study; from a gain of 48% in the Complete Clearance plot to a loss of 2% in the Mechanical Regrowth plot. The concentration in the Manual Regrowth plot increased by 29% while that of the Control plot increased by only 3% . None of these differences were found to be significant.

Calcium content also showed a similar pattern in all the treatment plots. After an initial rise in the first two months, it declined sharply at four months and then more gradually in the sixth month , except in the Complete Clearance plot where the decline was more or less constant.

e) *Magnesium*

Magnesium concentration showed a pattern of decline in all the plots in reverse order to that of potassium, decreasing gradually in the first four months and then sharply in the last two months. As was the case with potassium, the decline pattern during the gradual stage was more variable than in the fast stage. The decline in magnesium concentration, like that of potassium, was positively correlated with dry weight loss. The strongest correlation was observed in the Complete Clearance plot, $r = 0.997$; Mechanical Regrowth $r = 0.77$; Manual Regrowth $r = 0.87$; and Control $r = 0.86$. Magnesium content showed a similar and almost linear decline pattern in all the plots. The decomposing leaf litter had lost almost all its magnesium content at the end of the study period. The lowest loss of 93% was recorded in the Complete Clearance plot. In the other plots losses were above 95%, Mechanical Regrowth 99%, Manual Regrowth 97% and Control 99%.

5.3.4 Discussion

The effects of land clearance on decomposition has been extensively studied and reviewed (Stone, 1973; Bormann et al, 1974; Aber et al, 1978; Likens et al, 1979; Maheswaran and Gunatilleke, 1988) and the general conclusion has been that, land clearance or disturbance favoured decomposition processes for reasons cited in section 4.2.4.2. Swift et al (1979), stated three groups of variables that could have regulatory effects on decomposition processes; substrate quality, and macro and microclimate. The substrate was similar on all the treatment plots (mixed leaves from the natural forest). As the study site was in the same area, microclimate and the soil organisms of the treatment plots were the variables that differed.

5.3.4.1 Weight loss and decomposition rates

The results of weight remaining at the end of six months showed distinctive differences between the three treatments. The similarity in weight loss in the Control and Manual plots is probably as a result of the little disturbance caused by this technique on the vegetation and soils, but perhaps most important is the fact that slash was not burned. The results suggest that factors affecting decomposition activity remained unaffected or were very little affected to cause any significant change in decomposition.

The comparatively small weight remaining in the Mechanical Regrowth plot was probably as a result of increased decomposition generally reported to be favoured by increased solar irradiation and soil moisture content after land clearance. The most striking results were the high weight recorded in the Complete Clearance plot and the significant difference (p = 0.05) in weights between this plot and the Mechanical Regrowth plot. These results were unexpected since the Complete Clearance plot received the highest solar irradiation (100% of total solar irradiation as against 18.9% in the Mechanical Regrowth and 3.5% for the Manual Regrowth plots (Leakey 1987), and rainfall, factors favourable to increased decomposition processes. The following reasons could have contributed to the observed results:-

i) change in substrate quality and quantity as a result of total vegetation removal,

ii) production of new species of micro-organisms or adaptation of existing species to the new vegetation, in which case the decomposition of the leaf litter in the bags from the old vegetation (substrate) will be affected. Musoko (in prep) studying the effects of these methods on mycorrhiza population, found that the dominant species in the natural forest (before clearance) was in decline in this plot while there was a significant increase in one of the less represented species. In addition, a new and fast increasing species, originally absent in the natural forest, was discovered. These results as hypothesis above are most likely an effect of the change in substrate quality.

iii) reduced population of micro-organisms through top soil scraping and compaction during clearing.

iv) high temperatures on exposed soils, give rise to rapid loss of moisture and hence soil and leaf desiccation, thereby reducing decomposition processes. Soil and air temperature measurements carried out after clearance Mason et al (1989) showed an increase of 5.2 °C and 4.6 °C respectively in this plot. On the other hand the big trees in the other plots provided some shade to the soils hence moderating temperature variations. The soil temperatures recorded for the plots where as follows; Control plot, 22.2 °C; Manual Regrowth plot, 23.2 °C; Mechanical Regrowth plot, 23.2 °C and Complete Clearance plot, 28.4 °C. In contrast the air temperatures in general where slightly higher, 23° C in the Control and Manual Regowth plots, 23.8 °C in the Mechanical Regrowth plot and 27.6 °C in the Complete Clearance plot (Mason et al 1989).

v) to a lesser extent as a result of soil erosion. A few of the litter bags harvested in this plot where covered with eroded soils and their leaves where observed to be less decomposed compared to uncovered bags.

The above reasons are not mutually exclusive, any combination of them could possibly account for the observed results. Differences between the treatments were also apparent from the calculated decomposition constant values (*K*) for each harvest time and from regression equations. The *K*-values for the Control, Manual Regrowth and Complete Clearance plots, from the regression analysis, fall well within the range of values for tropical lowland forests given by UNESCO/UNEP/FAO (1978) and Anderson and Swift (1983) ($K = 0.9 - 4.7$). The values for the Control and Manual Regrowth plot are similar to those reported by Nye (1961), $K = 4.7$ for an evergreen forest in Kade (Ghana) and Bernhard (1970), $K = 4.2$, for another evergreen forest situated in a valley in Banco, Ivory Coast. That for the Mechanical Regrowth plot (6.5) is by far higher than values reported for tropical forests elsewhere.

NB: K-values derived here are not strictly comparable with those in most literature which are often calculated from litter-fall and standing crop data.

5.3.4.2 Nutrients

The release of nutrients from decomposing litter is an important internal pathway of nutrient flux in forested ecosystems. The release of nutrients from decomposing litter controls their subsequent availability for plant uptake or loss from the ecosystem, and affects ecosystem primary productivity (Blair, 1988). Nutrients may be released from litter by leaching or by mineralization (Swift et al, 1979). The rate at which the nutrients are released depend on several factors including the composition of the litter (including the initial concentration of the nutrient in the litter), the structural nature of the nutrient in the litter matrix, microbial demand for the nutrient, the availability of exogenous sources of the nutrient (Seastedt, 1984) and the moisture and temperature amounts in the environment. The release of elements that are not limiting to microbial decomposers and are not structurally bound in the litter may exceed mass loss. However, elements which are in short supply relative to microbial demand may be released at a rate slower than mass loss or may even accumulate in the litter during early phases of decomposition (Berg and Staaf, 1981).

a) *Nitrogen*

The increased nitrogen concentration in decomposing litter observed in all the treatment plots is a well established phenomenon (Bocock, 1963; Gosz et al, 1973) and explained as caused by nitrogen fixation (Granhall and Lindberg, 1977; Maheswaran and Gunatilleke, 1988; Blair, 1988); uptake from the surroundings by fungal hyphae growing in litter (Berg and Soderstrom, 1979); or atmospheric precipitation, insect frass, and plant material falling from the tree canopy (Bocock, 1963).

The general decrease in nitrogen content seemed to be associated with weight loss. A comparative analysis of the percentage weight remaining and percentage nitrogen content remaining showed that the faster the weight loss the greater the drop in nitrogen content. In a similar study in a lowland rainforest and deforested area in Srilanka, Maheswaran and Gunatilleke (1988) obtained similar results using two species *Cullenia ceylanica* and *Dicranopteris linearis*.

b) *Phosphorus*

The initial drop in phosphorus concentration in the first four months was presumably a result of leaching losses. The results at two months varied according to the intensity of disturbance of the plots, but at four months there was a sharp unexplained drop in the Control plot. The final increase in phosphorus concentration may be as a result of inputs from flowers, pollen and green materials from the canopy or surrounding vegetation. Decomposition studies carried out by Blair (1988), showed that the concentrations of nitrogen, phosphorus and sulphur increased during decomposition, following an initial leaching loss, and that there was a net immobilization of these elements in some of the litter types examined. A similar pattern for phosphorus to that of this study was obtained in studies by Gosz et al, (1973) in Hubbard Brook forest New Hampshire, and Maheswaran and Gunatilleke (1988) in Sri-Lanka.

The decreased phosphorus content could be explained similarly to that of nitrogen, by loss of dry weight. Lousier and Parkinson (1978) looking at elemental dynamics in decomposing leaf litter, found good correlation between dry weight and loss of phosphorus $r = 0.995$.

c) *Potassium*

The sharp drop in potassium concentration early in decomposition is a commonly observed phenomenon (Attiwill, 1968; Gosz et al, 1973; Lousier and Parkinson, 1978; Blair, 1988; Maheswaran and Gunatilleke, 1988). Potassium is not a structural component of plant litter and is subject to removal by leaching. Additionally, potassium inputs to the forest floor via canopy leaching are considerable and often exceed inputs in litter-fall (Swank, 1986). Therefore, potassium release is not strongly dependent on biotic activity (Alexander, 1977). This might explain the very close similarity in potassium loss in all the plots. The above explanations for potassium concentration possibly accounted for the similarly and corresponding fast decrease in its content in all the plots.

d) *Calcium*

Calcium is a structural component of plant tissue. Therefore, the release of calcium during decomposition is more dependent on biotic activity than leaching (Attwill, 1968; Thomas, 1969, 1970; Gosz et al, 1973; Blair, 1988), i. e. the loss pattern of calcium is similar to dry weight loss of plant tissue. However, some studies like the present study, have reported increased calcium concentrations during decomposition resulting from greater retention or even accumulation of calcium during the early phases of decomposition (Vogt et al, 1983; Bockheim and Leide, 1986; Yavitt and Fahey, 1986; Blair, 1988). Some of the retention or accumulation of calcium in litter has been attributed to the formation of calcium oxalate by certain fungi

(Cromack et al, 1975). Although the concentrations after six months in all the plots were generally greater than initial concentrations, they all showed a decline pattern. The differences between treatments were due probably to differences in the rates of decomposition.

Results of calcium content showed generally that calcium loss tracked pattern of weight loss in all the plots. The results at six months showed some similarity to those of weight loss. Net fluxes of calcium have been reported by, Thomas (1969), Gosz (1973), Staaf and Berg (1982), to follow pattern of mass loss.

e) *Magnesium*

Leaching does not appear to play a very important role in the release of magnesium which might explain the gradual decline observed in the first two months of decomposition. The sharp drop in the last two months could be as a result of differential removal by decomposers of tissue parts with relatively high concentration of magnesium. Unlike the other elements, magnesium content at six months did not seem to track weight loss pattern. This strengthens the hypothesis of possible preferential removal of plant tissues relatively rich in this element.

The pattern of magnesium release, like that of all other elements reported in decomposition studies, is variable depending on the substrate quality, quantity, microbial population and enviromental conditions.

5.4 Conclusion

The results of fine litter-fall, fine litter fraction on the forest floor and leaf litter decomposition studies showed that land clearing had effects on the flux of materials and nutrients in the ecosystem. Secondly, it was evident from the results that the extent of the effects depended on the intensity of the disturbance caused by the method on the ecosystem.

The similarity in results of the Control and Manual Regrowth plots (except for the huge accumulation of litter from the unburnt slash), showed the mildness and the little disturbance caused by this clearing technique to the ecosystem. The Mechanical Regrowth and Complete Clearance methods respectively, significantly ($p = 0.05$) and very significantly ($p = 0.01$) affected nutrient dynamics in the ecosystem. For example, only one seventh of the total nutrient input in the Control plot was recorded in the Complete Clearance plot and about one half in the Mechanical Regrowth plot over the one year study period (Table 18).

Nutrient concentration of fine litter-fall was not affected by the clearing methods, though litter caught in the Complete Clearance plot was composed mainly of leaves from the new and young vegetation. On the contrary , low nutrient concentrations were observed in the fine litter fraction of the forest floor in the Mechanical Regrowth and Complete Clearance plots . This was attributed to increased leaching from increased rainfall as a result of the partial and complete vegetation removal during clearing.

Decomposition processes increased in the Mechanical Regrowth plot hence the low leaf litter weight remaining and the high *K* - value. The high leaf litter weight remaining in the Complete Clearance plot and low *K* - value was most probably as a result of decrease in decomposition activity. The identical weight remaining and similar *K* - values observed in the Control and Manual Regrowth plots indicate no change in decomposition activity as a result of the mild effects of the Manual Regrowth technique.

No consistent pattern in nutrient concentration was shown by the decomposing leaves in the treatment plots, except for calcium and magnesium where the Complete Clearance plot showed the highest concentration at six months. In terms of mobility , the plots showed a similar trend of, K > Mg > Ca > P > N, obtained by Blair (1988). The dynamics of nutrient amounts in decomposing leaf litter, followed weight loss pattern. The greatest amount loss was in the Mechanical Regrowth plot with the lowest weight remaining and the highest *K* - value, and the lowest was in the Complete Clearance plot with the highest weight remaining and the lowest *K* - value. The Control and Manual Regrowth plots once again had similar values. However, significant differences were observed only for nitrogen, phosphorus and calcium and between the Mechanical Regrowth and Complete Clearance plots.

From the above results , it was clear that land clearance does not always result in increased decomposition activity. Based on these results, it can be concluded that the extent and direction of any change resulting from land clearing in a given ecosystem, depends among other things on the method of clearance and the intensity of the disturbance it causes to the ecosystem.

CHAPTER SIX

EFFECTS OF CLEARING METHODS ON THE GROWTH OF *Terminalia ivorensis* (A. Chev.)

6.1 Introduction

The tropical rainforest is a very complex and heterogeneous ecosystem in which natural evolution has not always been advantageous to man. He therefore has to intervene to achieve precise goals such as; the maintenance of sustained production with the highest possible yield, rational land occupation and the formation of high quality products.

Silviculture constitutes the principal means of attaining these goals. It offers man the necessary methods and techniques for the production of ligneous materials. Silvicultural activities are usually focused on tree species for which qualities and technological properties are well known. *Terminalia ivorensis*, is a member of this group of species and has long been in use for regeneration purposes. The first *Terminalia ivorensis* plantations were created in Nigeria in 1928. As a result of its rapid growth and technological properties, it was extensively planted in West Africa (Nigeria, Ghana, Ivory Coast, Sierra Leone and Bénin). It was also introduced and extensively planted in Trinidad, Fiji, Uganda and Zimbabwe (then Rhodesia) (Foaham, 1982). In Cameroon, other than its natural habitat (south west Province), it was introduced in Bilik and Kribi. Its introduction in Bilik (Mbalmayo) about 5 km from the site of the present study was very recent (1972) and was aimed at studying its adaptability and growth in this environment. The importance and reasons for increased interest in regeneration in general and in Cameroon in particular had been reviewed in the first chapter of this study.

This chapter concerns the growth of Framiré planted in the three differently cleared plots studied in the preceding chapters of this study. Land clearance was carried out in the month of May, 1987, not a very appropriate time for this activity (because of the rains) even though clearing was done only after prolonged rain stoppages and when the soils were relatively dry, and planting took place in September (1987). The plots were planted with potted Framiré plants with heights ranging between 0.5-1.5 m at distances of 5x5 m apart.

The succeeding sections of this chapter are not simply concerned with the effects of the different land clearing methods on the growth of the planted Framiré. They go further to investigate within-plot variations in plant growth, studying and where possible quantifying some of the causes of any observed differences.

6.1.1 Nomenclature

Family	*Combretaceae* (Combretum family)
Species	*Terminalia ivorensis.* A. Chev.
Trade names	Framiré, Black Afara.
Local names	Idigbo (Nigeria), Lidia (Cameroon), Emeri (Ghana), Bassi (Sierra Leone, Liberia).

6.1.2 Geographical characteristics of Framiré

6.1.2.1 Distribution

Framiré is a closed forest species, extending from Guinea (Conakry) to Cameroon (south west) (Figure 19). It is found both in high and in secondary formations, in the latter it seems to be more common. It prefers moist conditions but grows in various sites (Voorhoeve, 1965; Irvine, 1966). It is often found in old agricultural plantations like Fraké *(Terminalia superba)* with which it is often associated.

