SOIL AND VEGETATION DYNAMICS IN SECONDARY FOREST REGENERATION IN DEGRADED RUBBER PLANTATION, OROGUN, DELTA STATE

BY

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A Thesis in the Department of Geography Submitted to the Faculty of Social Sciences in Partial Fulfillment of the Requirement for the Award of the Degree of Doctor of Philosophy of the University of Ibadan

July, 2014

ABSTRACT

In Nigeria, secondary forests of different types are increasing in area, and becoming increasingly important for species diversity conservation and soil fertility regeneration. Previous studies on the dynamics of soil and vegetation have focused on secondary forests regeneration after shifting cultivation. Despite the increasing importance of secondary forest regeneration in degraded rubber plantation, there is hardly any comprehensive study on the dynamics of soil and vegetation in secondary forest regeneration in degraded rubber plantation. This study therefore examined the dynamics of soil and vegetation in secondary forests recovering from degraded rubber plots in Orogun, Delta State.

Soil samples were collected from 10 plots (each 30m x 30m) in 1-, 5-, 10- year forest and from adjoining mature forest (control). Soil physico-chemical properties (exchangeable cation (calcium, magnesium, potassium and sodium), available phosphorus, pH, bulk density, water holding capacity (WHC), total porosity, effective cation exchange capacity (ECEC), organic matter (OM) and nitrogen) were analyzed, using standard laboratory procedures. Vegetation above-ground biomass (AGB) and floristic parameters (tree height, density, diameter, basal area, above-ground biomass, number of tree species, number of plant species and species diversity) were measured in each plot. Litterfall was collected monthly in each plot for 12 months using 1m^2 litter traps. Analysis of variance was used to ascertain whether the soil and vegetation parameters differ among secondary forest categories and between pairs of secondary forest and mature forest at $P < 0.05$. Stepwise multiple regression model was used to ascertain the relationships between soil and vegetation parameters.

Soil exchangeable cation and available phosphorus concentrations increased significantly during the first five years of fallow but declined by the tenth year and thereafter, increased significantly in the mature forest (control) than all the secondary forest categories. Soil pH and bulk density decreased significantly over time, while soil WHC and total porosity increased significantly. Soil ECEC, OM and nitrogen increased significantly with increasing age of secondary forest. Above-ground biomass decreased significantly from 349 t/ha in the mature forest to 74 t/ha and 5.1 t/ha in the 10-year and 1-year fallows respectively. Species diversity and AGB were significantly higher in the mature forest than in all the secondary forest categories. Litterfall increased significantly from 1114.9kg/ha^{-1} year^{-1} in the 1-year fallow to 11324 kg/ha^{-1} year^{-1} in the mature forest. Litterfall and the amount of nutrients returned to the soil through litterfall increased significantly in the order of 1-year<5-year<10-year<mature forest. Species diversity, AGB and litterfall jointly accounted for 56%, 84%, 81% and 86% of the increase in ECEC, OM, WHC and total porosity respectively over time. Fifty two percent of the increase in OM was accounted for by above-ground biomass while species diversity and litterfall accounted for 18% and 14% respectively of the increase in OM.

Secondary forest regeneration in degraded rubber plantation is capable of minimizing species diversity losses and restoring soil fertility. Therefore, 5- to 10-year fallow cycles should be encouraged as a management strategy in secondary forest regeneration in degraded rubber plots. This would ensure sustainable cropping with or without fertilizer application.

Keywords: Litterfall, Soil Dynamics, Above-ground biomass, Species diversity, Degraded rubber plantation

Word count: 499

CERTIFICATION

I certify that this work was carried out by Mr. Victor Idigu ICHIKOGU under my supervision in the Department of Geography, University of Ibadan.

SUPERVISOR **PROFESSOR A. O. AWETO** **DEPARTMENT Of GEOGRAPHY** **UNIVERSITY OF IBADAN, NIGERIA**	**DATE**

DEDICATION

This work is dedicated to God Almighty, whose love lifted me when nothing else would do.

ACKNOWLEDGEMENTS

How does one say ‘thank you’ when there are so many people to thank? Obviously this Thesis is a thank you to my two fathers- my biological father (Late Chief Thomas Ichikogu) and Professor Albert Orodena Aweto, my academic father who are my role models, and to my mother who taught me love, kindness and honesty.

The people most directly responsible for this thesis becoming a reality are many. Professor Aweto did a magnificent job of using his hard earned money to travel to Delta State to inspect the study area and the design of the litter traps. He took his time, offering useful suggestions at every stage of the research, correcting grammatical errors that crept in despite my best efforts, providing relevant journal articles for the literature review, and timeously reading through the draft of the thesis. His specific suggestions on some of the action steps were invaluable. Much of the thesis’s value can be laid at his doorstep. Professor Aweto I am eternally grateful to you.

Thanks to Professor G.E Akinbola of Agronomy Department University of Ibadan, Professor A.S Gbadegesin of Geography Department University of Ibadan, Dr. I.O. Adelekan, Dr. D.D. Ajayi, Dr A Adedeji and Dr. F.O.A. Dada all of Geography Department University of Ibadan for their critical and valuable suggestions during the evaluation of the proposal that gave birth to this thesis. Your comments were essential; your suggestions were badly needed, mostly appreciated, and most beneficial to me.

My thank you also goes to all the other lecturers in Geography Department for their useful comments and suggestions during my proposal presentation in the weekly staff and postgraduate students’ seminar presentation of the Geography department.

Thank you my wife, Blessing, you made my life complete. Blessing is my partner in marriage, academics, and in life. Without her I would be lost. Thank you my wife for being there for me.

Thank you my siblings: Monday Ichikogu, Matthew Ichikogu, Franklin Ichikogu, Ovwighotite John and Ishekwene Pleasure; they took their time to assist me in the field during the collection of data.

Thanks to Mr. Aghogho the Laboratory Technologist who handled the laboratory tests of the soil and litter samples. Thank to Mr. Victor Oreavwote for helping me with the regression analysis of the data. Thank you Mr. Daniel Ovuefe Okoro for helping me with the map work.

I thank Philip Ighosoyivwi, Niyi Oyekun and Felix Igugu for the gift of friendship. I thank Kayode Samuel and Christian Onogbosele for accommodating me when I was yet to get accommodation in Ibadan.

I must also express my sincere gratitude to Mr. Enumah Friday for providing me an accommodation in Abuja where my office was, during the course of this programme. I am grateful to you. My special thanks also go to Mr. Akinola of the Federal Ministry of Lands, Housing and Urban Development who is my boss in the office, for making it possible for me to have the time to pursue the Ph.D programme, full time. God bless you sir.

Thanks to you Nigeria for giving me the opportunity to acquire knowledge.

I am finally grateful to God Almighty for his valuable gifts of life, good health, wisdom, providence, love and strength upon my life, for in Him there is no impossibility.