6.1.2.2 Climate

Framiré grows well in areas of abundant precipitation, well distributed throughout the year with an optimum of 1270 mm per annum. It is very susceptible to drought especially in the young stages of growth. Average temperatures in its natural habitat vary between 20 °C - 23 °C, and relative humidity generally exceeds 50%.

6.1.2.3 Altitude

Framiré is a low elevation plant. In Ghana it grows well up to 610 m of elevation while in Cameroon it can be found as high as 1219 m, considered as the maximum altitude for good growth. Trial plantations of Framiré at 1524 m in Nyamuka (Uganda) produced very poor results, while those at altitudes between 732 - 1219 m in the same area were very satisfactory. In general, Framiré is a species likely to do best below 1200 m above sea level.

6.1.2.4 Edaphic factors

Framiré has been found to grow well in a variety of soil types. Upland lateritic loams in Sierra Leone, sandy loam in western Nigeria, clay loams in Tanzania (Willan, 1966) volcanic soils of British Solomon Island (Leggate, 1966) and Cameroon are most suitable soils for Framiré growth. It has also been found to grow well in sandy clay soils in the Mbalmayo forest reserve (Cameroon). It is very sensitive to water logging, and does not grow well in porous (sandy) soils or soils with long flood periods.

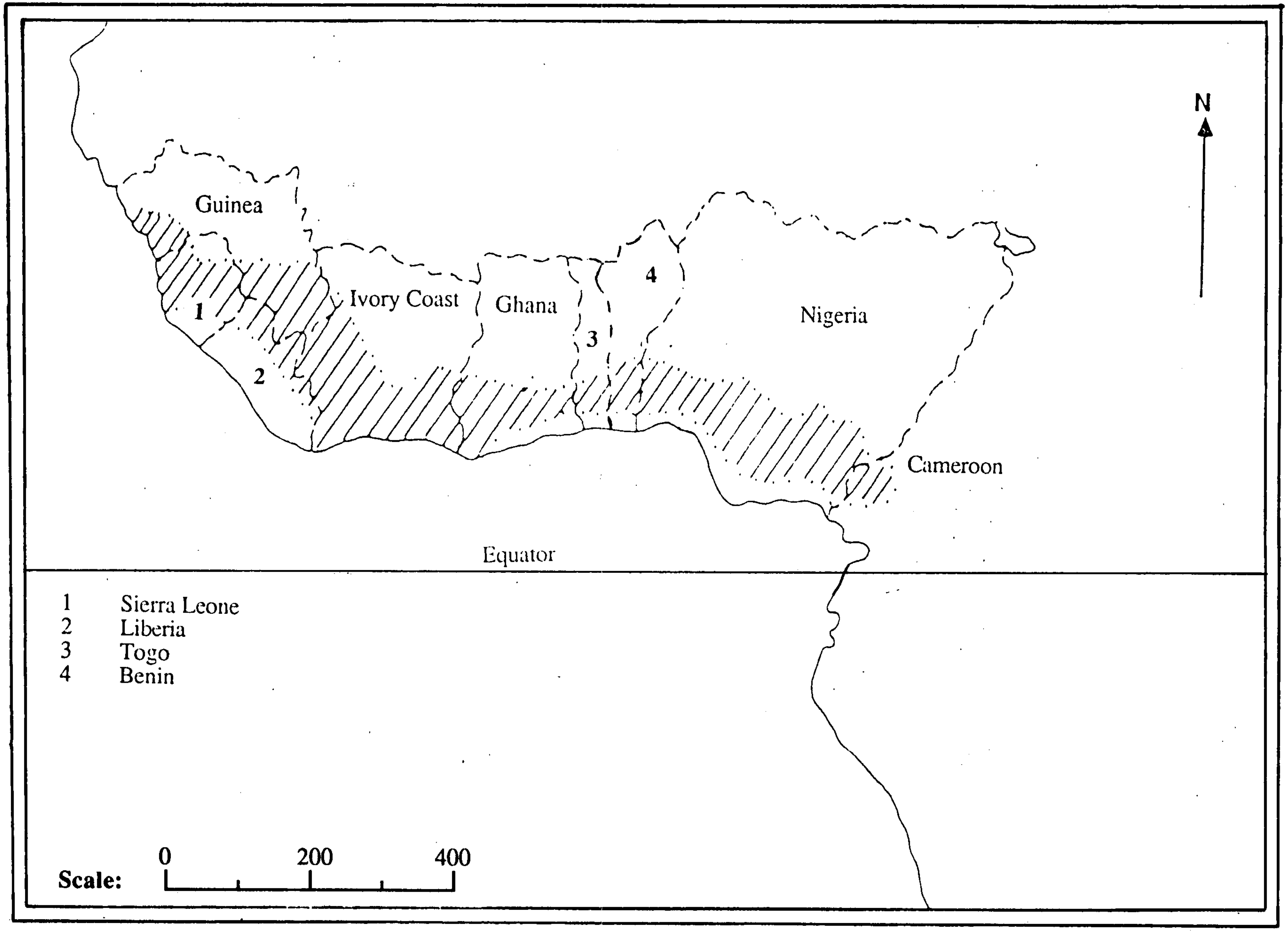

Figure 19: Natural distribution of *Terminalia ivorensis* (Modified after Foaham, 1982).

6.1.3 Description

Framiré is a large emergent tree. It may reach a height of 45 m and a diameter of 1.20 m. The base of the tree is straight when young, but it has heavy root swellings of up to 1 m high, sometimes extending in heavy surface roots, and is rather fluted when older. The bole is usually straight, rather angular near the base, cylindrical higher up (Figure 20b), and may reach a height of 25 - 30 m to the first branches. The bark on young trees is smooth and ashy brown, fairly thin, but when older (15-20 years) it becomes longitudinally fissured, then deeply grooved nearly black (in high forest, grey in secondary forest). The slash is fairly soft and fibrous, sometimes slightly brittle and brown outside, dark or bright yellow inside, paler near the cambium, soon turning ochre yellow or dirty light brown on exposure. Overmature trees may often have a swollen and defective lower half of the bole and brittle heart. The crown of younger trees is formed by wide-spreading, whorled branches, forming characteristic, horizontal storeys, but when the trees grow older the branches become more ascending and the storey character is more or less lost.

The leaves are simple, alternate, in tufts at the end of the branches (Figure 20a), tomentellous when young on petiole, rachis and nerves, glabrescent, shiny, medium green above, paler beneath, coriaceous. Petioles are 0.7-1.5 cm long, slender. Blade is (narrowly) obovate, 5-10 cm long, 2.5-4.5 cm wide. Midrib and nerves are impressed above, prominent beneath. Nerves 6-9 are on each side of the midrib steeply arching upwards but not looping (Figure 20a).

The tree is deciduous and sheds its leaves for about three months during the dry season. The new leaves appear around April, with the inflorescence. Flowering is in May and June. The young fruits soon appear, but are not ripe before December and January. They remain attached to the tree for a considerable time. The fruits are small; longitudinally winged nuts on slender (about 1 cm) long stalks, including the wing 5-10 cm long and 1.5-2.5 cm wide (Figure 20a).

Regeneration is abundant on such open sites as abandoned farms and logging roads. The tree is very self pruning and soon grows a clean straight bole. It coppices easily.

In the young stage Framiré and Fraké are very similar. The seedlings are easily distinguished because the first pair of leaves is alternate in the present species, opposite in Fraké.

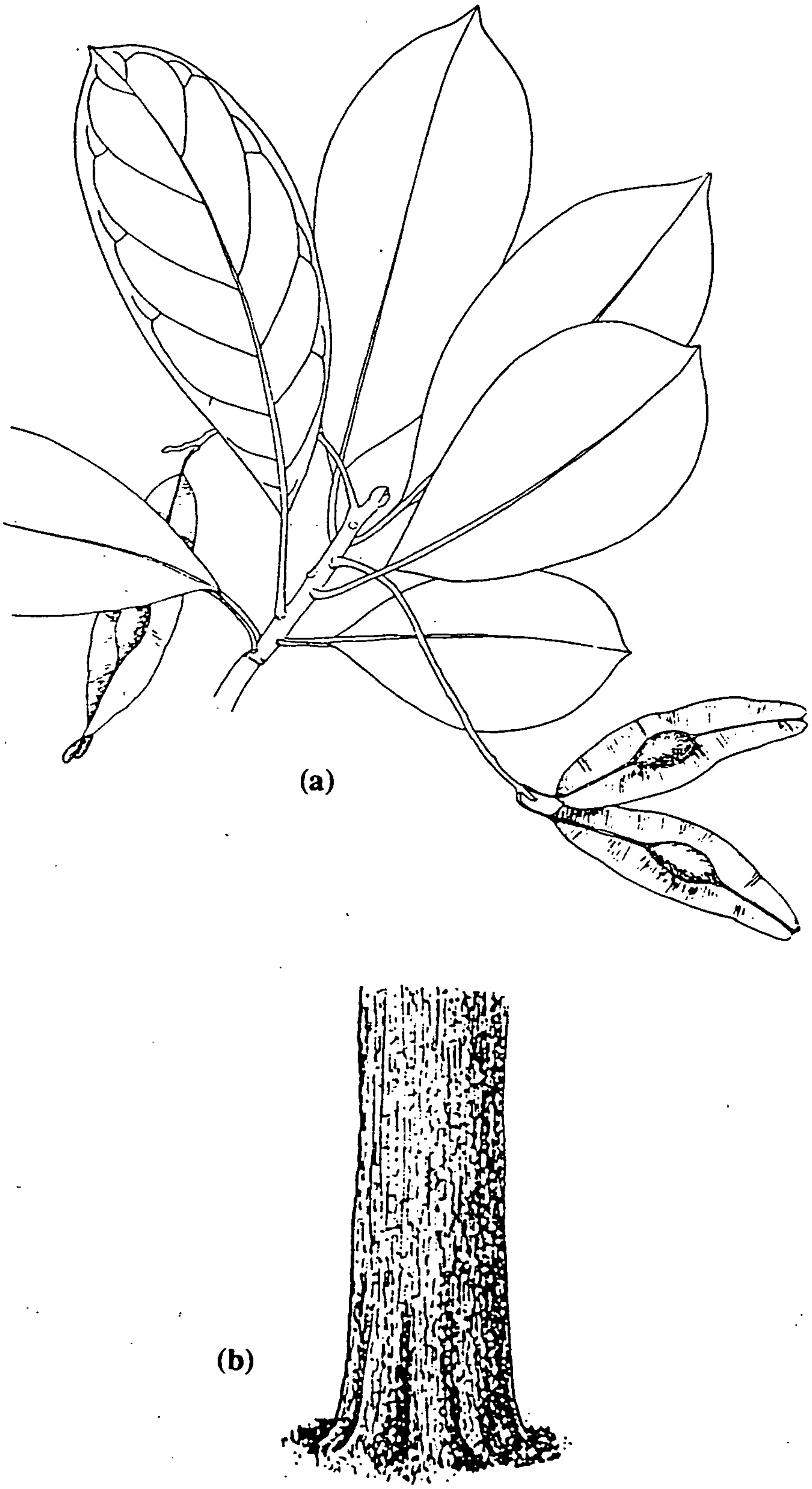

Figure 20: (a) Branchlet with leaves and winged fruits and, (b) Trunk base of *Terminalia ivorensis*

6.1.4 Importance

A yellow dye obtained from the bark of this tree is used in Sierra Leone for dying cloth. It is largely used for roofing shingles and lasts 15-20 years. It takes nails and glues well and will produce high polish, but is most difficult to treat with preservatives. Easy to work, it is superior in quality to the timber of Fraké and is suitable for house building, green-house, cabinet and interior work, school handwork, furniture, panelling and for carriage fittings. It is useful for door and window frames, panelled doors, and stair treads. Its local uses include carpentry and mortars. The wood is useful as fuel (Irvine, 1961; Nepveau, 1976).

6.1.5 Silviculture

Framiré posses good silvicultural properties that makes it an interesting species for large scale regeneration such as; fast growth, abundant fruit production, self pruning. In addition, it has a straight bole and is not subject to serious parasitic attacks. It is a light demander and does not tolerate shade after germination (Lamb and Ntima, 1971). It is often found in the tropical moist forest conditions, but it is predomonantly a tree of the seasonal forest zones and is often found mixed with Fraké where it shows some of the latter's characteristics, being a strong (aggressive) light demander and a good colonizer of abandoned farms. Because of its nature of light demander, its distribution in the natural forest and growth in plantations may reflect on the density of shade in the high forest or the amount of light reaching the plantation.

6.1.5.1 Fruiting

Framiré produce abundant fruits but the fruiting period varies from place to place. In Sierra Leone, seeds are available between February and April. In Ghana the period of fruit production is situated between May and August (Foaham, 1982), while in Nigeria it extends from December to March. However, it was noted by Cooper and Bramwell (cited by Foaham, 1982) that viable seeds were those harvested after the month of January. In the artificial Framiré plantations at Bilik (Cameroon), seeds are mature between January and February, but the most viable seeds are those harvested between the months of March and April (Foaham, 1982). One kilogram contains 5,500-6,200 winged seeds (Voorhoeve, 1965).

6.1.5.2 Germination

The germination period for Framiré seeds varies between 15 and 50 days (Voorhoeve, 1965; Foaham, 1982) owing to the hard coat. The period was fourteen days for the bioassay experiment carried out in this study. The rate of germination is poor, generally between 30-50%. MacGregor mentioned by Foaham, (1982) obtained 30% germination while Cooper and Bramwell also mentioned by Foaham, (1982) obtained germination percentages between 25-50%. Taylor and Kinloch mentioned by Voorhoeve (1965) reported that germination could be raised to about 40% when the seeds are pre-treated for a week by alternate soaking and sun-drying. Bibani mentioned by Foaham (1982) obtained 50% germination when seeds were soaked for 48 hours before sowing. In the bioassay experiment of this study, soaking seeds for 72 hours produced a similar result to that of Bibani (53%). Another common problem with Framiré seeds is attack from insect borers.

The seedlings are susceptible to drought therefore nursery beds need to be lightly shaded until seedlings are well established.

6.1.5.3 Plantation

a) *Type of plant*

For transplanting either stripped plants or stumps may be used, but nursery stock should not be planted out until the second rainy season, when the plants may be about 1.5 m high . As the trees are susceptible to drought, they should be planted when the soil is moist, ie not before the rainy season has actually started. Roots should not be heavily pruned (Voorhoeve, 1965).

b) *Method*

Since Framiré is a light demander, the silvicultural method used should be one that enables sufficient plant lighting. In Nigeria large plantations of Framiré were successfully established using the taungya method. Generally, most of the old Framiré plantations were established using this technique where and when conditions were favourable (available agricultural labour force and land scarcity) or the typical slash and burn technique of shifting agriculture. The line method has been utilized very little and the Manual Regrowth method is a very recent technique.

Framiré is a very fast growing species and tends to suppress other vegetation. With a spacing of 3x3 m an area may be covered in three years. Hence it should not be mixed unless with good shade bearers (Voorhoeve, 1965). The drawback to the cultivation of Framiré is that after a certain age, the trees are attacked by an insect which causes severe damage to the plantation. Therefore, monoculture plantations are too great a risk, but wide line plantings in young secondary forest, or mixed plantations may be successful (Voorhoeve, 1965).

At Bilik in (1972), 15.9 ha of land was planted with Framiré using two silvicultural methods, Manual Regrowth method (4.5 ha) and line method (11.4 ha). Foaham (1982), carried out growth and adaptation analysis of these planations and reported they were doing well ten years after planting. At the age of six years, the average annual growth of the trees was > 4 cm in diameter and >200 cm in height. A comparative analysis of the results showed significant differences between the two methods, with better growth observed in trees of the two line method plots. This difference was probably due to differences in initial plant densities of the plots (250 plants ha^{-1} in the Manual Regrowth plot and 111 plants and 83 plants ha^{-1} in the two line method plots). At the age of nine years , three years after thinning, trees of the thinned subplot in the Manual Regrowth method showed significant growth increases. However, those of the thinned subplots in the two line method plots on the other hand were not affected by the thinning operation.

In another growth analysis study, this time on Fraké, with very similar characteristics to those of Framiré, in the Congo and Zaire, similar results to those of Bilik (the natural habitat of Fraké) were reported (Mémento du forestier, 1978). At the age of fifteen years, average annual increase was between 2.5-3.1 cm in diameter and 1.4-1.8 m in height. Total volume was estimated at 20-25 m^3 with trees at distances of 6x6 m apart. The average increase in diameter was found to decrease with plant age and at the end of plantation revolution was estimated at 1.1-1.5 mm. It was estimated that plantation exploitation would take place at the age of 50 years and at this stage, the plantation would comprise 60 trees with average diameter of 70 cm and total volume of 270 m^3 (Mémento du forestier, 1978).

6.2 Materials and methods

Eleven months after planting and plant establishment (July, 1988), monthly assessment of tree survival and growth in the centrally marked out 50x50 m areas in each treatment plot (Figure 10) was commenced and carried out for thirteen months (July, 1989). Tree growth was assessed by measuring tree heights, from the ground to the apex of the principal shoot, and diameters at a height of 5 cm above ground. The number of dead and destroyed trees at each sampling time were also recorded for tree survival analysis. Since Framiré is a light demander, light measurements of the trees enclosed by the central 50x50 m areas were taken in an attempt to investigate their relationship with growth. With the assistance of Grace and Furley, the light amount reaching each tree in the Manual Regrowth and Mechanical Regrowth plots was measured above the crown and expressed as a fraction of readings taken in the open (Complete Clearance plot). Height measurements were taken simultaneously with those of light.

In addition, detailed sampling of the ten best and worst growing trees in each of these areas (judging from heights) was carried out to determine within plot treatment effects. The soils under these trees were sampled and analysed for pH, nutrients, bulk density and water content. Soils for pH and nutrient analysis were collected at five random points under the tree crown just below the litter layer (horizon H_0), and bulked before subsamples were collected, after thorough mixing, for analysis as described in appendix 1. Soil cores were collected under each tree and bulk densities determined as described in section 4.1.2.2. Soil water content was roughly estimated by measuring the difference in the fresh and oven-dry weight of soils, to enable a quick estimation of the effect of compaction. Light amounts received by each of these trees were also measured by Mason (pers. comm.) in March (1989), simultaneously with their heights and diameters. Light measurements, this time, due to plant heights, were taken at a height of about 2 m above ground close to each tree but in the open to avoid effects of tree crown. The photon flux density measurements (photosynthetically active radiation-PAR) were taken with a SKP 200/215 Quantum, Radiation Sensor and measuring Unit, manufactured by Skye Instruments, LLandrindod Wells (UK).

Leaves were randomly harvested from these trees and after oven drying at 105 °C over night were analysed for nutrients as described in appendix 1.

6.3 Results

6.3.1 Tree survival

The results of tree survival twenty three months after planting are summarized in Table 23 below.

Treatment	Total number of trees planted	Number of trees dead or destroyed	Number survived	(%) Survival
Man. Reg.	108	11	97	90
Mech. Reg.	118	13	105	89
Comp. C.	117	21	96	82

Table 23: Percentage survival of Framiré trees in the different treatment plots twenty three months after planting (September 1987 - July 1989) in the Mbalmayo forest reserve.

These results show similar percent survival in the Manual Regrowth and Mechanical Regrowth plots, but the Mechanical Regrowth plot had more planted and has more surviving trees. The highest number of dead (especially) and destroyed trees were encountered in the Complete Clearance plot with the least survival percentage. The lowest number of planted trees was recorded in the Manual Regrowth plot, a direct effect of the big trees and tree stumps left behind during clearing.

6.3.2 Tree growth

The average monthly heights and diameters of Framiré in the centrally marked out areas in each plot for the period July (1988) to July (1989), are represented in Figure 21. The best results of tree growth (both height and diameter) were shown by the Mechanical Regrowth plot, followed by the Complete Clearance plot, with trees of the Manual Regrowth plot unexpectedly showing the worse growth. Trees of the Complete Clearance plot showed very fast growth over the study period, increasing from a similar average height to those trees of the Manual Regrowth plot in September

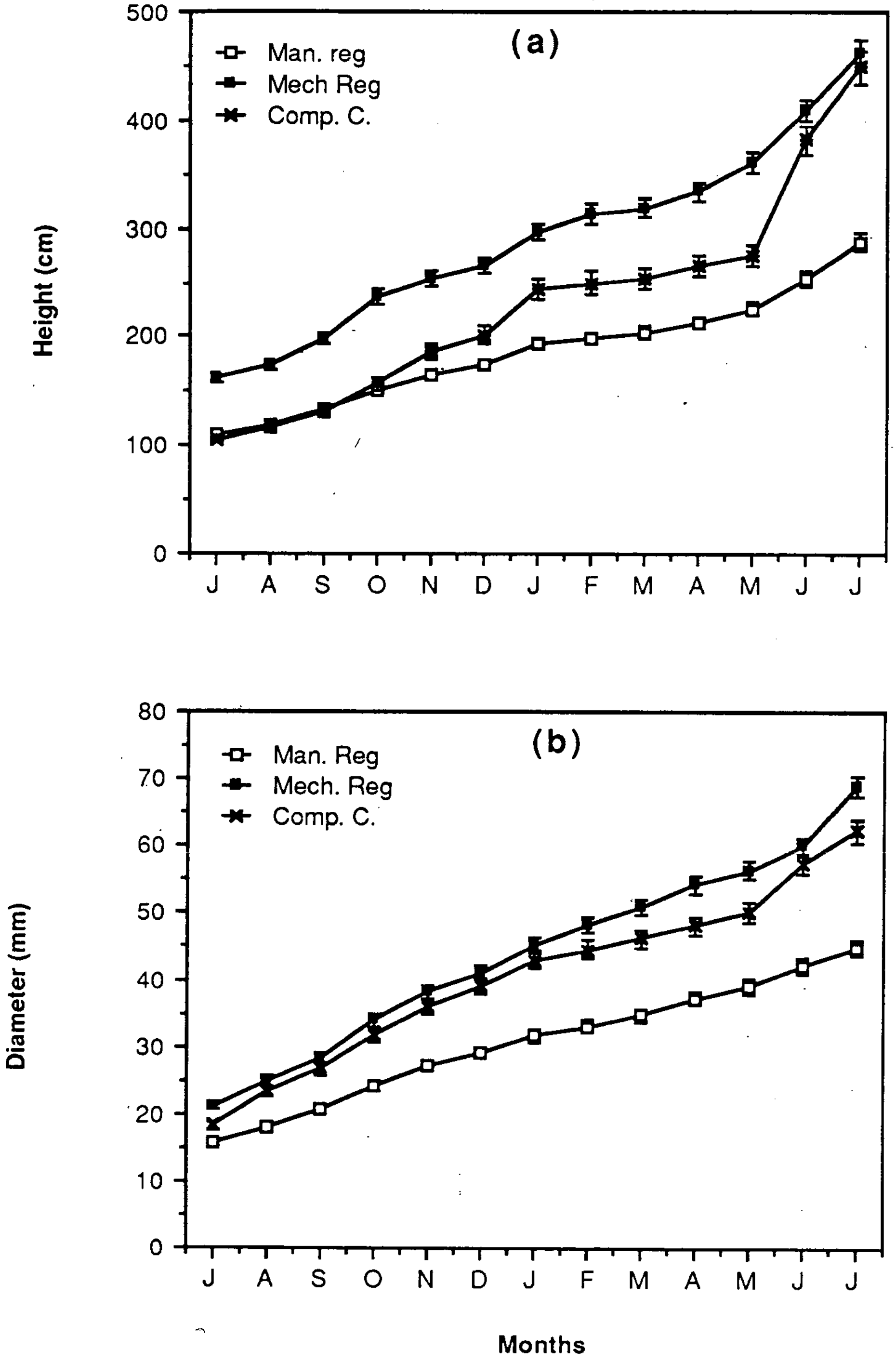

Figure 21: Average monthly plant heights (a) and diameters (b) in the different treatment plots for the period July 1988 to July 1989. Monthly tree assessments started eleven months after planting. Bars are standard errors of at least 96 trees.

(1988) and attaining that of plants in the Mechanical Regrowth plot in July (1989). The pattern of diameter increase in these two plots was almost constant throughout the study period. The differences in growth (height and diameter) between the Manual Regrowth plot and the other two plots increased continuously over the thirteen months observation period.

Average growth of Framiré over the thirteen months study period is summarized in Table 24 below.

Treatment	Height (cm)	Diameter (mm)
Manual Regrowth	178	29.1
Mechanical Regrowth	299	47.3
Complete Clearance	343	44.1

Table 24: Average growth of Framiré in the different treatment plots over the thirteen months study period.

These results like those of monthly tree growth (Figure 21) show trees of the Complete Clearance plot to grow faster in height than those of the other two plots. The growth rate (height) in the Manual Regrowth plot was about half that in the Complete Clearance plot over this period.

The relationship between plant heights and diameters (Figure 22 (a), (b), (c)) of the different plots is linear with identical coefficients of correlation ($r = 0.77$), but with different slopes.

The frequency distribution of tree heights and diameters illustrated in Figure 23, revealed very poor growth of the trees in the Manual Regrowth plot. Only 9% of the trees in this plot had attained or exceeded 4 m in height while the number with diameters ≥ 60 mm were only 11% of the total surviving trees at the end of the study period. The Mechanical Regrowth and Complete Clearance plots had similar percentage trees with heights ≥ 4 m, 60% and 59% respectively. However they differed slightly in their percentage diameters (≥ 60 mm) 59% and 54% respectively.

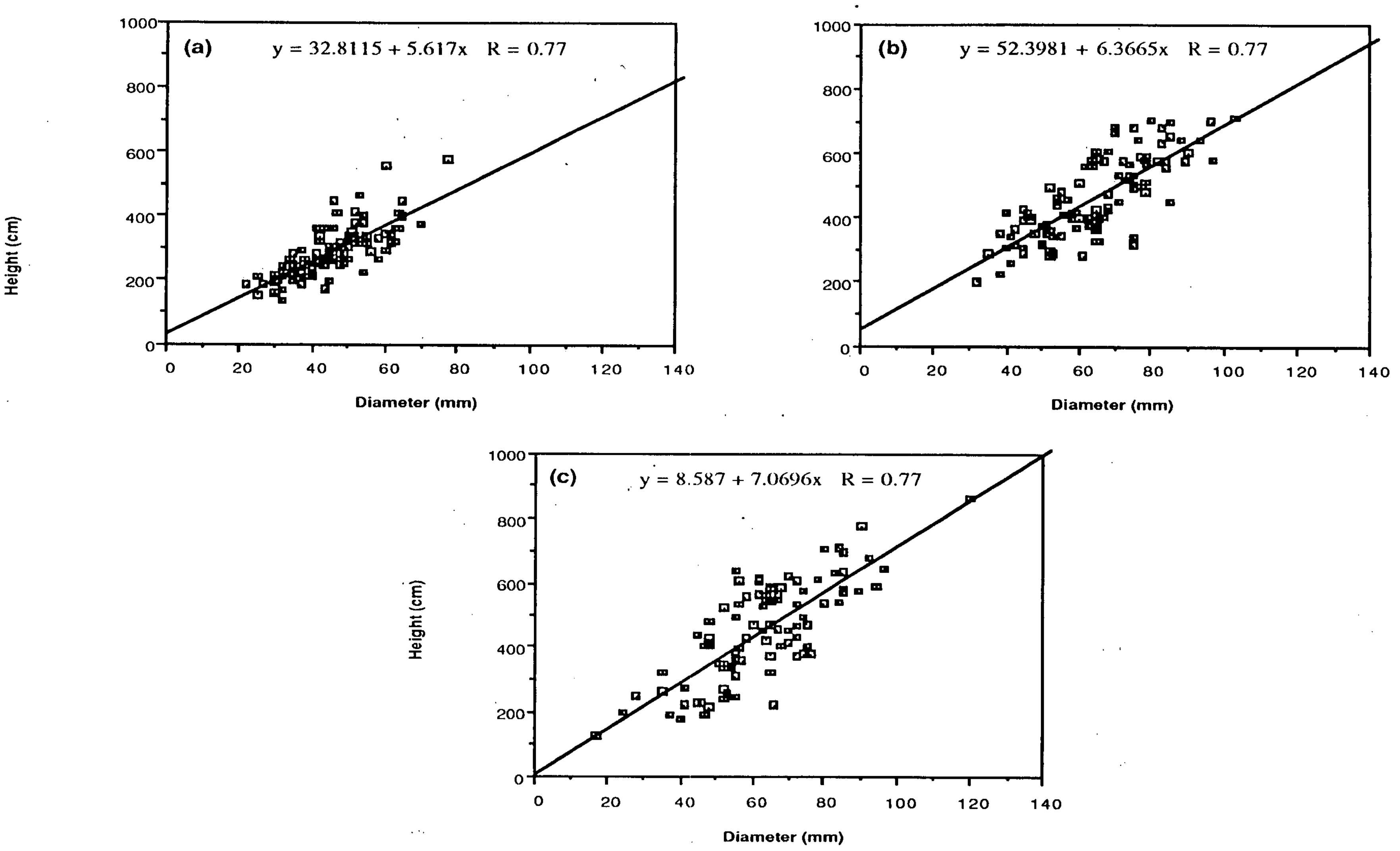

Figure 22: Relationship between plant heights (cm) and diameters (mm) twenty three months after planting in the different treatment plots. (a) Manual Regrowth plot. (b) Mechanical Regrowth plot. (c) Complete Clearance plot.

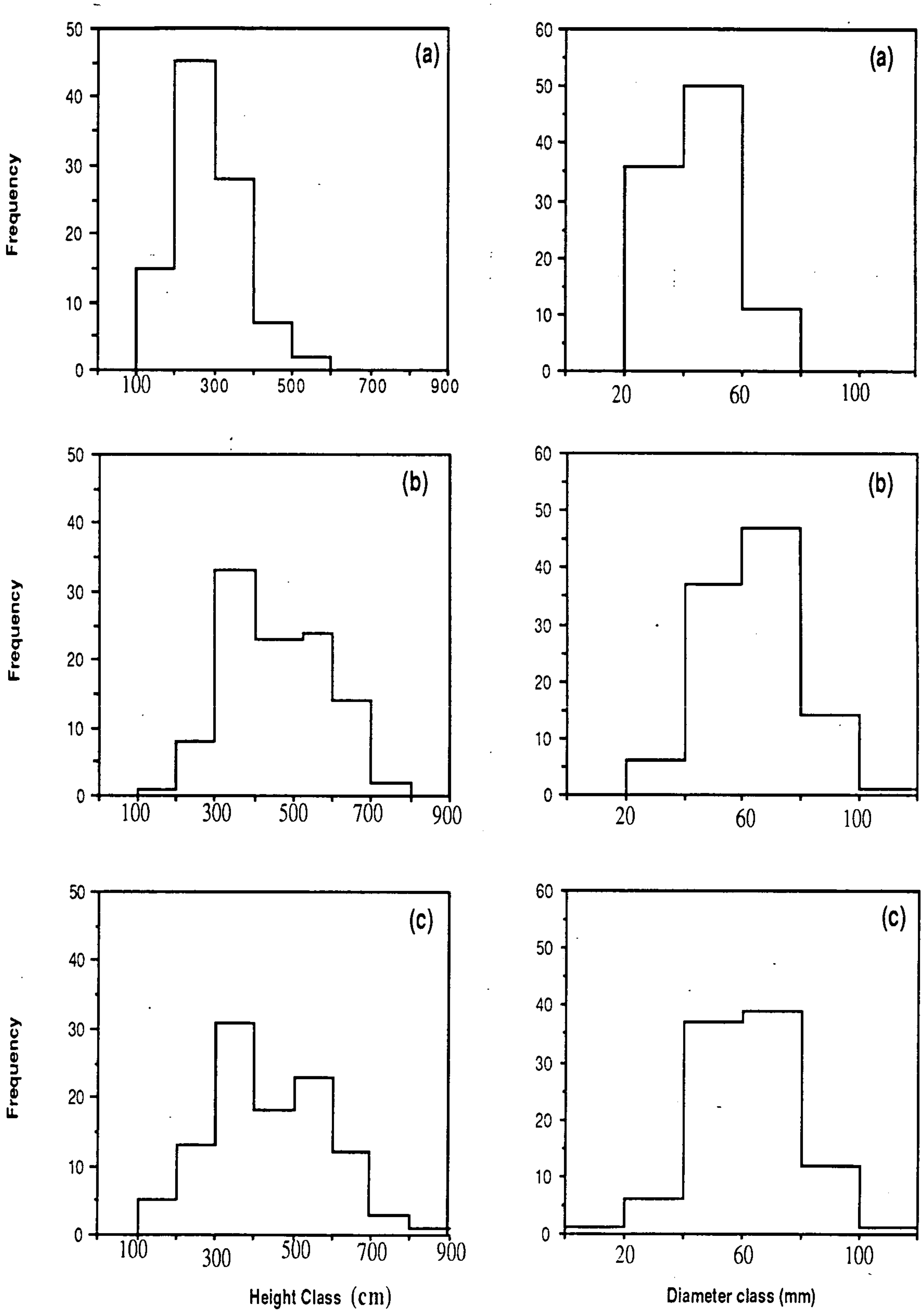

Figure 23: Frequency distribution of plant heights and diameters in the different treatment plots twenty three months after planting (July, 1989). (a) Manual Regrowth plot. (b) Mechanical regrowth plot. (c) Complete Clearance plot.