Victor Idigu ICHIKOGU
June, 2014

TABLE OF CONTENT

CHAPTER THREE: METHODOLOGY 34

CHAPTER SIX: MODELING THE RELATIONSHIP BETWEEN SOIL AND VEGETATION 156

CHAPTER SEVEN: SUMMARY, CONCLUSION AND POLICY IMPLICATION 196

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

APPENDICES

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Over much of southern Nigeria secondary forest conversion for subsistence agriculture, industrial logging and plantation agriculture and settlement expansion as well continues to be the predominant causes of deforestation. These activities have left a large portion of the forest biome disturbed and in various states of natural regeneration (Brown and Lugo, 1990), stagnation (Samiento 1997, Silver *et al*., 2000) or managed recovery (Fernandes and Matos 1995, Parrota *et al*., 1997). In Delta state, rainforests are cleared and used for rubber plantation, palm plantation and food crops production. However, most of the rubber plantations are now abandoned in the state because of poor productivity, plant diseases and death of tree plants arising from inappropriate tapping or other reasons. Therefore, most of the areas that were occupied by plantations are now occupied by secondary forests at different stages of regrowth. This land use change could alter the structure and function of any ecosystem and could trigger off new feedbacks in terms of subsequent human use (Peet 1992, Buol, 1994).

Although highly altered, these lands are valuable for human use (Brown and Lugo 1990) and provide important ecosystem services such as watershed protection, sources and havens of biodiversity, erosion prevention, soil fertility recovery by improved fallows (Szott *et al*., 1991, Scalley *et al*., 2010) and atmospheric carbon sinks (Fearnside and Guimares 1996, Silver *et al*., 2000). However the potential of the abandoned land to recover and maintain these roles is dependent on the intensity of previous land use (Uhl *et al*., 1988, Nepstand 1990, Aide *et al*., 1995, Alves *et al*., 1997), soil nutrient limitations (Lochrane and Sanchez 1982, Smyth and Cravo 1992, Laurence *et al*., 1999), and seed inputs and seedling establishment (Nepstand *et al*., 1996). These impediments to vegetation growth may be more severe in abandoned tree plantation compared to shifting cultivation.

Nutrients absorbed by plants are used for their growth and production in the ecosystem. According to Stark and Jordan (1997), minerals in the soil are almost immediately taken up by thick mat of roots and rootlike fungi. The fungi are known as mycorhizae, many of which are in symbiotic relationships with plants roots. The plants supply the mycorhizae with sugars while the mycorhrizae supply the plants with minerals and water. The association between plants and the fungi is so close that in some cases there is direct nutrient cycling-nutrients move from dead organic matter into the roots without entering the soil (Stark, 1971).

Effective nutrient cycling is very essential for plant growth and the restoration of soil fertility. There is cycling of nutrient elements between the soil and vegetation in nature. The nutrients that are taken up by secondary vegetation are eventually returned to the soil through the fall and mineralization of litter (Nye and Greenland 1960).

Litterfall is an essential process in nutrient cycling and it is the chief means through which the nutrients that are immobilized by plants from the soil are returned to the soil (Vitousek and Sanford 1986, Regina *et al*., 1999). Litter from trees help to maintain soil fertility by increasing the organic matter in the soil. The nutrient contents of litter have generally been taken as a measure of the annual nutrient turnover (Nye and Greenland 1960, Edwards and Grubbs, 1977).

The examination of litter quantity and quality is highly important for understanding of energy flow, primary productivity and nutrient cycling in forest ecosystems. Quantification of the nutrient fluctuation associated with litter fall is important to the understanding of ecosystem dynamics. Litter production and nutrient cycling patterns are likely to change during succession and may be affected by gap size, intensity of disturbance and age of fallow (Chandreshekera and Ramakrishnan 1994).

The work of Bartholomew *et al*., (1953), is one of the few attempts to study the pattern of element cycling in tropical secondary successional fallows. These studies revealed that the storage capacity of leaves and litter is saturated at early stage in the successions and thereafter, the total storage capacity increase more slowly and in the woody materials only.

Since nutrients cycling may not follow the same pattern in secondary forests regenerating from soils with different degree of perturbation, it is more satisfactory to make observations of nutrients cycling under re-growth secondary forest of different ages subjected to the cultivation of similar crops with comparable intensity of farming and management practices prior to the fallow period.

1.2 Rationale for the Study

Secondary forests form large and ever-growing proportion of forest cover in many countries today (Brown and Lugo, 1990) and are becoming an increasing components of forests cover in many countries as regrowth following deforestation. This large and growing renewable resource can provide a wide range of valuable goods and services important at the local, national and international levels. The importance attached to secondary forest has assumed phenomenal dimensions, since it is the dominant forest type today. In order to establish clear policies with regard to secondary forest, incorporate them into land use plans, and guide their management along sustainable pathway, it is essential to understand the true nature of the resources and the dynamics of soil nutrient under the various types it encompasses. Regrettably, the magnitude of forest regeneration (particularly secondary forest re-growth or re-growth of degraded abandoned plantation lands), appears not well documented.

Since secondary forests are increasing and becoming the principal forest type in many countries in the world today, and will gradually have to fill the roles of former primary forest, secondary forests should offer many of the same benefits that primary forests provide – from non timber forests products (NTFPS) to environmental services. The current uses of products from secondary forests offer potentials for improved use of their products.

One of the outcomes of these increased uses of products from secondary forest is the growing interests of researchers in studying secondary forest in most parts of the world today. For instance, legions of studies have addressed the species richness of swidden fallow secondary forest; (that is secondary forest regenerating from shifting cultivation) (Bartholomew *et al*., 1953, Ross 1954, Ewel, 1983, Aweto 1981a, Saldariaga *et al*., 1986) and post extraction secondary forest (that is secondary forests resulting from logging activities) (Ewel, 1983). By and large, these studies have shown that secondary forests accumulate woody plant species at relatively rapid rates such that within a span of

80years or less, the number of species approaches that of mature forests (Brown and Lugo, 1990).

The study of nutrient cycling in secondary forest regenerating from shifting cultivation has also attracted wide attention (Bartholomew, 1953; Ewel, 1976; Nye and Greenland, 1960; Ramakrishna and Toky, 1983; Aweto, 1981b; and Uhl, 1987). Numerous studies on nutrient cycling in secondary forest following logging are also available (Ewel 1983, Williams-Linera 1983). These studies revealed that the analysis of litter quantity and its quality is highly important for the understanding of nutrient dynamics, primary productivity and energy flow in secondary forest ecosystems. And that the quantification of the nutrient flux associated with litterfall is important to the understanding of ecosystem dynamics. These studies also revealed that nutrient cycling patterns are likely to change at different stages of development in secondary forests and may be affected by gap size, intensity of disturbance, nature of disturbance, age of fallow and the floristic composition of the secondary forest.