6.3.3 Light measurements

The first light measurements taken in the month of July (1988), corresponding to the period of rain break, showed that the trees in the Manual Regrowth plot received 26% and Mechanical Regrowth 33% of the light amount recorded in the open (Complete Clearance plot).

A plot of the plant heights against their relative light fractions for these two plots is illustrated in Figure 24. No relationship was revealed by the results between plant height and light, but there was a more even distribution of light in the Mechanical Regrowth than in the Manual Regrowth plot.

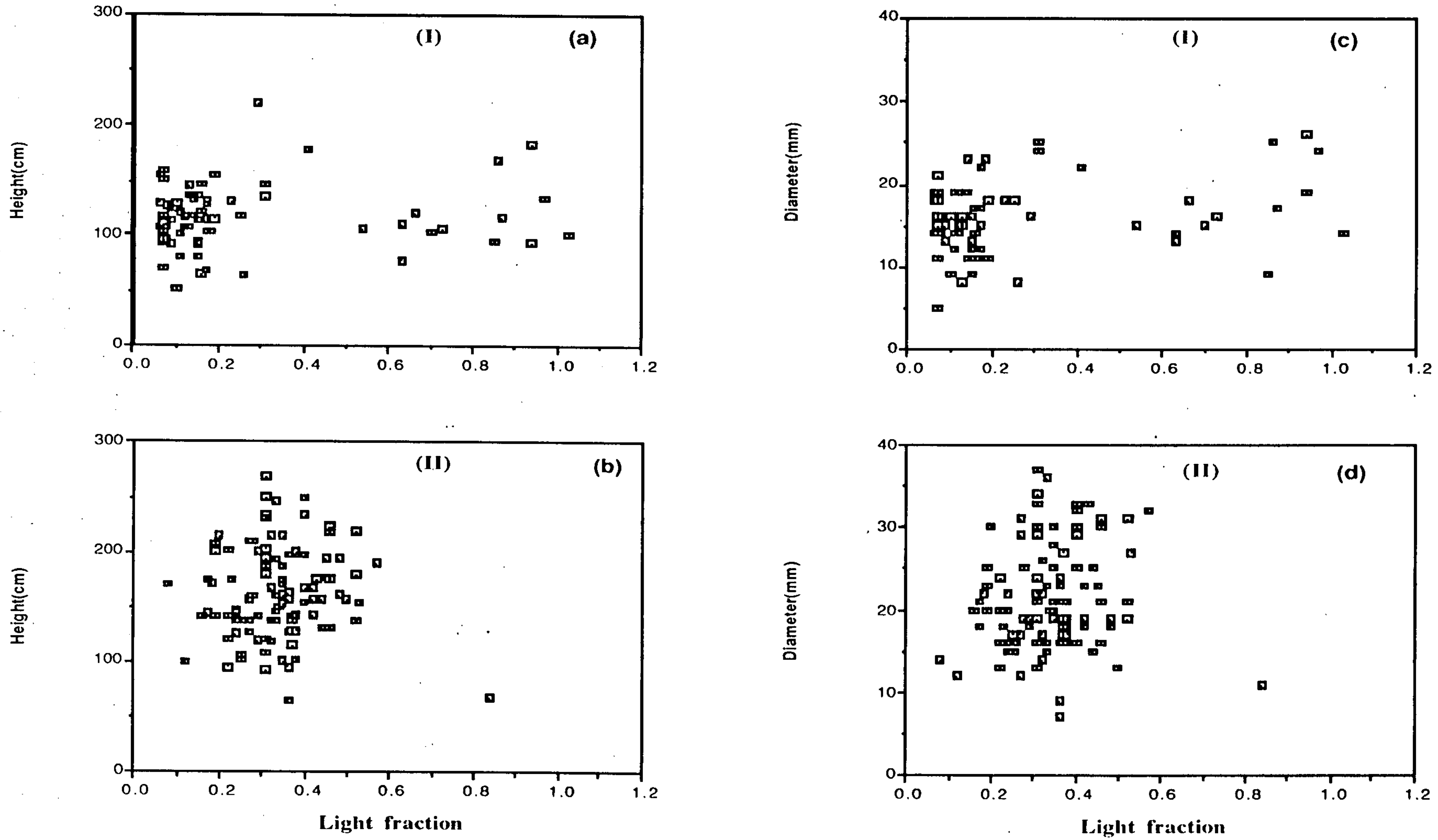

Figure 24: Relationshionship between tree heights (a, b), diameters (c, d) and relative light fractions eleven months after planting in the Manual Regrowth (I), and the Mechanical Regrowth (II) plots. The light results are relative to measurements in the Complete Clearance plot representing the open.

6.3.4 Within plot treatment effects on the growth of Framiré (based on ten best and worst growing trees)

6.3.4.1 Average height and diameter

Figure 25 shows the average heights and diameters of the ten best and worst growing trees per treatment plot after twenty three months of planting. These results reveal very significant differences in the growth of these two sets of plants. Once again between plot comparison showed the worse results in the Manual Regrowth plot and the best in the Mechanical Regrowth plot closely followed by the Complete clearance plot, which showed slightly better results for the best trees.

6.3.4.2 Selected properties of soils

Results obtained from the analysis of soils collected under the ten best and worse growing trees are given in Table 25. The best and worse growing trees in the Manual Regrowth and Mechanical Regrowth plots were found to be growing in soils with similar nutrients, hence the differences in growth were not due to the lack of nutrients. The differences did not seem either to be caused by soil compaction or water stress, results of which were found to be very similar in the soils from under these two sets of plants. On the contrary, there were significant differences in the nutrients, soil compaction and water content of soils collected below the best and worse growing trees in the Complete Clearance plot, suggesting these factors might be responsible for the observed differences in growth.

6.3.4.3 Nutrient composition of tree leaves

The nutrient concentration of leaves harvested from the ten best and worse growing trees in each of the treatment plots are presented in Table 26. The results in general are a direct reflection of the results of the soils in which the trees are growing. No differences were therefore, observed in the nutrient concentrations of leaves from the best and worse growing trees in the Manual Regrowth and Mechanical Regrowth plots. Similarly, there were differences in the nutrient concentrations (except K) of leaves harvested from the best and worse growing trees in the Complete Clearance plot though at a smaller scale than in the soils.

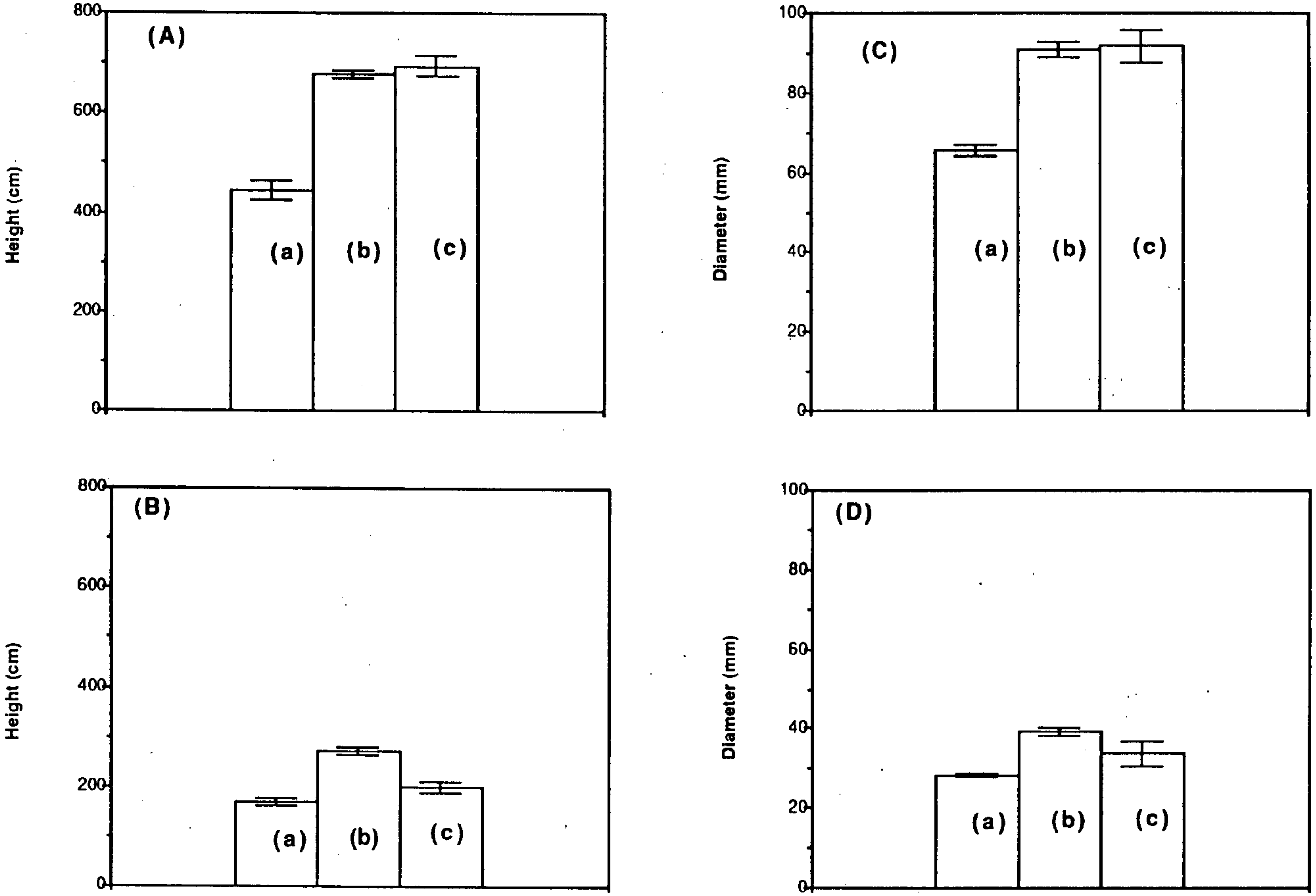

Figure 25: Average height (cm) of the ten best (A) and worst (B) growing trees, and their corresponding average diameters (mm) C and D, respectively in the different plots twenty three months after planting. Bars are standard errors of means. (a) Manual Regrowth plot, (b) Mechanical Regrowth plot, (c) Complete Clearance plot.

Treatment	mg/100g		cmol kg^{-1}			pH	Bulk density (g cm^{-3})	(%) Water content
	N	P	K	Ca	Mg			
	Best (tallest) trees							
Man. Reg	5.3 ±0.86	0.07 ±0.017	0.12 ±0.01	0.37 ±0.10	0.28 ±0.05	4.5 ±0.19	1.10 ±0.03	23.9 ±2.72
Mech. Reg	3.3 ±0.72	0.05 ±0.014	0.13 ±0.01	0.48 ±0.04	0.35 ±0.03	4.8 ±0.18	1.23 ±0.03	20.8± 1.06
Comp. C.	1.5 ±0.43	0.04 ±0.007	0.12 ±0.01	0.28 ±0.09	0.20 ±0.03	4.6 ±0.17	1.18 ±0.03	19.3 ±2.53
	Worst (shortest) trees.							
Man. Reg.	4.9 ±0.80	0.08 ±0.012	0.13 ±0.01	0.37 ±0.10	0.33 ±0.05	4.5 ±0.23	1.14 ±0.03	24.4 ±1.89
Mech Reg.	2.8 ±0.87	0.06 ±0.01	0.15 ±0.01	0.62 ±0.10	0.40 ±0.05	4.9 ±0.24	1.10 ±0.03	19.0 ±1.87
Comp. C.	1.1 ±0.34	0.01 ±0.003	0.08 ±0.01	0.09 ±0.04	0.11 ±0.02	4.6 ±0.16	1.32 ±0.03	16.3 ±1.87

Table 25: Selected properties of soils taken under the ten best and worst growing trees in the different plots. Results are means ±SE.

Treatment	N	P	K	Ca	Mg
	Best (tallest) trees				
Man. Reg.	2.0 ±0.15	0.15 ±0.03	0.57 ±0.05	0.79 ±0.07	0.30 ±0.03
Mech. Reg	2.3 ±0.08	0.16 ±0.01	0.81 ±0.07	0.75 ±0.04	0.30 ±0.02
Comp. C.	2.3 ±0.06	0.13 ±0.01	0.51 ±0.04	0.72 ±0.14	0.21 ±0.05
Worst (shortest) trees					
Man. Reg.	2.3 ±0.08	0.16 ±0.01	0.67 ±0.08	0.71 ±0.10	0.29 ±0.03
Mech. Reg	2.3 ±0.08	0.15 ±0.01	0.61 ±0.05	0.58 ±0.04	0.26 ±0.02
Comp. C.	1.6 ±0.13	0.10 ±0.01	0.59 ±0.04	0.51 ±0.04	0.12 ±0.01

Table 26: Nutrient concentration (% dry weight) of leaves harvested from ten of the best and worst growing trees in each of the treatment plots. Results are means ± standard errors.

6.3.4.4 Light measurements

The results of light measurements taken at about 2 m above ground in the open close to each tree are summarized in Table 27. Similar amounts of light were received by the best and worst growing trees in the Mechanical Regrowth and Complete Clearance plots. In the Manual Regrowth plot on the other hand, there were significant differences in the light amounts reaching the best and worst growing trees, suggesting this might be a probable cause of the differences in plant growth. Between plot comparison showed the following light reception pattern, Complete Clearance plot > Mechanical Regrowth plot > Manual Regrowth plot.

Treatment	Photon flux density (PAR) µmol m^{-2} s^{-1}
	Best (tallest) trees
Man. Reg	302 ± 44.9
Mech. Reg.	477 ± 94.7
Comp. C	908 ± 30.9
Worst (shortest) trees	
Man. Reg	156 ± 38.9
Mech. Reg	442 ± 114
Comp. C.	1002 ± 43.1

Table 27: Average light amounts (quantity) received by the ten best (tallest) and worst (shortest) growing trees in each of the treatment plots nineteen months after planting (March 1989).

The relationship between the average heights of the best and worst growing trees and the photon flux densities is illustrated in Figure 26. Also shown on this graph, in brackets, is the average nitrogen concentration of leaves randomly harvested from these trees.

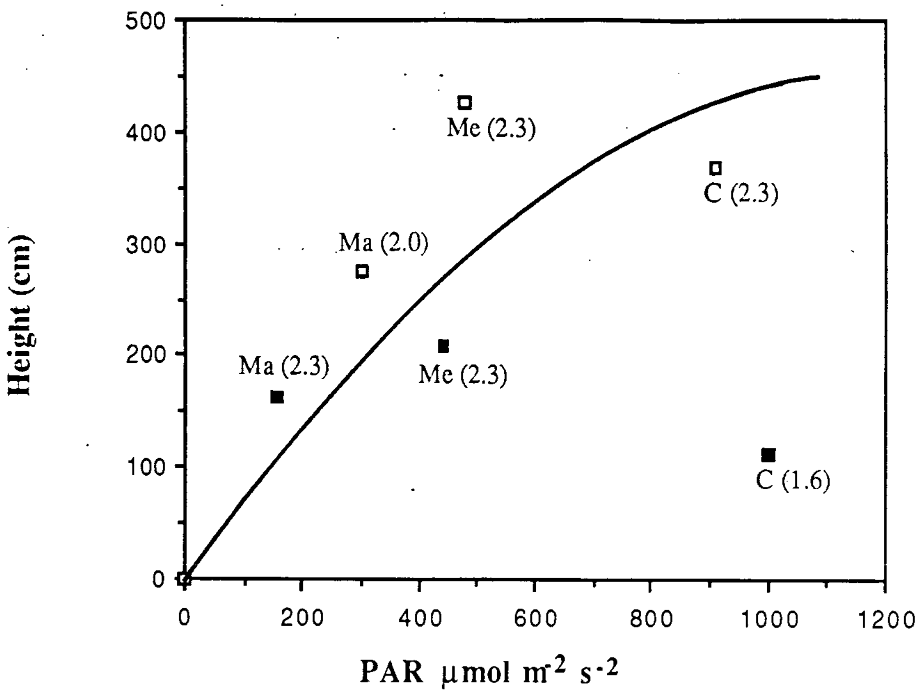

Figure 26: Speculative relationship between PAR and tree height, when data for nitrogen concentration ≥ 2% are considered. It is presumed that at PAR =0, tree height =0. Data points are average results for the ten best (□) and worst (■) growing trees in the different treatment plots nineteen months after planting (March 1989). Ma. (Manual Regrowth), Me. (Mechanical Regrowth), C. (Complete Clearance) plot.

There is evidence from Figure 26 of a relationship between light and tree height. Results of plant heights illustrated in Figure 25, four months later (July, 1989), show that the best growing trees in the Complete Clearance plot had caught up with those in the Mechanical Regrowth plot and the worst trees in the Complete Clearance plot were growing slightly better than their counterparts in the Manual Regrowth plot.

6.4 Discussion

6.4.1 Tree survival

The results of tree survival revealed some disadvantages of the land clearing methods. The Manual Regrowth method for example had the least number of planted trees. This was a direct consequence of leaving big trees and stumps of felled trees behind during clearing, thereby reducing eventual planting space. In the Mechanical Regrowth plot, there was a similar problem with the big trees, but since the felled trees were uprooted and pushed away, this created more planting space than in the Manual Regrowth plot, hence the higher number of planted trees. The space problem faced in the Complete Clearance plot was not with the big trees but with their stumps which could not be uprooted by the *D8 straight rake bulldozer* used in its clearance. This explains the similarity in the number of planted trees with the Mechanical Regrowth plot.

In the Manual Regrowth and Mechanical Regrowth plots, the main danger to tree survival was from falling branches. A total of 97 trees were alive and growing well in the Manual Regrowth plot twenty three months after planting. Eleven of the original 108 trees planted were missing, eight of which were damaged by fallen branches. In the Mechanical Regrowth plot, the thirteen missing trees were either damaged by fallen branches or appeared to have died from water stress due to the effects of soil compaction. In addition, shading from the big trees could have contributed to the observed mortality rates. All the missing trees (twenty one) in the Complete Clearance plot were killed from water stress as a result of soil compaction due the repeated passage of heavy machinery (section 4.1.4.1) or water logging, observed in some cases.

Although the highest percentage of tree survival was recorded in the Manual Regrowth plot, the Mechanical Regrowth plot (1% short of the former) had the highest number of planted and surviving trees which is an important factor in determining the best method of land clearance for plantation establishment.

6.4.2 Tree growth

Results of average monthly heights and diameters of trees (Figure 21) and frequency distribution of tree heights and diameters twenty three months after planting (Figure 23), show the plants in the Mechanical Regrowth plot to have the best growth with the worse results shown by plants in the Manual Regrowth plot. The relationship between plant heights and diameters (Figure 22) is linear with identical correlation coefficients but different slopes which suggest how the conditions prevailing in the different plots may influence the form of the tree stem a very important end product of the plantation.

The increasing differences in growth over time between the plants in the Manual Regrowth plot and the other two plots (Figure 21) is probably as a result of differences in plant growth rates (Table 24).

Results of average monthly plant growth (Figure 21), average growth of trees over the study period (Table 24) and the slopes of the regression analysis of tree heights and diameters, show fastest growth of trees (height) in the Complete Clearance plot. These results were unexpected considering results of the physical and chemical properties of soils in the three plots reported in chapter 4 which showed the most drastic ecosystem effects and unfavorable growth conditions in the Complete Clearance plot. It is thought these results could be an indirect effect of the revegetation of this plot resulting in increase nutrient inputs and the amelioration of soil properties. But perhaps the most important suggestion is that, plant growth is a complex process and is not conditioned simply by the physical and chemical properties of the environment.

6.4.3 Nutrients in soils and leaves of selected trees

Within plot analysis of nutrients showed similarities in the soils (Table 25) and leaves (Table 26) of the best and worst growing trees in the Manual Regrowth and Mechanical Regrowth plots. This suggest therefore, that the observed differences in growth of these trees were not due to nutrient deficiencies. The results of their soil pH, bulk density and water content did not seem to account for these differences either, which strengthens the above hypothesis about the complexity of growth. In contrast, the drastic effects of the Complete clearance method seemed to have had an effect on the growth of the two set of plants studied. The significant compaction of the soils under the worst growing trees probably resulted in the observed significant differences in their water content, nutrient contents and leaf nutrient concentrations. The accumulation of these effects could have probably accounted for the differences in the growth of the two set of plants within this plot.

There is lack of scientific information on the nutrient needs of Framiré. Aluko and Aduaji (1983) reported on the response of Framiré to varying levels of nitrogen and phosphorus fertilizers with little indication of amounts needed for good growth.

Between plot comparison of these results revealed the following general pattern for the soil properties and leaf nutrient concentration of the planted Framiré, Manual Regrowth > Mechanical Regrowth > Complete Clearance. However, comparative analysis of the growth of Framiré showed a different pattern to the above; Mechanical Regrowth > Complete Clearance > Manual Regrowth. This implies therefore that the measured soil properties do not limit or totally determine the growth of Framiré

6.4.4 Light measurements

Results of light measurements in the different treatment plots so far was the only parameter (except bulk density) that showed the Complete Clearance plot with a consistently higher value than the other plots. Figure 24, showed no apparent relationship between plant heights and diameters and the relative light fractions. This suggest that though Framiré is a light demander, light alone is not sufficient to condition its growth. It could also be possible that it was too early for any growth factors to significantly affect plant processes. This second hypothesis was more or less verified eight months later when trees were assessed for within plot treatment effects. Results of this study illustrated in Figure 26 show some relationship between plant growth and light amounts under similar conditions of nutrients.

Framiré is a light demander commonly found in old secondary forests and classified among species of primary vegetation succession. This characteristic of Framiré might possibly account for its relative good growth in the Complete Clearance plot (at least at this stage) in spite of the drastic effects on its soils and the relative low nutrient amounts and inputs (Chapter 4 and 5). Similarly, the significant differences in the light amounts reaching the best and worst growing trees in the Manual Regrowth plot could be the underlying cause of the observed differences in their growth.

None of the above measured parameters seem to have been responsible for the significant differences in growth between the best and worst growing trees in the Mechanical Regrowth plot. This once more is in line with the hypothesis that growth is a complex process that depend on the interaction of many factors, environmental as well as physiological.

6.5 Conclusion

The results of the tree survival assessment revealed some inconveniences of the different methods of land clearance. The relatively slight vegetation disturbance in the Manual Regrowth plot (big trees and stumps of felled trees left behind during clearing) reduced available planting space. Secondly, the big trees provided a source of danger to the young Framirés through branch fall. In the Mechanical Regrowth plot the big trees left behind, like in the Manual Regrowth plot, also provided a source of danger through branch fall. However, the uprooting of smaller trees during clearing opened up more planting space but led to some soil compaction. In the Complete Clearance plot, there was still some space problem this time from the stumps of the felled big trees that could not be uprooted. However, the most important disadvantage of this method was perhaps soil compaction from the repeated passage of heavy machinery during clearing causing high plant mortality from water stress and water logging.

A comparative analysis of the number and percentage of surviving trees showed the Mechanical Regrowth plot > Manual Regrowth plot > Complete Clearance plot. However, results of plant growth illustrated in Figure 21 and 22 and summarized in Table 24, revealed fastest growth in the Complete Clearance plot. This was thought to be a response of the plants to the continuous increase nutrient input and amelioration of soil properties through the growth and maturity of the revegetation.

The significant difference in soil compaction between the best and the worst growing trees in the Complete Clearance plot, was probably responsible for the observed differences in water content and nutrients and consequently the differences in the growth of these plants. In the Manual Regrowth plot the significant difference in the growth of the best and worst trees was attributed to the significant differences in light amounts reaching these trees, considering the light demanding characteristic of Framiré. However, in the Mechanical Regrowth plot, none of these factors differed significantly between the best and the worst trees, suggesting that these parameters were not the only growth determining factors.

Generally, the results of the various analysis show the Mechanical Regrowth method to be the most appropriate land clearing method for the regeneration of Framiré. However, plants of the Complete Clearance method with the most drastic and adverse effects on the ecosystem performed better than those of the Manual Regrowth method with the mildest effect on the ecosystem and are fast catching up with plants in the Mechanical Regrowth plot. If attention was to be focused entirely on growth rates, then the tendency at this stage is in favour of the Complete Clearance method of land clearance. However, since other factors are usually taken into consideration such as the sustainability of the method (a very fundamental factor of land use and plantation creation) discussed in the next chapter, this method still has to stand its test in tropical silviculture.

However, based on the results obtained after twenty three months of planting, it can be concluded that, Framiré (plant) growth is a complex process that does not depend entirely on the physical and chemical properties of the soils nor the light amounts reaching the plant.

CHAPTER SEVEN

GENERAL DISCUSSION AND CONCLUSIONS

This project was designed to investigate the effects of different site preparation methods on the ecosystem of a tropical lowland rainforest in Cameroon, and how the indigenous tree species *Terminalia ivorensis* performed under these different conditions.

An ecosystem is made up of a series of complex and interacting components, as illustrated earlier in Figure 2, through which materials and nutrients circulate. The effects of each clearing method was investigated on the highlighted compartments. The results have been presented and discussed in chapters 3 to 5. This chapter summarizes the discussion and conclusions and makes some suggestions for improvements to the methods of silviculture being practiced in Cameroon, in particular, and West Africa in general. In particular it considers ways to enhance and sustain tree crop productivity.

7.1 A critical evaluation of the project

The most regrettable aspect of this ecological study and most other studies conducted in tropical forests, is the lack of plot replication. Most ecosystem studies which cover a considerable length of time (eg several years) are restricted in space, while those which are extensive in space usually represent only one point in time. A combination of both approaches, though very expensive, is the most appropriate scientific approach to studies aimed at establishing the effects of site disturbance on nutrient cycling during reforestation with indigenous hardwoods.

Another point of concern is the short time scale of the study (3 years), which does not permit final recommendations or conclusions to be drawn as regard the application of the methods of site preparation on the end of rotation yield (30-40 years).

The lack of replication hindered the determination of variations within treatment plots, some of which could be very important especially with soils. Soil analysis would have provided better information if sampling had been done at closer time intervals in the first year, which is the most crucial period of change. There are many important aspects which, if studied, could have thrown more light on the effects of the site clearance methods. One such aspect whose complete investigation was hindered by lack of time was the small scale effects of land clearance. For example the retention of trees and tree stumps in the mechanized plots resulted in the accumulation of soils around them during clearance. This increased soil depth at the base of the trees and resulted in enhanced vegetation growth. These soils were sampled in a series of transects to determine the effects of micro-variation within the plots, but unfortunately it has not been possible to analyse and present the results in this thesis. Other parameters like, through-fall, stem-flow, and nutrient inputs in rainfall could have given extra information about the nutrient cycle had these been investigated.

In spite of these constraints and mistakes, the study has revealed some very interesting results which enable me to make recommendations for a land clearing method that allows the successsful, early establishment of Framiré plantations in the Mbalmayo Forest Reserve.

7.2 Discussion on the effects of methods on soil physical and chemical properties

The scientific literature contains much information on the effects of land clearing methods on soil physical and chemical properties especially in agricultural systems (van der Weert, 1974; Lal, 1975; Folster, 1976; Sanchez, 1976; Seubert et al, 1977; Mambani, 1986; Alegre et al, 1986). These include comparative analysis of the changes with time. This topic has been extensively reviewed by Sanchez (1980, Sanchez et al, 1985). Most comparative studies have contrasted various forms of mechanization (Lal, 1986) with the typical slash and burn technique of shifting agriculture. The latter is generally considered to be superior to the former because of the value of the ash as a fertilizer and the absence of soil compaction and topsoil displacement, which are common with mechanization. The advantages presented by the slash and burn technique to agricultural crops, with short production circles, might not apply to forest tree crops where growth is slow and rotations are very long. For example, increased nutrient input from ash has been shown to last for less than a year (generally up to the first rains), a period long enough for many agricultural crops to complete their rotation. However, most tree crops which have long rotations (15 - 50 years) are only becoming established within this timescale.

The effects on soil chemical properties of land clearance by the Manual Regrowth method, show a pattern generally opposite to that reported for the slash and burn technique. After slash and burn, the concentration of elements increase (rapidly and attains a maximum after six months) before subsequently declining (see review by Sanchez 1980). In the Manual Regrowth method, the unburnt litter and logs provide a long term source of nutrients for the growth of the planted trees. This represents an important aspect for the sustainability of this system of plantation establishment, which contrasts strongly with those of the slash and burn.

The general effects of the mechanized methods of site preparation were similar to those reported in agricultural literature. For example, soil compaction, disturbance and displacement of topsoil and its exposure to erosion were all consequences of mechanized clearance. The consequences of these effects were also similar to those reported elsewhere (Seubert et al, 1977; Lal and Cummings, 1979; Sanchez, 1980; Soane, 1986; Moreau, 1986; Alegre et al, 1986). However, the selective nature of the Mechanical Regrowth method had the advantage of slightly reducing both vegetation and soil damage. Consequently, the resultant effects on soil nutrients and their changes with time were less drastic than in the method of conventional bulldozing used in the Complete Clearance plot.

In the study of the effects of different passes (each with a pressure of 66 K Pa) of heavy machinery on soil compaction, four passes were sufficient to cause damage to the soils of the site. These two factors (machinery weight and number of passes) are very important in any attempts to alleviate soil compaction effects. The minimization of soil damage can be achieved to some extent by hiring operators who are sensitive to the potential damage of soil compaction and topsoil displacement. Alternatively, training programmes can be initiated for bulldozer drivers in the techniques for mechanical land clearance operations. This latter approach would be the most relevant to ONAREF which is aiming at the extensive utilization of the Mechanized methods in its plantation programme.

7.3 Discussion on the effects of methods on nutrient dynamics

Although the study of litter-fall was carried out over only a one year period, it provided adequate data to compare the amount of damage caused to the vegetation by each clearing method and the repercussion on nutrient inputs. Most work on litter-fall has been carried out on the natural forest or established plantations (Gorham, 1964; Proctor et al, 1983). The effects of land clearing methods on material and nutrient inputs through litter-fall, forest floor litter amounts and litter decomposition rates in the tropics is generally recognized, but there is a general lack of data of these aspects. For example, it is clear that in the traditional slash and burn technique, the big trees left behind provide continuous nutrient input through litter-fall to the site before and after revegetation and plant growth. The amount of litter on the floor after burning, if any, will depend on the intensity of the burn.