In Nigeria, previous works on nutrient cycling in secondary forests have tended to concentrate more on secondary forests regenerating from shifting cultivation agricultural practices (Aweto, 1978; Areola, 1980; and Adedeji, 1984), plantation (Aweto, 1987b; Ola Adams and Egunjobi, 1992; Oladoye *et al*., 2007; and Adedeji, 2008) and on post burn vegetation (Odiwe and Muoghalu 2003, Muoghalu *et al*., 1993). Studies on the analysis of the dynamics of soil and litterfall in secondary forest regenerating from degraded abandoned plantations of rubber, cocoa and other tree crops have received minimal attention from researchers. Our understanding of the nutrient status of the soil and the natural regenerative ability of this secondary forest type, through soil fertility restoration by means of litterfall is therefore limited. Plantation agriculture, which in most instances proved to be little more permanent than shifting cultivation, is a major cause of secondary forest in Nigeria. Most of the plantations are abandoned today because of soil nutrient impoverishment, animal pests, plant diseases, old age, or other reasons, and as such large areas of secondary forest now develop on the sites. Individuals of long living tree crops, such as rubber trees and oil palms, now survive in the secondary forest as vestiges of past cultivation. While there are plethora of studies on various aspects and various types of secondary forest, there is hardly any comprehensive study on secondary forest regenerating from abandoned plantations of rubber (*Hevea brasiliensis)*, cocoa cola, and palm trees. This study is therefore set out to fill this gap.

Such a study will provide us with empirical information for the sustainable management of secondary forest. In addition, the study of this nature is essential to the understanding of the changes in soil nutrient when successional fallows (secondary forest) take the place of tree plantation. Also, determining nutrients constraints to re-growth and conditions of secondary forest is an important step in managing and/or enhancing abandoned site rehabilitation. This study therefore, seeks to evaluate the dynamics of soil and litterfall in secondary forest regenerating from degraded abandoned rubber plantation in a part of southern Nigeria, with a view to providing empirical information for the sustainable management of secondary forests regeneration in degraded abandoned rubber plantations. This will help to build up data, knowledge, and management know-how on secondary forests and their sustainable management.

1.2 Research Questions

In view of the above issues, the fundamental questions associated with this study are:

1 Are there significant differences in the physical and chemical properties of soil under secondary forests at different stages of secondary succession in abandoned plantations?

2 What are the differences in the physical and chemical characteristics of soils under mature forest cover and those under recent fallows in secondary forests rejuvenating from abandoned plantations?

3 Are there significant differences in the nutrient content of litter in fallows at different stages of secondary succession in degraded abandoned plantations?

4 Are there significant differences in the quantity of litter produced in fallows of the different age categories and mature secondary forest regenerating from degraded abandoned rubber plantations?

1.3 Aim and Objectives

The primary aim of this study is to examine the dynamics of plant litter and its nutrients content in abandoned rubber plantation at various stages of secondary succession in a part of the rain forest belt of southern Nigeria and analyze the physical and chemical characteristics of soils under them.

The specific objectives are to:

1 Assess the differences at the amount of litter produced and the nutrient content of litter in fallows in different stages of secondary succession in abandoned plantations in order to ascertain the rate at which litter return nutrients to fallow soils at different stages of regeneration.

2 Determine the seasonal pattern of litterfall in fallows in different stages of secondary succession with a view to understanding the effects of season on the pattern of litterfall at different stages of regeneration in abandoned plantations.

3 Assess the differences in soil physical and chemical properties related to soil fertility in fallows of different ages with a view to understanding the changes which take place in the soil that result in the restoration of soil fertility status during the fallow period in secondary forest regenerating from degraded abandoned rubber plantations.

4 Analyze the floristic changes and changes in vegetation aboveground biomass parameters in the plant community during the course of secondary succession through quantitative characterization of the floristic and aboveground biomass of seral and climax communities. This is with a view to understanding the dominant plant species that generate the litter produced under the different age categories of fallow and the mature forest and how the vegetation biomass and floristic parameters influence the rate of litterfall.

5 Examine the relationships between soil physical and chemical properties and vegetation floristic and biomass parameters. This is with a view to understanding the effects of the vegetation parameters on soil physical and chemical properties.

1.4 Hypotheses

(1) In an area of uniform regional climate, differences exist in the nutrient content of litterfall under secondary forests in the different stages of secondary succession.

(2) There is significant seasonal variation in the amount of nutrient return by litter to the soil in the rainy season and the dry season in each of the secondary forest category

(3) There is significant seasonal variation in the amount of litter produced in the fallow in each age category

(4) In an area of homogeneous topography and uniform regional climate, differences exist in the characteristics of soils under secondary forests in different stages of secondary succession

(5) Soil physical and chemical properties are significantly affected by vegetation floristic and aboveground biomass parameters.

1.5 Justification for the Choice of Study Area

Studies involving side-by-side comparison of soil, aboveground biomass and litterfall in different stages of developments can only be valid if the different sample plots are chosen from a zone that is uniform with respect to land use practices and the factors of the physical environment. This was achieved in this research by selecting for investigation, locations that are reasonably similar with respect to the factors of the physical environment (such as topography, climate and lithology) except for differences in plant cover which is due to ecological succession. The effect of regional climate in modifying the characteristics of soils and vegetation was eliminated by confining the study area to a zone in the tropical lowland rain forest belt, which has no marked variations in climate. The effects of variations in lithology were eliminated by choosing all the sample plots from monolithologic zone of sandstone materials.

According to Aweto (1978), it is well established that within areas of uniform rock formations, variations in topography modify the characteristics of soils by affecting the level of the groundwater table and soil moisture regime. In a similar vein, the floristic composition of vegetation varies especially with spatial variations in soil moisture regime. To eliminate the influence of variations in soil moisture regime in modifying the floristic composition of vegetation in this study, sample plots were selected from areas with well-drained soils.

This study was confined to soils derived from sandstones parent materials since they are widespread in the study area.

The problem of reducing the inherent variability of soil properties could not be resolved by merely selecting all sample plots from an area of uniform lithology since variations in local topography markedly affect the properties of soils down the slope (the catenary effect). Hence there was the need to eliminate the catenary effect which results in variations in the properties of soils derived from the same parent materials. Eliminating the catenary effect was accomplished by confining plots to a plain or either the lower slope or upper slope positions of the catena. In this study, the plain was selected for sampling because in the study area most of the farms are located in the plain land.

Within a section of the soil catena, striking variations in slope gradient will result in different degrees of organic matter and nutrients when the soil is exposed during the cropping period and at the beginning of the fallow period before the establishment of a bush re-growth that adequately shields the soil against erosion. The greater the slope angle, the greater the loss of nutrients through erosion. It was therefore important to sample plots of secondary forest land which show little variations in slope angles to ensure they were exposed to about similar degree of nutrients loss during the preceding cropping period. In this study, all the secondary forests studied were sampled from flat or gently sloping locations where the slope angle does not exceed 2^0.