In the Manual Regrowth plot, the litter from the slashed vegetation and logs from the felled trees was neither burned nor removed from the plot. This therefore minimized nutrient losses, from leaching and water runoff after rainfall, often encountered after slash and burn and mechanized land clearance. In addition, the big trees provided a source of continuous nutrient supply. In the Mechanical Regrowth plot, soil disturbance and exposure created favourable conditions for nutrient loss. However, the maintenance of some big trees provide a source for continuous nutrient input.

In the Complete Clearance plot, the effects on nutrient dynamics were very drastic since, soil litter as well as the vegetation was completely removed during land clearance. Nutrient inputs were virtually non-existent, for sometime after clearance, except for meagre inputs blown in from nearby forest. This was reflected in the meagre twofold increase in nutrient amounts recorded in this plot over the obaervation period of one year (started 14 months after land clearance). On the contrary, results of litter-fall studies over the same observation period show a remarkable recovery in nutrient input amounts in Mechanical Regrowth plot, where a twentyfold increase was recorded at the end of the study period. Similar results were revealed by nutrient amounts of the fine forest floor litter fraction.

The amount of soil disturbance and consequently floor litter left behind after mechanized land clearance can vary depending on the type of machinery and its accessory attachments. For example, a shear blade with a flat bottom, kept above ground, would leave more litter plus roots and stumps in the soil than a dozer blade or root rake. However, the type of clearing implements are usually conditioned by the vegetation type and tree densities.

In spite of the fact that all the litter input in the Complete Clearance plot and most of that in the Mechanical Regrowth plot came from new vegetation in these sites, no differences were observed in nutrient concentrations. The differences recorded in nutrient content, summarized below in Figure 27 were due solely to differences in litter dry weight. Although differences were observed in the fine litter fractions on the forest floor, differences in litter amounts was the dominant factor which accounted for the differences in nutrient amounts summarized in Figure 28.

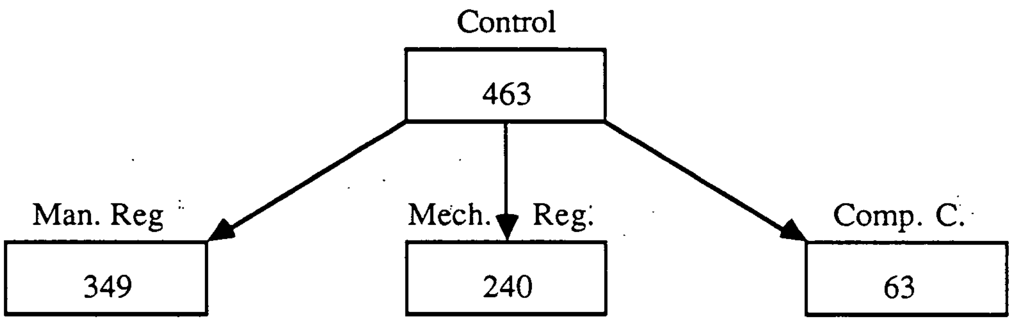

Figure 27: Effects of land clearing methods on total nutrient (N, P, K, Ca, Mg) amounts (kg ha^{-1}) of fine litter-fall in the different plots (June 1988 - May 1989).

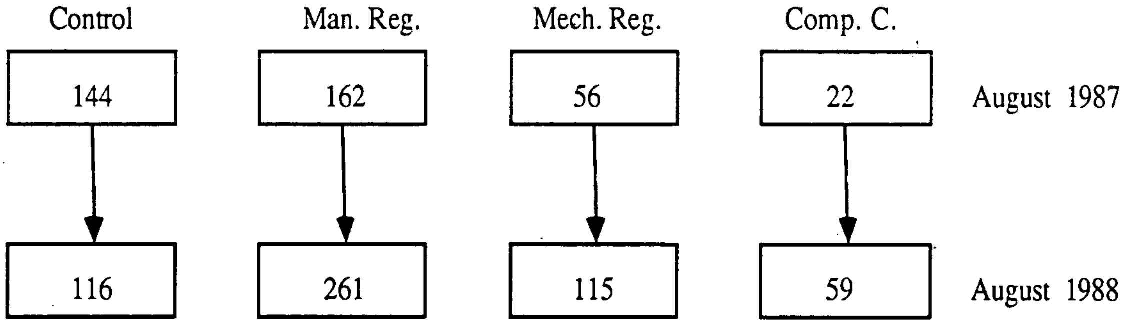

Figure 28: Effects of land clearing methods on total nutrient (N, P, K, Ca, Mg) content (kg ha^{-1}) of the fine litter fraction on the forest floor in the different plots.

The recovery of ecosystem properties, like fertility, after land clearance will depend, from above results, on the intensity of the original ecosystem disturbance.

Another aspect of tropical forest that has received relatively little attention is litter decomposition, and like litter-fall, most of the studies have been confined to the natural forest or established plantations. The few studies on effects of land clearance (slash and burn, and mechanized) have generally indicated increases in soil moisture and temperatures leading to increase mineralization and decomposition and hence increase nutrient release and loss to soils. Results from the current study have shown that this is not always true. The summary of total elements (N, P, K, Ca, Mg) remaining in the decomposition bags presented in Figure 29 below, showed the lowest loss, similar to that of dry matter, in the Complete Clearance plot. This suggests that decomposition processes were negatively affected in this plot. It seems therefore that there is a limit to the amount of disturbance that will create favourable conditions for increased decomposition.

Most of the results of the clearing methods presented, so far, show the most unfavourable growth conditions in the Complete Clearance plot. However, actual tree growth results discussed below contradicts this expectation.

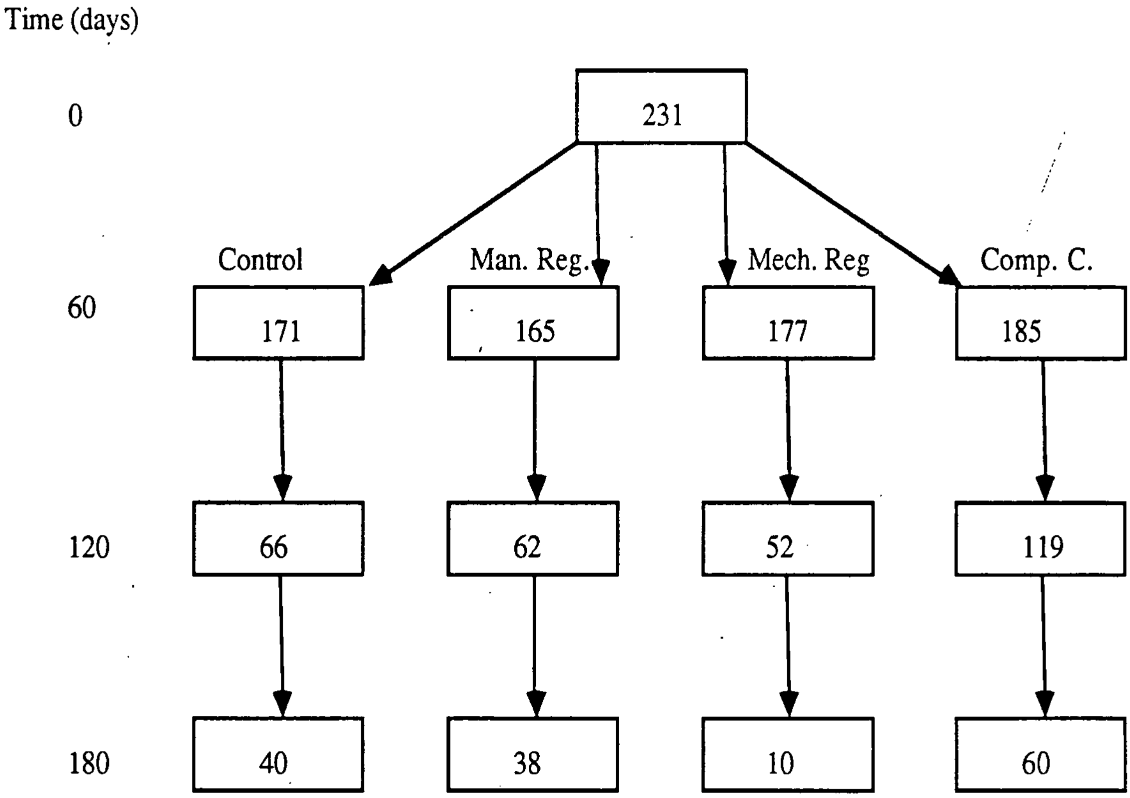

Figure 29: Total nutrient (N, P, K, Ca, Mg) amounts (mg) remaining with time in decomposing leaf litter in the different plots.

7.4 Discussion on the effects of methods on tree survival and growth

The comparative analysis of tree survival and growth (June 1988 - May 1989) shows highest mortality in the Complete Clearance plot, as expected, but surprisingly, trees in this plot showed slightly better growth than those in the other two plots. If the only factor determining the choice of an appropriate method was plant growth, then this method seems the most appropriate to date from the present results. However, there are many more important factors to be considered. One such factor concerns the sustainability of production from the system. The drastic disturbance of the Complete Clearance method on the ecosystem raises the question of its sustained use. It could be argued that after 30 years (the approximate rotation period for Framiré) the ecosystem should be sufficiently reconstituted to enable continuous and sustained productivity, but this of course needs to be verified.

The Manual Regrowth plot unexpectedly, in spite of its large nutrient inputs and good soil physical conditions, had the poorest tree growth. It is possible that this poor growth is due to inadequate levels of irradiance for light demanding species like *Terminalia ivorensis,* and that changes will occur once the poisoning of the big trees (after plant establishment) left behind during clearing begins.

In many ways the Mechanical Regrowth method showed intermediate results, generally better than the Complete Clearance plot, but with some ecological damage. Tree survival and growth was satisfactory. The big trees left behind will serve as a source of continuous nutrient input, at least until they are poisoned, and soil compaction and topsoil displacement was less drastic providing this treatment with a better prospect for sustained production than the Complete Cleared plot.

The greatest concern for Framiré plantations is that of extensive damage caused by insect attack between the ages of 20 -30 years (Voorhoeve, 1961) or plantation die back (Ofosu-Asiedu and Cannon, 1976). Outbreaks of die back occurred in Ghana and the Ivory Coast between 1958-1966 causing widespread and highly destructive damage (Ofosu-Asiedu and Cannon, 1976). The cause of this problem is as yet undetermined. It could be a pathogen in rotting stumps, nutrient starvation due to high tannin content of the leaves perhaps made worse by mycorrhizal population changes (Musoko, in prep). The fact that healthy trees were found between rows of affected trees seem to suggest transmission was not through tree roots (Ofosu-Asiedu and Cannon, 1976). No cases have been reported in Cameroon as yet. Pure plantations in general are more vulnerable to attacks and disease explosions than mixed ones. It is therefore advisable to maintain the interline bands of vegetation in the plantations to create a mix stand conditions. In the case of an outbreak this might provide a substitute nutrient source thereby reducing the intensity of the attack and the rapid spread among the planted trees. Alternatively, leaves and barks of some species in the mix stand might contain poisonous substances which might help slow the spread of pests or check them when fed upon by the predators.

Another important factor that affect plantation creation is the cost of land clearance. The cost of the same technique may vary from one place to another depending on, the density of the forest, the type of machinery used and the clearing implements. The Manual Regrowth method of this study took 29 man-hours, while the Mechanical Regrowth method took 11 man-hours and 5.5 hours of the bulldozer. The Complete Clearance method on the other hand, took 24 hours with the bulldozer team, 12 hours of the bulldozer and 30 man-hours with a chain-saw gang. The intervention of the chain-saw gang to help fell the big trees in the Complete Clearance plot was necessary since the bulldozer, equiped only with a root rake, could not do so.

7.5 Recommendations

Ideally, recommendations should only be made at the end of at least one plantation rotation period when all the elements for an objective evaluation have been obtained. Results of subsequent silvicultural operations such as, poisoning of big trees and thinning are most likely to create significant changes in the present results, from which any recommendations will be based. The unexpectedly good growth of the trees in the Complete Clearance plot, for example, renders predictions and results extrapolation very difficult. However, one of the objectives of this study was to help propose a suitable method of site preparation for the regeneration of *Terminalia ivorensis* and other fast growing tree species. The results of the investigations have shown that *Terminalia ivorensis* , in plantation, like maximum light conditions as well as adequate nutrients for good growth. These factors cannot be viewed in isolation from the cost at which they must be achieved (cost of land clearance).

Based entirely on the results presented in this thesis, the Mechanical Regrowth method seems to present the best compromise between, cost, plant growth and ecological stability for the early establishment of *Terminalia ivorensis* plantations.

The subsequent results of this study are very important for future recommendations and the success of plantation forests. However, this can only be achieved through continuous monitoring of these plantations, which is an aspect with a very poor history in the tropics.

A simple monitoring programme could be established, by ONAREF, in which less demanding aspects (tree survival and growth, litter-fall, litter standing crop) are measured at one yearly intervals whilst detailed studies of soils for nutrients, mycorrhizal population, micro-organism etc could take place on a five yearly basis. The general lack of information on plantation trials in the tropics is generally attributed to lack of monitoring or monitoring over very short time periods. The consequence is that the same mistakes are made over and over again because of the lack of a sufficiently long run of information for guidance.

7.6 Future research

As mentioned at the beginning, this study aimed at laying the foundation for a long-term ecological study of plantation forests with indigenous hardwoods in Cameroon. In the process, many questions have been created some of which need urgent and immediate answers, whilst others need the full rotation period of tree growth for answers. This project has opened up many new and interesting fields of research, some of which were carried out simultaneously with this study. This involved the determination of the effects of the different clearing methods on mycorrhizal population (Musoko, in prep). *Terminalia ivorensis,* the investigated species, is known to be an aggressive light demander. It would therefore be important and necessary to find out the behaviour of other plantation species of different light demands, especially shade tolerant species under these conditions. The current study has revealed changes in soil physical and chemical properties as affected by different conditions of canopy opening and soil disturbance. There is need for more research to explain the processes from which these changes evolved. The variously cleared plots with their new vegetation presents numerous research opportunities like the determination of the early successional vegetation types, influence of the vegetation types on insect populations, micro-fauna and flora, and herbivores. Questions relating to the sustainability of the system have to wait for at least one plantation rotation before verification, so at moment we can only hypothesise as to the long-term effects.

7.7 Conclusion

It can be concluded at this early stage of plantation establishment that:-

i) The Manual Regrowth method is the best ecological method of site preparation but it does not offer sufficient light conditions for the good growth of light demanding species like Framiré

ii) Although the Complete Clearance method had the most drastic effects on the ecosystem it provided sufficient light conditions which favoured good growth of Framiré in areas with adequate nutrients and mild soil compaction effects. The major problem about the method concerns its sustained use.

iii) Total land clearance, contrary to the generally accepted hypothesis suggesting increased decomposition, can create unfavourable environmental conditions that give rise to a decrease in turnover rates.

iv) The Mechanical Regrowth method (after the two years study period) presents the best compromise between cost, plant growth and ecological stability for the regeneration of fast growing indigenous hardwoods species like *Terminalia ivorensis*.

Site preparation generally has adverse effects on the ecosystem but the degree and the extent of the effects depend on the intensity of ecosystem disturbance and may be reflected in plant growth,

The development of a sound silvicultural system for forest regeneration with indigenous hardwoods, requires a greater understanding and mastering of land clearing techniques. Such knowledge would enable optimum canopy opening to allow sufficient light for the tree crop without causing too much damage to the soil and vegetation. The move towards highly productive, genetically-improved, clonal plantations of indigenous hardwoods necessitates the maintenance of a stable ecosystem and the development of sound silvicultural systems. The results of this study suggest that with proper technical skills and careful execution of operations under the guidance of a good silviculturalist, one can achieve increased productivity and ecological stability by suitable systems of site preparation.

This study has laid the baseline for furtherwork to understand fully the various processes involved in plant growth in the different treatment plots, and how these processes are changed with time. This information is considered very important to help avoid the many mistakes made in project planning and to ensure long-term sustainable tree crop production and the conservation of the tropical forest.

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Appendix 1: Laboratory Methods of soils and plant material analysis.

In the laboratory at Mbalmayo, soils were air-dried and sieved through a 2 mm sieve. Samples for particle size determination were analysed in the soils laboratory at Yaoundé. The remaining samples were transported and analysed for chemical properties in the University of Edinburgh.

Plant materials were oven dried at 105 °C overnight, in the laboratory of the Ecole Nationale des Eaux at Fôrets Mbalmayo, ground to fine powder and subsamples collected after thorough mixing in self-sealing polyethene bags. These, subsamples, were transported and analysed for nutrients in the University of Edinburgh.

Details of the methods used can be found in (Metson, 1961; Black et al 1965, Allen et al, 1974).

1.1 Soils

pH: The pH-H_20 was measured potentiometrically using a glass electrode in a 1:2.5 fresh-soil:water suspension after stirring and allowing to stand for 30 minutes.

Carbon: Organic carbon was determined by an absorptiometric modification of the Walkley and Black method (Metson, 1961). 1 g of fine soil (75 µm mesh size) was weighed into 250 ml erlenmmeyer flasks. 15 ml of 4N sodium dichromate solution was gently added and to this mixture was immediately added 30 ml of concentrated sulphuric acid. After swirling for a few minutes the solution was allowed to stand for 10 minutes then distilled water (100 ml) was added and allowed to stand for 2 hours. Some of the solution was then centrifuged (2000 rpm) for 10-15 minutes and the absorption measured in a EEL colorimeter using filters (760 nm). The carbon percentage was then read from standard curves.

Particle size analysis: Analysis for particle size determination was done by the pipette method. 20 g of soil (fine earth ≤ 2 mm) was treated with 20% hydrogen peroxide to destroy organic matter and dispersed with sodium hexametaphosphate. The mixture was made up to 500 ml with distilled water and shaken in a 1000 ml cylinder overnight before determination of particle size.

1.1.1 Extractable nutrients

1.1.1.1 Nitrogen and aluminium

10 g of air dried soil was measured into 250 ml erlenmeyer flasks. To these was added 100 ml of 1N KCl and extracted for 2 hours in an orbital shaker before filtering through a Whitman No. 42 filter paper. The leachate was then analysed for NH_4-N, NO_3-N, and Al, colorimetrically in an autoanalyser.

NH_4-N: Determination of ammonium nitrogen was by flow injection analysis and gas diffusion using sodium hydroxide as reagent plus an indicator (acid base). The Sample was injected into a carrier stream and was merged with NaOH stream. In the resulting alkaline stream, gaseous ammonia was formed which can diffuse through a gas permeable membrane into an indicator stream reacting and increasing the ion concentration of the indicator. A colour shift results which was measured photometrically.

NO_3-N and No_2-N: Determination of the sum of nitrate and nitrite nitrogen was by flow injection analysis, using 2 reagents, acidic sulphanilamide (R1), and N-(1-Napth)-ethylenediamine dihydrochloride (R2). The sample was injected into a carrier stream where the nitrate is reduced to nitrite in a cadium reductor. On addition of R1, a diazo compound was formed which then reacts with R2 provided from a second merging stream. A purple azo dye was formed, the intensity of which was proportionate to the sum of the nitrate and nitrite concentrations.

Al: Aluminium was determined by flow injection analysis, using 3 reaghents: R1= 50 ml of a solution of, 5.6 g hydroylammonium chloride and 0.56 g 1.10-phenanthroline monohydrate dissolved in 100 ml, diluted to 500 ml; R2= 50 ml of a solution of, 0.125 g of pyrocatecholviolet dissolved in 100ml, diluted to 500 ml. R3= 39 g of hexamethylentetramine dissolved in 350 ml of distilled water plus 2.28 g of sodium hydroxide, diluted to 500 ml. The patassium chloride soil extract was injected into a carrier stream which had the same matrix composition as the sample matrix and merged with a masking solution for iron (R1) and subsequently with the colour reagent for aluminium (R2) and a buffer (R3). The coloured complex between aluminium and pyrocartecholviolet was measured at 585 nm.

1.1.1.2 Phosphorus

10 g of air dried soil was extracted as described above using a solution of 2% acetic acid. The extractant was determined colorimetrically for phosphorus in an autoanalyser using ammonium molybdate and stannous chloride as reagents. Ammonium molybdate reacts with orthophosphate to form heteropoly molybdophosphoric acid , which was reduced to blue phosphomolybdeum by stannous chloride in a sulphoric acid medium. The colour formed was measured at 690 nm.

1.1.1.3 Exchangeable bases

Soil extraction for the determination of exchangeable bases was similar to that described above for nitrogen but using a solution of 1N ammonium acetate at pH 7.0. Potassium is determined by flame photometry and Magnesium and Calcium by atomic absorption spectrophotometry.

1.1.2 Total nutrients

1.1.2.1 Nitrogen

Total nitrogen was determined using kjeldahl digestion method. 1 g of air dried soil (2 mm mesh size) was weighed into 300 ml kjeldahl digest flasks. Distilled water (4-5 ml) was added to the sample and swirled before allowing to stand for 30 minutes. Two kjeldahl tablets and 20 ml of concentrated sulphuric acid was added to the mixture. Flasks were then fitted to the condensation outlets and heated, cautiously at first, till frothing ceased then the mixture was gently boiled until digestion became pale green, after which heating continued for 1 hour. The digestion was then filtered and made up to 500 ml with distilled water. Nitrogen was determined colorimetrically based on the principle described above.

1.1.2.2 Phosphorus

Total phosphorus was determined by dry ashing. 0.5 g of oven dried soil was treated with 20% magnesium acetate and oven dried overnight before ashing in a furnace at 450 °C. After cooling in a desiccator, samples were put in a steam bath. 5 ml of concentrated hydrochloric acid (HCl) was added and solution heated for 15 minutes, covered with wash glasses. 1 ml of nitric acid (HNO_3) was added to the mixture and heated to dryness, after which heating continued for 1 hour. 1 ml of distilled water and 1 ml HCl was added and swirl to dissolve residue before complete dissolution with 10 ml of distilled water. Samples were then filtered and made up to 50 ml with distilled water. P was determined colorimetrically as described above.

1.2 Plant material

Approximately 0.1 g of the ground plant material was accurately weighed to four decimal places and placed in a digest tube. Sulphuric acid (2 ml concentrated) was added and vigorously shaken. In a fume cupboard, 1 ml of H_2O_2 (Hydrogen peroxide) was added to the mixture in two stages. 0.5 ml was added slowly and given a gently shake. After the initial vigorous reaction has subsided, the other 0.5 ml was added and tubes were heated in blocks at 340 ^{o}C until all samples had cleared (about 5 hours). After cooling, samples were made up to 50 ml and then chemically analysed. N and P were determined colorimetrically as above, K by flame photometry and Mg and Ca by atomic absorption spectrophotometry.

Appendix 2: Field Profile descriptions (After ORSTOM, 1969)

Profile i

Date of examination: 07/03/87
Location: Ebogo (Mbalmayo forest reserve)
Slope: 5%
Vegetation: old secondary semi-deciduous forest (*Alstonia congensis, Albizzia sp, Fagara sp, Miranthus sp, Musanga cercopioides, Rhicenodendron)*
Drainage: Moderately well drained
Parent matrial: Alluvium/colluvium
Geomorphology: Riverine plains or palaeoriver plains

0-5 cm	Dark yellowish brown (10 YR 4/4), sandy clay; very weak fine and medium angular to subangular blocky, breaking into weak fine and medium granular; slightly sticky; slightly plastic; friable; many fine, medium and coarse pores; many fine, medium and coarse roots; clear and smooth boundary.
5-25 cm	Dark yellowish brown (10 YR 4/6); sandy clay; weak fine and medium angular to subangular, blocky, breaking into weak and medium granular; slightly sticky; slightly plastic; friable; few fine interstitial pores; few medium and coarse tubular pores; many fine and medium roots; clear and smooth boundary.
25-60 cm	Dark brown (7.5 YR 4/4), with few medium yellowish red (5 YR 4/8) mottles; sandy clay, with a few gravels in the form of nodules 2 to 5mm in diameter; weak fine and medium angular to subangular blocky; breaking into weak and medium granular; sticky; plastic; friable; many fine and medium tubular pores; few interstitial pores; few fine roots; gradual and smooth boundary.
60-130 cm	Strong brown (7.5 YR 4/6), with few medium yellowish brown

(10 YR 5/6) mottles; clay; weak fine and medium angular to subangular blocky, breaking into weak and medium granular; sticky; plastic; friable; many fine tubular pores; few interstitial pores; few fine roots; gradual and smooth boundary.

130-170 cm Strong brown (7.5 YR 5/6) with few distinct yellowish brown (10 YR 5/6) mottles, clay; weak fine and medium angular to subangular blocky, breaking into weak and medium granular; sticky; plastic; friable; many fine and medium tubular pores; very few roots.

Profile ii

Date of examination: 7/03/87
Location: Ebogo (Mbalmayo forest reserve)
Slope: 5%
Vegetation: Old secondary semi-deciduous forest (*Musanga cercopioides Voacanga sp. and Terminalia superba)*
Drainage: moderately well drained
Parent material: Alluvium/colluvium
Geomorphology: Riverine plains or palaeoriver plains

0-17 cm Dark yellowish brown (10 YR 4/4), sandy clay; very weak fine and medium angular to subangular blocky, breaking into weak fine and medium granular; slightly sticky; slightly plastic; friable; many fine, medium and coarse pores; many fine, medium and coarse roots; gradual and smooth boundary.

17-44 cm Dark yellowish brown (10 YR 4/6); clay; weak fine and angular to subangular blocky, breaking into weak and medium granular; sticky; plastic; friable; many fine and medium tubular pores; many fine and medium roots; gradual and smooth boundary.

44-105 cm Yellowish browm (10 YR 5/6); clay; weak fine and medium angular to subangular blocky, breaking into weak and medium granular; sticky; plastic; friable; many tubular pores; few fine roots; gradual and smooth boundary.

105-130 cm (7.5 YR 5/6), with few medium yellowish red (5YR 4/8) mottles; clay; weak fine and medium angular to subangular blocky, breaking into weak to moderate fine and medium granular; few medium and coarse tubular pores; very few roots; gradual and smooth boundary.

130-170 cm Strong brown (7.5 YR 5/8), with many gravels, quartz and yellowish brown (10 YR 5/6) mottles and few distinct red (2.5 YR 4/8) mottles; clay; very weak fine and medium angular to subangular blocky, breaking into weak fine and medium granular; sticky; plastic; friable; few fine and tuber pores, very few fine and medium roots.

Profile iii

Date of examination: 21/08/87
Location: Control
Slope: 2%
Vegetation: Old secondary semi-deciduous forest (*Musanga cercopiodes, Afromomum sp, Peptadena sp)*
Drainage: Moderately well drained
Parent material: Alluvium/Colluvium
Geomorphology: Riverine plains or palaeoriver plains

0-5 cm Dark brown (10 YR 4/3); sand clay, very weak fine and medium angular to subangular blocky, breaking into weak fine and medium granular; slightly sticky; slightly plastic; friable; many fine, medium and coarse pores; many fine, medium and coarse roots; clear smooth boundary.

5-20 cm Dark yellowish brown (10 YR 4/4), sandy clay; weal fine an medium angular to subangular blocky, breaking into weak and medium granular; slightly sticky; slightly plastic; friable; many fine and medium pores; many fine and medium roots; clear and smooth boundary.

20-50 cm	Dark brown (7.5 YR 4/4), with few medium yellowish red (5 YR 4/8) mottles; clay; weak fine and medium angular to subangular, breaking into weak and medium granular; slightly sticky; slightly plastic; friable; many fine and medium tubular pores; few fine and medium roots; gradual and smooth boundary.
50-100 cm	Strong brown (7.5 YR 4/6); clay; weak fine and medium angular to subangular blocky, breaking into weak and medium granular; sticky; very friable; many fine and medium tubular pores; few fine roots; gradual and smooth boundary.
100-125 cm	Reddish brown (5 YR 4/4) clay; weak fine and medium angular to subangular blocky; breaking into weak and medium granular; many coarse elements, gravels, laterites, quartz; sticky; friable; many fine and tubular pores; few roots; clear and distinct boundary.
125-150 cm	Yellowish red (50 YR 4/6); clay; strong and course angular to subangular blocky, breaking into strong and medium granular; many gravels, few stones, lateriles; sticky friable; few tubular pores; few roots.

<u>Profile iv</u>

Date of examination: 21/08/97
Location: Manual regrowth plot Ebogo (Mbalmayo forest reserve)
Slope: 7%
vegetation: undergrowth and small trees cut, presence of big trees *(Petersianthus sp,Voacanga sp.)*
Parent material Alluvium/Calluvium
Geomorphology: Riverine plains or palaeoriver plains

0-15 cm	Dark brown (10 YR 4/3), sndy clay; very weak fine and medium angular and subangular blocky, breaking into weak fine and medium

	granular; slightly sticky; slightly plastic, friable; many fine, medium and coarse pores; many fine, medium and coarse roots, clear amd wavy boundary.
15-24 cm	Dark yellowish brown (10 YR 4/4); sandy clay; strong and medium angular to subangular blocky breaking into strong and medium granular; sticky; friable; many fine and medium pores; few fine and medium roots; clear and smooth boundary.
24-40 cm	Dark yellowish brown (10 YR 4/6), with many yellowish brown (10 YR 5/6) mottles; sandy clay; strong and medium angular to subangular blocky, breaking into strong and medium granular; sticky; plastic; friable; few tubular pores; few roots; sharp and smooth boundary.
40-70 cm	Dark brown (7.5 YR 4/4); clay; strong and medium angular to subangular blocky, breaking into strong and medium granular; sticky, plastic; friable; many fine tubular pores; few fine and medium roots; gradual and smooth boundary.
70-110 cm	Strong brown (7.5 YR 4/6), with common strong brown (7.5 YR 4/6) mottles; clay, with many coarse elements; gravels, laterites, quartzs; weak fine and medium angular to subangular blocky breaking into strong and medium granular; slightly sticky; slightly plastic; friable; few fine and medium pores; few roots; clear and smooth boundary.
110-14 0cm	Yellowish red (5 YR 4/6), clay, with many course elements (as above); weak fine and medium angular to subangular blocky; breaking into strong and medium granular; slightly sticky, slightly plastic; friable; few fine and tubular pores, few roots, clear and smooth boundary.
140-170 cm	Prominent red (2.5 YR 4/6) with common yellowish brown (10 YR 5/6) mottles; clay loam; weak fine and medium angular to subangular blocky, breaking into weak and medium granular; slightly sticky;

slightly plastic; friable; few fine and medium pores; very few roots;

Profile v

Date of examination: 21/08/87
Location: Mechanical Regrowth plot - Ebogo (Mbalmayo forest reserve)
Slope: 1%
Vegetation: No ground vegetation, cleared with bulldozer, presence of big trees (*Terminalia surpeba)*; topsoil partly scraped.
Drainage: Moderately well drained
Parent material: Alluvium/Colluvium
Geomorphology: Riverine plains or palaeoriver plains

0-20 cm	Dark brown (10 YR 4/3); sandy clay; structureless due to compaction; slightly sticky; slightly plastic, friable; very few faintly visible pores; few fine to medium roots, clear and smooth boundary.
20-40 cm	Dark yellowish brown (10 YR 4/4) sandy clay with many coloured quartz; strong and medium angular to subangular blocky, breaking into strong and medium granular; sticky, slightly plastic; friable; few tubular pores due to compaction, few fine and medium roots; clear and smooth boundary.
40-60 cm	Dark yellowish brown (10 YR 4/6); clay; weak fine and medium angular to subangular blocky, breaking into weak and medium granular; slightly sticky; slightly plastic; friable; few fine and medium tubular pores; few fine and medium roots; gradual and smooth boundary.
60-125 cm	Dark brown (7.5 YR 4/4); clay, with few coloured quartz; very weak fine and medium angular to subangular blocky, breaking into weak fine and medium granular; sticky; friable; few tubular pores, few roots; gradual and smooth boundary.
125-180 cm	Strong brown (7.5 YR 5/6); clay, with few course sand; very weak

fine and medium angular to subangular blocky, breaking into weak fine and medium granular; sticky; friable; very many tubular pores; very few roots.