The low, fairly uniform topography with extensive surfaces which are nearly flat, the presence of secondary forests regenerating from degraded abandoned rubber farms coupled with logistic reasons informed the decision to choose the study area (Orogun, Delta State) for this study. Due to the uniformity of the topography and the similarity of the previous land use in the study area, the problem of inherent variability of soil characteristics over small areas as a result of the influence of heterogeneity of topography and differences in land use is minimized in this area.

1.6 THE STUDY AREA

1.6.1 Location

The study area (Orogun in Ughelli North Local Government Area) which is part of the low deltaic plain of southern (Niger Delta) Nigeria is bordered to the north by Abraka in Ethiope East Local Government, to the south by Emevor in Isoko North Local Government and to the west by Kokori in Ethiope East local Government and to the east by Abbi and Amai in Ukwuani Local Government Areas respectively. The study area is located between latitudes $5^{0}26^{'}$N and $5^{0}48^{'}$N and between longitudes $5^{0}51^{'}$E and $6^{0}12'$E (see Figures 1 and 2).

1.6.2 Geology and Landscape

The surficial geology of the study area according to Odemerho (2007b) comprises the Sombreiro-Warri Deltaic plain formation. Much of the Deltaic plain – an area Aweto (1987), referred to as the ‘Urhobo Plains’ is covered by the Sombreiro Warri formation. The Sombreiro-Warri formation is made up of highly weathered and flood-prone sedimentary unit of silty clay soil (Kaolinite) and fine-medium sized sand (quartz), was deposited by the Niger River in late Pleistocene on top of the Benin formation. The lithologies of the surficial materials show evidence of a variety of depositional environments that include deltaic, fluvial and ages ranging from Miocene through Pleistocene to the recent (Wright, 1985). At the end of the Pleistocene ice age, the gradual rise in sea level and ground water table produced the requisite hydromorphic environment for the podzolization of the base deficient and deeply weathered sand rich deltaic plain alluvium deposits to form the ‘white sand’ especially in the swamps and abandoned river flood plains where savanna type of vegetation currently predominate (Aweto, 1987a).

The landscape is low-lying deltaic plain interspersed with waterlogged depressions and freshwater swamps. With an elevation of less than 25 meters above sea level, the area is liable to annual flooding that spread highly fertile alluvium on the region (Odemerho, 2007).

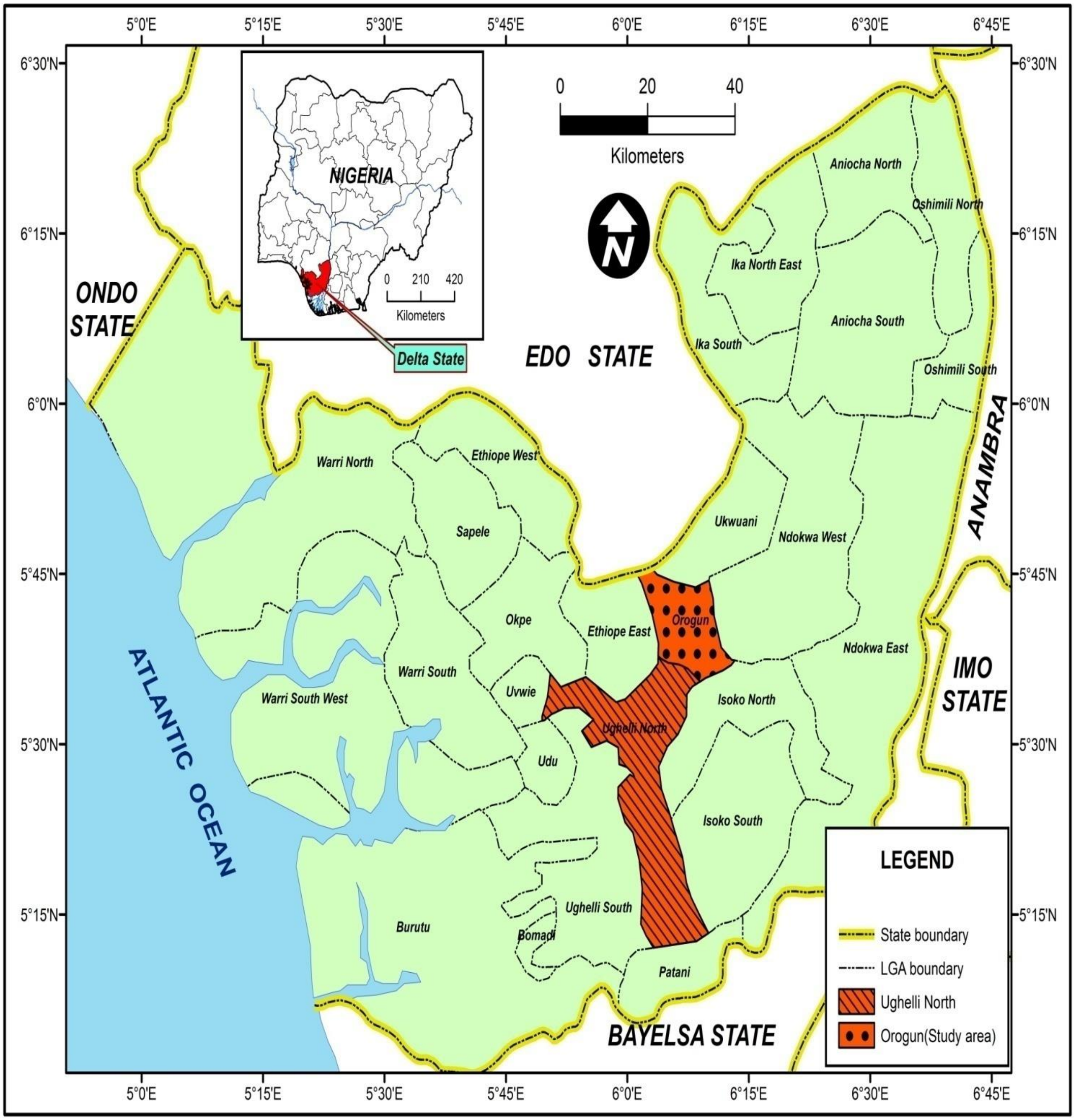


Figure 1: Delta State showing Ughelli North Local Government Area

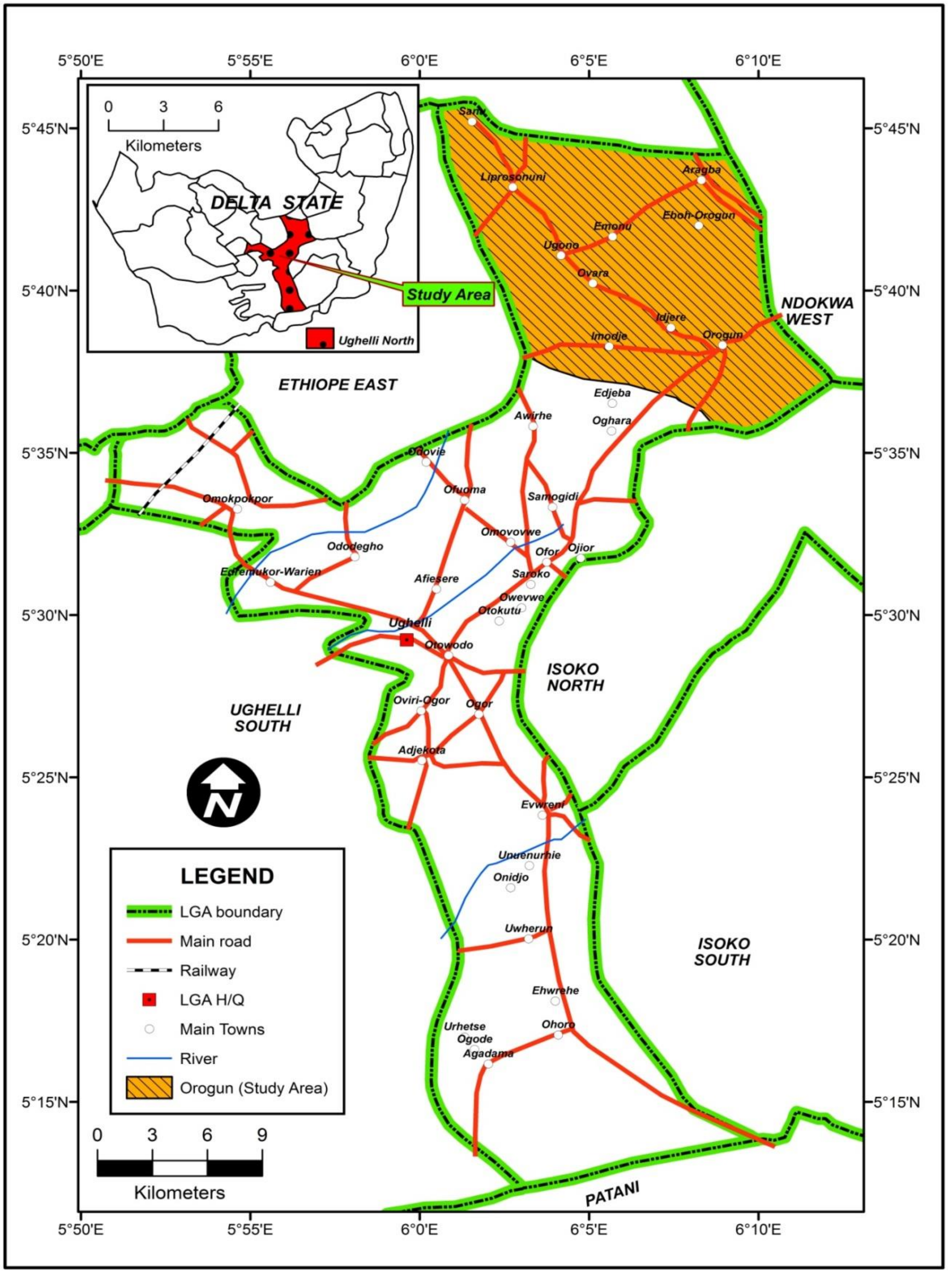


Figure 2: Ughelli North showing the study area

1.6.3 Soils

The soils of the area are mainly derived from coastal deposits which consist of well drained loam over coarse sandy loam subsoil. The soil order can be grouped under the Oxisols following United States Soil Taxonomy (Soil Survey Staff, 1994). They possess the characteristics of the soils in the lowland rainforest ecosystem of the tropical region. Oxisols are rich in iron and aluminium oxides, highly weathered, and consequently depleted in minerals and nutrients (King, 2009). The profiles of Oxisols contain mixtures of quartz, kaolin, iron and aluminum oxides and organic matter. Oxisols have a high aluminum and iron oxide content and low silica content. The presence of aluminum oxides and iron oxides in abundance in these soils results from chemical weathering and heavy leaching. Many Oxisols contain plinthite layers because of seasonally fluctuating water table. Oxisols depend mostly on the quality and amount of organic matter for retention of cation. Without fertilizer, they can support extensive agriculture only under shifting cultivation or with tree crops that protect the soil.

Albeit the soils in the tropical forest ecosystem are said to be nutrient-poor, the ecosystem are known to be very productive due to the rapid rate of decomposition of organic materials that fall to the ground. The nutrients released into the soil are rapidly taken up by the surface roots of trees and other plants or occasionally leached from the soil.

1.6.4 Climate

The climate of the study area is generally warm, moist and humid (Efe, 2006). It is dominated by the two, prevailing air masses: the tropical maritime air mass (MT) or south westerly monsoon air mass, which is warm, moist and humid, prevails throughout the wet season from March to October and the tropical continental air mass which is prevalent during the dry season. The tropical continental is dry and dusty and it is associated with harmattan season in the area (Efe, 2006). The distribution of rainfall pattern during the year is characterized by the double maxima regime; the two periods of maximum rainfalls being in July and September. Mean annual rainfall ranges from 2000 to 2500mm. Temperatures are high throughout the year with no sharp seasonal variations.

The mean annual range is 2 ^{0}C (Efe, 2006). The months of February and March are the months with highest temperature in the study area. The temperature fluctuates between 30 ^{0}C and 32 ^{0}C throughout the year (*op cit*).

The relative humidity of the atmosphere is usually high throughout the year owing to the dominance of the tropical maritime air mass. During the rainy season, the relative humidity of the air is usually over 83 %. The air is less humid during the dry season but the relative humidity of the air is still over 65 %. The seasonal pattern of the area according to Iloeje (1965) and Efe (2006) is as summarized below:

1 Long dry season: This is the harmattan season between November and mid March.

2 The short dry season: This is the August break. It lasts for some two weeks in August.

3 Long wet season: This lasts from mid-March to July. It is the season of torrential rainfall and high humidity.

4 Short wet season: This occurs between September and October immediately after the August break.

1.1.5 Vegetation

The rainforest, freshwater swamp and grassland are the vegetation types found in this area. Each of the vegetation types is described below:

1 The freshwater swamp vegetation: The freshwater swamps thrive around the water bodies in the study area. It is characterized by two tree canopy layers – the lower and the upper canopies. Trees in the upper canopy layer can reach a height of 40-45 meters. They include expansive area of riparian vegetation found in the study area. The raffia palm – *Raphia hookeri and Raphia vinifera* are the most common variety of plants found in this ecosystem (Keay, 1959). The lower canopy trees found in the fresh water swamp include mangrove plants of different varieties.