Profile vi

Date of examination: 21/08/87
Location: Complete clearance plot - Ebogo (Mbalmayo forest reserve).
Slope: 1-2%
Vegetation: Non, cleared using bulldozer, topsoil scraped
Drainage: Moderately well drained
Parent material: Alluvium/Colluvium
Geomorphology: Riverine plains or palaeoriver plains

0-10 cm	Dark brown (10 YR 4/3); sandy clay; structureless, due to compaction; slightly sticky; slightly plastic; friable; few faintly visible pores; few fine medium and coarse roots, clear and smooth boundary.
10-15 cm	Dark yellowish brown (10 YR 4/4); clay; structureless due to compaction; sticky, plastic friable; few fairly visible tubular pores; few medium and coarse roots; gradual and smooth boundary.
15-25 cm	Dark yellowish brown (10 YR 4/6) with few medium strongbrown (7.5 YR 4/6) mottles; sandy clay, with many quartz; weak fine and medium angular to subangular blocky, breaking into weak and medium granular; slightly sticky; slightly plastic; friable; very many fine and medium tubular pores, few fine roots; gradual and smooth boundary.
25-125 cm	Yellowish brown (10 YR 5/6) with few coarse light yellowish (10 YR 6/4) and medium strong brown (7.5 YR 5/6) mottles; sandy clay; very weak fine and medium angular to subangular blocky; sticky; plastic; many fine and medium tubular pores, very few roots; gradual and smooth boundary.

125-170 cm	Strong brown (7.5 YR 4/6) with few medium prominent red (2.5 YR 4/6) mottles, sandy clay, with many coarse elements (many coarse gravel and medium quartz); weak fine and medium angular to subangular blocky, breaking into weak and medium granular; slightly sticky, slightly plastic; friable; few tubular pores; very few roots; abrupt and smooth boundary.
170-185 cm	Strong brown (7.5 YR 5/6) with many medium dark red (2.5 YR 3/6) mottles; clay, with many coarse elements (as above); very weak fine and medium angular to subangular blocky, breaking into weak fine and medium granular; slightly sticky; slightly plastic; less friable; very few pores; very few roots.

<u>Profile vii</u>

Date of examination: 21/08/87
Location: complete clearance plot - Ebogo (Mbalmayo Forest reserve)
Slope: 5%
Vegetation Non, cleared using bulldozer, topsoil scraped.
Drainage: moderately well drained
Parent material: Alluvium/colluvium
Geomorphology Riverine plains or palaeoriver plains

0-5 cm	Dark brown (10 YR 4/3); sandy clay; structureless due to compaction; slightly sticky; slightly plastic; less friable; very few faintly visible pores; few fine, medium and coarse roots; clear and smooth boundary.
5-25 cm	Dark yellowish brown (10 YR 4/4); sandy clay; structureless due to compaction; sticky plastic; less friable; few faintly visible tubular pores; few fine and medium roots; abrupt and smooth boundary.
25-55 cm	Dark brown (7.5 YR 4/4); sandy clay; strong and medium angular to subangular blocky, breaking into strong and medium granular; sticky;

	plastic; less friable; many fine and medium tubular pores; few fine and medium roots, gradual and smooth boundary.
55-130 cm	Strong brown (7.5 YR 4/6); clay; weak fine and medium angular to subangular blocky, breaking into weak and medium granular; sticky; plastic; friable; many fine and medium tubular pores; few fine and medium roots; gradual and wavy boundary.
130-150 cm	Strong brown (7.5 YR 5/6); clay, with many coarse elements, gravels in form of nodules, laterites, quartz; very weak fine and medium angular to subangular blocky, breaking into weak fine and medium granular; slightly sticky; slightly plastic; friable; few fine and medium tubular pores; few fine roots; abrupt and smooth boundary.
150-175 cm	Yellowish red (5 YR 4/6); clay; very weak fine and medium angular to subangular blocky, breaking into weak fine and medium granular; many coarse elements (as above); sticky, plastic; friable; very few tubular pores; very few roots.

Appendix 3: Percentage nutrient concentration of plant parts from the bioassay experiment

Treatment	Leaves				
	N	P	K	Ca	Mg
Depth 1	3.09	0.25	1.75	0.91	0.27
Depth 2	1.50	0.14	1.76	1.01	0.27
Litter	2.88	0.25	1.63	1.15	0.29
Fertilized	2.69	0.21	1.42	0.84	0.23
Control	2.98	0.27	1.69	1.00	0.27
Stems					
Depth 0-20 cm	1.31	0.19	1.55	0.65	0.22
Depth 20-40 cm	1.10	0.17	1.54	0.57	0.22
Litter	1.46	0.28	1.97	0.65	0.35
Fertilized	1.20	0.15	1.90	0.45	0.15
Control	1.14	0.14	1.34	0.53	0.25
Roots					
Depth 0-20 cm	1.09	0.09	1.34	0.34	0.19
Depth 20-40 cm	1.09	0.09	1.26	0.36	0.20
Litter	1.06	0.13	1.52	0.30	0.23
Fertilized	1.45	0.12	1.61	0.23	0.13
Control	1.20	0.10	1.15	0.31	0.23

Appendix 4: Mean monthly litter-fall fractions (g m^{-1}) in the different plots over the one year study period (June, 1988 - May, 1989)

Treatment	Fraction	J	J	A	S	O	N	D	J	F	M	A	M
Control	Leaves	65.9	35.7	50.2	55.0	77.1	39.9	35.6	72.7	113	94.1	34.6	31.2
	WM	28.9	5.7	4.2	19.4	10.6	16.7	16.0	27.4	36.0	46.8	66.9	29.9
	Others	7.7	2.9	24.4	15.8	1.9	9.0	8.4	1.2	9.8	25.7	58.9	30.0
	Total	102.5	44.3	78.8	90.2	89.6	63.4	60.0	101.3	159.0	166.6	160.4	91.1
Man. Reg.	Leaves	31.2	24.3	27.2	37.9	41.5	47.0	63.0	114.9	114.3	100.9	77.8	31.7
	WM	8.2	7.7	4.6	4.0	4.9	21.8	12.1	9.0	10.3	28.8	41.2	17.7
	Others	8.7	1.0	4.5	6.7	0.35	8.2	6.1	3.1	7.9	20.5	20.2	20.7
	Total	48.1	33.0	36.3	48.6	46.8	75.5	78.0	127.1	132.6	150.2	139.3	70.1
Mech Reg.	Leaves	18.3	12.0	21.3	30.8	47.3	32.9	36.2	61.7	62.5	56.0	56.2	49.5
	WM	11.4	8.7	10.1	4.1	8.6	6.6	5.6	3.6	14.5	12.2	13.8	15.0
	Others	3.6	0.0	7.8	8.2	0.54	8.6	4.4	2.9	17.4	21.2	10.2	9.3
	Total	33.3	20.7	39.1	43.1	56.4	46.7	45.2	68.3	94.3	89.4	79.4	73.8
Comp. C	Leaves	1.6	2.4	11.4	14.9	10.1	8.2	5.5	16.9	24.0	25.9	14.7	15.5
	WM	0.03	0.0	0.0	0.01	0.0	0.97	0.42	1.6	0.0	0.0	1.4	3.5
	Others	0.18	0.11	2.6	0.31	0.18	0.05	0.39	1.2	3.2	7.7	3.9	2.8
	Total	1.8	2.5	14.0	15.2	10.3	9.2	6.0	19.7	27.2	33.6	20.0	21.7

Appendix 5: Nutrient concentration (%dry weight) of monthly fine litter-fall fractions in the different plots over the one year study period (June 1988 - May 1989) in the Mbalmayo forest reserve. (Elt. = element)

Treatment	Elt.	Fraction	J	J	A	S	O	N	D	J	F	M	A	M
Control	N	L	1.59	2.19	2.19	2.34	1.47	2.07	2.32	2.04	1.83	1.86	2.37	2.17
		WM	1.16	1.46	1.12	1.16	1.40	1.80	1.47	1.60	2.24	1.91	2.02	1.59
		O	1.84	2.14	3.00	2.75	1.02	1.55	2.30	2.02	2.25	2.37	2.36	2.46
	P	L	0.048	0.050	0.061	0.058	0.035	0.073	0.090	0.09	0.08	0.08	0.10	0.10
		WM	0.034	0.037	0.040	0.037	0.031	0.061	0.060	0.08	0.10	0.08	0.05	0.07
		O	0.052	0.070	0.077	0.070	0.033	0.083	0.110	0.19	0.15	0.12	0.11	0.14
	K	L	0.41	0.44	0.39	0.37	0.276	0.28	0.30	0.44	0.49	0.24	0.24	0.39
		WM	0.20	0.29	0.13	0.19	0.20	0.25	0.19	0.10	0.42	0.21	0.47	0.20
		O	0.33	0.93	0.14	0.31	0.29	0.38	0.39	1.09	0.71	0.31	0.28	0.30
	Ca	L	1.31	1.09	1.18	0.79	1.07	1.42	1.23	1.36	1.37	1.10	1.21	1.36
		WM	1.00	1.30	0.77	1.33	0.89	1.01	1.48	2.09	1.04	1.43	2.30	1.70
		O	0.79	0.96	0.76	0.85	0.36	0.91	1.33	0.83	0.98	0.78	0.90	1.31
	Mg	L	0.38	0.32	0.35	0.24	0.30	0.38	0.38	0.35	0.42	0.30	0.30	0.36
		WM	0.29	0.32	0.21	0.21	0.19	0.25	0.32	0.28	0.36	0.32	0.42	0.30
		O	0.29	0.32	0.22	0.23	0.10	0.19	0.29	0.29	0.30	0.22	0.21	0.32
Manual Regrowth	N	L	1.55	1.56	1.32	1.30	1.56	1.53	1.55	1.51	1.46	1.53	2.02	1.85
		WM	1.41	1.30	1.56	0.82	0.97	1.11	1.32	1.20	1.56	1.51	1.61	1.55
		O	2.84	2.18	1.85	1.39	2.12	2.12	2.42	2.16	1.83	2.40	2.30	2.21
	P	L	0.029	0.047	0.035	0.035	0.027	0.058	0.07	0.07	0.07	0.07	0.10	0.09
		WM	0.040	0.030	0.035	0.026	0.032	0.038	0.06	0.09	0.08	0.04	0.09	0.06
		O	0.090	0.035	0.049	0.081	0.061	0.106	0.15	0.18	0.13	0.15	0.11	0.18
	K	L	0.36	0.46	0.37	0.28	0.33	0.34	0.46	0.61	0.48	0.34	0.23	0.26
		WM	0.19	0.30	0.29	0.37	0.29	0.22	0.22	1.08	0.60	0.09	0.33	0.27
		O	0.69	0.54	0.71	0.45	0.37	0.46	0.52	1.04	0.86	0.46	0.22	0.49
	Ca	L	1.09	0.91	1.21	1.17	1.14	0.86	1.27	1.44	0.98	0.91	0.83	0.84
		WM	1.36	1.37	2.03	1.33	1.32	1.28	1.30	1.53	1.29	1.14	1.20	1.45
		O	0.19	0.74	1.13	1.05	1.03	0.96	0.78	0.71	0.89	0.55	1.07	0.81
	Mg	L	0.35	0.29	0.34	0.31	0.32	0.35	0.45	0.41	0.27	0.30	0.27	0.27
		WM	0.34	0.34	0.31	0.24	0.28	0.22	0.30	0.50	0.29	0.16	0.28	0.34
		O	0.24	0.24	0.22	0.24	0.23	0.32	0.28	0.27	0.33	0.22	0.36	0.34

Appendix 5: Continued

Treatment	Elt.	Fraction	J	J	A	S	O	N	D	J	F	M	A	M
Mechanical Regrowth	N	L	1.50	1.51	1.14	1.22	2.16	1.74	1.22	1.28	1.49	1.66	1.91	1.83
		WM	1.15	1.18	0.95	1.09	1.45	1.32	1.02	0.004	1.12	1.28	0.69	1.25
		O	2.47	-	2.37	1.58	2.00	2.61	2.40	2.21	2.36	2.20	2.37	-
	P	L	0.042	0.051	0.034	0.043	0.059	0.064	0.07	0.07	0.07	0.07	0.08	0.07
		WM	0.023	0.036	0.021	0.028	0.030	0.050	0.04	0.01	0.06	0.04	0.06	0.07
		O	0.099	-	0.055	0.050	0.069	0.156	0.17	0.17	0.22	0.14	0.11	-
	K	L	0.24	0.42	0.33	0.28	0.32	0.34	0.38	0.42	0.39	0.29	0.30	0.28
		WM	0.14	0.27	0.22	0.19	0.23	0.18	0.38	0.41	0.37	0.18	0.18	0.33
		O	0.50	-	0.53	0.38	0.36	0.68	0.36	0.96	1.12	0.37	0.19	-
	Ca	L	1.09	1.13	1.08	1.18	1.31	1.14	1.42	1.33	1.16	1.13	0.95	1.23
		WM	0.16	1.03	0.78	1.23	0.94	2.50	1.19	0.33	1.15	1.17	1.39	1.24
		O	1.07	-	0.91	0.90	0.68	1.01	1.02	1.46	1.19	0.88	1.37	-
	Mg	L	0.35	0.40	0.34	0.32	0.34	0.38	0.43	0.38	0.29	0.26	0.31	0.39
		WM	0.37	0.22	0.16	0.25	0.30	0.25	0.24	0.05	0.25	0.20	0.37	0.28
		O	0.30	-	0.31	0.28	0.22	0.45	0.35	0.44	0.38	0.26	0.26	-
Complete Clerance	N	L	2.60	2.03	1.45	1.67	1.06	1.45	2.14	1.52	1.56	1.56	1.76	1.69
		WM	0.96	-	-	-	1.21	0.60	0.77	0.76	-	-	1.24	1.25
		O	1.75	-	1.66	1.11	-	1.87	2.22	2.18	2.46	2.22	2.26	2.29
	P	L	0.041	0.080	0.042	0.033	0.035	0.062	0.09	0.07	0.07	0.06	0.06	0.06
		WM	0.032	-	-	-	0.026	0.033	0.03	0.05	-	-	0.04	0.04
		O	0.060	-	0.057	0.030	-	0.150	0.10	0.12	0.15	0.09	0.12	0.11
	K	L	0.69	0.35	0.33	0.16	0.20	0.31	0.43	0.71	0.57	0.25	0.17	0.17
		WM	0.11	-	-	-	0.19	0.25	0.70	0.96	-	-	0.14	0.13
		O	0.22	-	0.79	0.43	-	0.48	0.83	0.97	1.22	0.18	0.16	0.21
	Ca	L	0.96	0.99	1.04	0.94	1.17	0.95	1.46	1.34	1.25	1.16	1.15	1.29
		WM	1.33	-	-	-	1.42	0.63	1.47	1.90	-	-	1.04	0.63
		O	1.38	-	1.09	0.86	-	0.79	1.02	1.30	1.19	1.05	1.08	1.07
	Mg	L	0.32	0.19	0.33	0.27	0.28	0.34	0.38	0.41	0.35	0.24	0.29	0.35
		WM	0.18	-	-	-	0.23	0.29	0.38	0.54	-	-	0.30	0.25
		O	0.19	-	0.25	0.23	-	0.27	0.29	0.44	0.47	0.30	0.31	0.33