2 The grassland vegetation: The grassland in this area occurs in disjoint distribution and it is uniquely different from those of the savanna ecosystems in northern

Nigeria. This vegetation includes the different grasslands that abound in places such as Ugono, Arhagba and Ovara. Grasses are the dominant plants in the areas where grassland vegetation is found. The grasslands are the aftermath of centuries of tree felling by humans and fire and the adaptive ability of grasses to the environmental conditions. *Hyparrhenia* species, *Panicum maximum,* and *Imperata cylindrica* are the dominant species of grasses in the grassland ecosystem in the study area (Aweto, 1987).

3 The rainforest vegetation: The natural vegetation of the rainforest is the tropical lowland rainforest of the moist evergreen type (Aweto, 2002). Due to the prevalence of agriculture, fuel wood exploitation and other anthropogenic disturbances most of the original forests have been destroyed and replaced by secondary re-growth fallow in different stages of succession. Mature riparian forests are now restricted to swampy areas adjacent to the river valley and confined to sacred grooves on well drained sites that have been specially preserved for ceremonial purposes. The undisturbed forest is well developed physiognomically with the three distinct tree layers, a shrub layer and an herb layer on the floor of the forest. The tree species occurring in the forest area include T*riplochiton scleroxylon, Milicia excelsa, Piptadeniastrum africanum, Albizia adianthifolia, Terminalia superba,* and *Pentaclethra macrophylla* among others (Keay, 1959).

The fallow vegetation can be grouped into two broad classes on the basis of the importance of woody plants in the spatial structure of the vegetation. They are as follow: (1) The pseudo woody fallow and (2) The woody fallow proper. The pseudo woody fallows are young fallows of one to five years. Their floristic composition is dominated by a single plant species C*hromolena odorata* – which is a perennial vagrant "weed". The woody fallows proper is a fallow in which many perennial erect woody species such as A*ntiaris toxicaria, Tetrapleura tetraptera, Anthonatha macrophylla, Funtumia elastica, Albizia adianthifolia, Berlinia grandiflora and Milicia excelsa* play an important role in spatial structure of the vegetation (Aweto,2002). The ten year old fallow falls into the woody fallow category.

1.6.6 Farming, Land Use Pattern and Practices

Agriculture is an important aspect of rural economy in the forest zone in southern Nigeria. Food crop farming and cash crop farming are the main features of the agricultural economy in the study area.

Food crop farming is done by the traditional agricultural system of bush fallow by clearing the bush in fallows which are considered to have sufficiently regenerated their fertility. The shrubs and small trees are cut down and then left to dry and then burnt. The burnt bush supplies ash, which adds nutrients to the soil. Planting of crops is done after burning. Cassava (*Manihot esculenta crantz*) is the chief crop (Ideh, 2007). However, other crops such as maize (*Zea mays*), yam (*Discorea* spp), pepper, and cocoyam are frequently inter-cropped with it. Cycles of cropping activities in the area is related to the seasons of the year. The bush is cleared between November and February. The dry harmattan and the sunny weather that characterize this period assist in drying the shrubs and trees that have been cut down, thus facilitating burning. Planting is done about March so that the crops can take advantage of the early rains for their growth.

Usually, the land is allowed to revert to fallow after a crop of cassava is harvested. Cassava is usually harvested after about one year, but in most cases left growing on the farm with weeds for up to 15 months. The period of fallow varies from 3 to 5 years depending on land availability. In very rare cases fallows of 10 years exist, while the 5 years fallows are more common. Irrespective of the fallow period, the farms are cropped once before they are left to fallow.

Plantation agriculture of rubber used to be a main feature of the economy of the study area. As a result of disease infestation, death of tree plants arising from inappropriate tapping, poor productivity and soil nutrient impoverishment, peasant farmers have resorted to clearing their old rubber plots and subsequently using the cleared sites for growing food crops. The cleared sites are not fertilized before cultivation nor are they fertilized during the productive life of the rubber. The felled rubber trees are removed and are either sold or used for firewood.

Farms are confined to the well drained and moderately well drained soils. The poorly-drained soils are left unused because of their unfavourable water regime which results in flooding and waterlogged conditions during the rainy season. Riparian forests that usually occur on poorly drained sites are left undisturbed.

The low, fairly uniform topography with extensive surfaces which are nearly flat and the presence of secondary forests regenerating from degraded abandoned rubber plantation in the study area make this area suitable for carrying out the study.

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Conceptual Framework

The concept of nutrient cycle is the basic concept underpinning this study. Plants absorb nutrients available in soil and water and store them in their tissues. The nutrients are transferred from one trophic level to another through the food chain. Nutrients contained in dead plants and animal tissues, after passing through the decomposer trophic level, are ultimately released by bacterial and fungal decomposition, a process that reduces complex organic compounds into simple inorganic compounds available for reuse by plants.

Nutrient cycles and energy balances can be considered as the main coalescing characteristics in understanding the relations between different parts of an ecosystem. Soil fertility is sustained when nutrients are efficiently recycled through the soil plant animal system. Knowledge of this nutrient cycling is essential background to the understanding of the way in which the fertility of the top soil is restored during the fallow period.

The nutrient cycle according to Nye and Greenland (1960) is predicated on the following processes, which take place between the soil and vegetation.

1 Transfer of nutrients between soil and vegetation
2 Movement of nutrients within the soils
3 The losses from and gains to the soil-vegetation system

2.2 Transfer of Nutrients between Soil and Vegetation

Nye and Greenland (1960), posited that there are three processes concerned in this type of transfer. They are; (a) Uptake by the vegetation (b) removal from the vegetation and return to the soil, by litter, rain-wash, by burning and in root excretions and (c) mineralization of litter. The processes in nutrient cycling are examined below.

2.3 Nutrient Uptake and Storage by the Vegetation

Nutrients are being endlessly transferred between soil and vegetation. The uptake and accumulation by the tree according to Nye and Greenland (1960), is the major process in this cycle, although in the early years after planting of trees, uptake of nutrients by vigorous leguminous cover plants growing in the almost open conditions can exceed that by the trees. Watson (1964) reported contents of 284 kg of nitrogen, 25 kg of phosphorous, 110 kg of potassium, 34 kg of magnesium and 114 kg of calcium per hectare in creeping legumes at two years after planting; as the cover die back under the developing tree shade, these nutrients that were immobilized by the cover vegetation are thus return to the soil and remain in active cycle early in the life of the successional vegetation. In Banco, Ivory Coast, Bernhard-Reversat (1977) reported contents of 1400 kg/ha nitrogen, 100 kg/ha phosphorus, 600 kg/ha potassium, 1200 kg/ha calcium and 530 kg/ha magnesium immobilized by the aboveground biomass of a mature rainforest. Toky and Ramakrishnan (1983) in India, reported contents of 490 kg/ha nitrogen, 60 kg/ha phosphorus 1380 kg/ha potassium, 440 kg/ha calcium and 230 kg/ha magnesium immobilized by the aboveground biomass of a 20-year old secondary forest.

Feldpausch *et al*., (2010), in Central Amazonian Brazil reported that although woody biomass accumulated more rapidly than foliage, nutrient stocks for all nutrients accumulated more quickly in foliage. They reported that nitrogen stocks in foliar biomass (42.6 kg/ha /year) accumulate much more rapidly than woody stocks (15.5 kg/ha/year) with time after abandonment of pastures. They reported that phosphorus stocks in foliage biomass accrued twice as fast as wood phosphorus stocks. However foliar calcium stocks (22.3kg/ha /year) accrued at a similar rate to wood stocks (20.6 kg/ha/year).

In southwestern Nigeria the biomass of a 10-year old plantation of Teak (*Tectona grandis*) studied by Nwoboshi (1985) was greater than that of a 40-year secondary forest at Kade Ghana, studied by Greenland and Kowal (1960). Both the natural rainforest at Kade, Ghana and *Gmelina* plantation at Gambari near Ibadan, Nigeria, had similar soils-alfisols. The annual rainfall at Kade was, however, slightly more than that of Gambari where the 10-year old plantation was established. With the exception of nitrogen, the 10-year *Gmelina* plantation at Gambari immobilized more nutrients than the 40-year old secondary forest in Ghana and even more than a mature forest ecosystem in Cote d’Ivoire. The quantities of potassium, magnesium and phosphorus stored in the 10-year *Gmelina* plantation were 2-3 times the quantities immobilized in the 40-year secondary forest at Kade, Ghana. Tree plantations established in savanna areas also grow much faster, hence immobilize more nutrients in their standing biomass than native savanna. A 10-year old plantation *Pinus caribean* in the Guinea savanna vegetation zone of Northern Nigeria had a larger biomass and higher amounts of immobilized nitrogen than Guinea savanna vegetation which had been left undisturbed for 20 years in Ejura, Ghana (Nye and Greenland 1960). Though it may be contended that these studies were carried out in different areas where climatic, soil and substrate conditions are not identical, the study of Bernhard-Reversat (1996), who compared nitrogen cycling in *Eucalyptus* and *Acacia* plantations with native savanna vegetation in Pointe Noire (Congo Brazzaville), indicated that the quantities of nitrogen immobilized in the aerial parts of *Eucalyptus* plantations were 3-5 times the quantities stored in adjoining uncultivated savanna with similar soils. Leguminous trees planted in plantations immobilize substantially larger amount of nitrogen (a significant proportion is fixed from the atmosphere) than non-leguminous trees. Bernhard-Reversat (1996) reported that the quantity of nitrogen immobilized in the aerial parts of *Acacia mangium* plantations of 5-7 years old in Pointe Noire was almost five times the level in *Eucalyptus* plantation which was 7-9 years old. The quantity of nitrogen in the adjoining savanna vegetation was a mere 5 % of the quantity stored in the *Acacia* plantation.

In mature forest any persisting ground covers are likely to play a minor role since, except under particular circumstances, they do not develop vigorous growth under shade. After two to three years of fallow, the trees assume a dominant position in the nutrient cycle, nutrients are taken up in substantial quantities and a large proportion are immobilized within the trunk, roots and main branches, whilst smaller proportions remain in active cycle by returning to the soil surface in the annual defoliation, by seed and branch fall, and by intermittent root death, particularly of surface feeding roots during period of dry soil conditions (Shorrocks, 1965).

The total amount of uptake of nutrients (in excess of any that may be returned to the soil, through the roots) is equal to the increase in storage in the vegetation plus the amount removed from the vegetation. Nutrients accumulation during the first few years of fallow is more rapid than during the later period (Nye and Greenland 1960, Julio *et al*. 2007 Feldspauch *et al*. 2010). The reason for the change after the first five years, and the succeeding relatively low increase in storage is that the leaves and branches, which are richer in nutrients than other components of the vegetation, rapidly increase to their maximum amount in the fallow, and further storage takes place in the wood and roots (Nye and Greenland 1960, Julio *et al*. 2007 Feldpausch *et al*. 2010).

2.4 Removal from the vegetation

In forest, wooded savanna and monocultural tree plantations, litterfall and mineralization are the main mechanisms of recycling nutrients from aerial parts of the vegetation to the soil. Throughfall and stemflow are secondary mechanisms of nutrients removal from the vegetation and recycling to the soil. In a Ivorian rain forest ecosystem litterfall represented 70-84 % of the nitrogen, calcium and phosphorus recycled from the aerial part of the vegetation, while throughfall accounted for 40 % of the magnesium and 62 % of the potassium recycled to the soil (Bernhard-Reversat, 1977). In the adjoining indigenous tree plantation of *Terminalia ivorensis*, litterfall accounted for 60 % of the phosphorus and 69 % of the potassium returned by the plantation to the soil. Litterfall constitutes (together with root turnover) a major portion of nutrient cycling between plants and soils, and therefore reflects constraints on internal fluxes of C, N and P at the ecosystem scale (McGroddy *et al*., 2004; Berg and Laskowski, 2006; Julio *et al*. 2007). The role of litter nutrients may be critical in tropical secondary forest, where seasonal pulses of nutrients in litterfall constitute an important aspect of nutrient cycling (Campo *et al*., 2001). Studies on litter nutrient dynamics in tropical secondary forest indicates that there is a strong change in the intrasystem cycling, especially for P, during succession (Read and Lawrence, 2003a; Ca´rdenas and Campo, 2007).

The nutrient content of litter has generally been taken as an indication of the annual rate of nutrient turnover. Litterfall is the major pathway for the return of organic matter and nutrient from aerial part of the plant community to the soil and has an important bearing on soil formation and fertility (Proctor *et al*., 1983, Spain 1984, Odiwe *et al*., 1983). Transformed litter is also the basis of many food chains in tropical forest and is a principal source of energy for the flora of the forest and soil (Spain, 1994). When litters fall they undergo decomposition, as they decompose the nutrients that are locked up in the litter are released to the soil, thereby helping to restore the fertility of the soil and recycling in the plant soil vegetation system.

Rainwash removes nutrients from the vegetation in two ways; throughfall and stem flow. Throughfall is the part of precipitation that reaches the ground directly through the vegetation canopy, through spaces in it and as drips from leaves, twigs and stems. Under fallow vegetation, there may be substantial changes in solute chemistry as the water interacts with the leaves and stems of plants due to leaching from vegetation, biotic uptake and the wash off of dry deposited elements. It has been long noticed that the loss of nutrients from the leaves by throughfall may be an important loss of nutrients from growing vegetation. The extent of the loss varies widely according to the treatment of plants (Brassel and Sinclair, 1983). In tropical Australia, study by Brassel and Sinclair (1983), shows that the annual amounts of nutrients in throughfall and litter fall were more than in temperate wood lands, but were similar to those of other tropical forests.

In a study carried out over a six months period in Malaysia, it was found that with a 100 inches of rain per annum 10 kg of nitrogen, 20 kg of potassium, 0.5 kg of phosphorus, 1.5 kg of magnesium and 15 kg of calcium may be leached out of the foliage annually (Shorrocks 1965).

2.5 The Rate of Mineralization of Litter

Under a woody fallow, when the litter layer has been built to equilibrium level, the rate of mineralization of litter clearly equals the rate of addition (Nye and Greenland, 1960). In tropical conditions this level is rapidly attained, and possible increase in storage of nutrients in the form of litter need hardly be taken into account after a few years of fallow. From the data of Jenny *et al*., (1941), Nye and Greenland (1960) calculated that when the litter layer had attained its maximum or stability level, 3.25 % of the litter decomposed in one week, or over one year the amount of litter decomposing was 170% of that found on the forest floor at any particular time.

The optimum level of individual nutrients stored in the litter will be even more rapidly attained. The ones that are leached most rapidly will reach this level most quickly. In fresh forest potassium is lost very rapidly from litter. Bartholomew *et al*., (1953) in Yagambi (Belgian Congo) opined that after 10 weeks, 51 % of nitrogen, 61 % of phosphorus, 93 % of potassium, 50 % of the calcium, and 82 % of magnesium in the original litter are mineralized. On the other hand the ratio of calcium to potassium in the litter of all the forest examples is significantly greater than in the fresh leaves or wood.

The study on nutrient cycling in primary, secondary forests and cocoa plantation in the Ashanti region of Ghana by Owusu-Seykere *et al*., (2006), revealed that, decomposition of leaf litter from primary and secondary forests were relatively faster than that of cocoa leaf litter. And that primary forest leaf litter showed rapid decomposition as compared to secondary forest even though leaf litter of the latter was dominated by a legume *Griffonia simplicifolia* tree species. Leguminous tree species are known to decompose faster but soil and forest floor microorganisms play a significant role in decomposition (Swift *et al*., 1979). They attributed the faster decomposition of leaf litter in the primary forest to greater population of microorganisms in the primary forest environment than in the secondary forest. Decomposition was completed within a year cycle for the forests leaf litter (primary and secondary). Cocoa leaf litter, however, decomposed at a slow rate and extended beyond 12 months (Owusu *et al*., 2006).

Owosu-Seykere *et al*. (2006) reported that the nutrients released from the decomposing leaf litters were fast for nitrogen, phosphorus, potassium, calcium and magnesium for primary and secondary forests leaf litter. They revealed that in the Cocoa plantation, except phosphorus the other nutrients were released gradually than the loss of decomposing leaf material. The release of nitrogen, potassium, calcium and magnesium from cocoa plantation leaf litter according to Owosu-Seykere *et al*., (2006), was comparatively slower and amounts were lower than those released from the forest land uses. The releases of nitrogen, phosphorus, calcium and magnesium of secondary forest were characterized by fluctuations in the initial 6 months of exposure to decomposition and almost all the nutrients were released before the 8th exposure month except for N from secondary forest.

2.6 Losses and Gains from the Soil-Vegetation System

According to Nye and Greenland (1960), the loss processes operating are leaching of nutrient out of the rooting zone of the vegetation, removals in runoff water, volatilization of nitrogen through oxidation when the vegetation is burnt. While gain processes consists of additions in litterfall, rainfall, throughfall, stemflow, dust and fixation of atmospheric nitrogen by micro organisms and fertilizer applications by man.

In Malaysia, limited analytical data on rainwater collected in the open, indicates that with an annual rainfall of 100 inches roughly 20 kg nitrogen, 12 kg potassium, 3 kg magnesium, 38 kg calcium and 0.2 kg phosphorus may be added to 1 hectare of soil per annum (Proctor *et al*.1983). The amount of nitrogen is similar to those reported by Bautista *et al.* (2003) and Nye and Greenland (1960) in Ghana, when due allowances are made for the amount of rainfall, but the levels of phosphorus, potassium and magnesium are lower, and calcium higher than the value reported by these workers.

The nutrient content of the soil-vegetation systems is depleted during the clearing of the land from forest and in preparation for planting crops. Exposure of the soil followed by erosion and by increased mineralization of the organic matter and subsequent losses of nitrate-nitrogen and cations by leaching can rapidly result in marked deterioration of the soil unless a ground vegetation cover is quickly established (Oladoye *et al*., 2005, Watson *et al*. 1964). During planting operations the manner of disposal of the cleared vegetation can also markedly affect the content of the soil vegetation system. If the trees after clearing are completely removed from the land, marked depletion of the vegetation will result, even after only one planting. Such depletion is likely to be serious on soils of low total nutrient content. If the vegetation is heaped and burnt most of the nitrogen and sulphur will be lost to the atmosphere and other nutrients will be concentrated at the burnt sites giving an enriched soil at a few localities and poor soil over the rest of the field.

It would be preferable therefore, to let the timber decompose on the ground surface, returning the nutrients slowly to the soil, rather than to waste large quantities of nitrogen by burning or removing all the nutrients with the cleared vegetation from the land.

The analysis of the concept of nutrient cycling shows the quintessential role of litter in removing nutrients from the vegetation and returning same to the soil through the fall and mineralization of litter. This removal and addition role of litter makes the concept of nutrient cycling very suitable to this study.

2.7 Literature Review

With reference to past research efforts by previous researchers in respect to the subject matter of this research, the literature review in this study is divided into three sections. The first section focuses on soil changes during succession in tropical secondary forests. The second section reviews studies on secondary forests litterfall, while the third section reviews studies on nutrient cycling in fallow communities and plantations in Nigeria.

2.7.1 Soil Changes during Succession in Tropical Secondary Forests

Documenting the changes in soil properties in secondary forests has been an active area of research in both temperate (e.g. Marrs, 1993; Compton and Boone, 2000) and tropical areas (e.g. Bartholomew *et al*., 1953, Nye and Greenland, 1960; Aweto, 1978).

Bruijinzeel and Proctor (1995) and Bautista-Cruz and del Castilo (2005) observed from their individual studies in different locations that the conversion of croplands to secondary forest in areas originally occupied by tropical rain forests results in substantial gain of soil organic carbon sequestration during the first 15years of forest development. And after 15years, soil organic carbon sequestration follow a different path depending on soil depth and time interval.

Galindo *et al*., (2002) reported that in Chiapas highlands of Mexico, early successional soil of pine forest were less acidic than late successional soil under hardwood. Similar changes in soil pH during secondary succession have been found in other tropical areas (e.g. Brady and Weil, 1999; Bautista *et al*., 2003; Bautista-Cruz and del Castilo, 2005). Bautista-Cruz and del Castilo (2005) adduced various reasons for the natural increase of soil acidity during secondary succession. At least four reasons have been identified by Bautista-Cruz and del Castilo (2005), for such an increase (i) the uptake of nutrient cation and (ii) the release of acidic litter by the growing vegetation (iii) the weathering of parent material favoured by soil acidification and (iv) higher affinity of the exchange complex by hydrogen and aluminum ions over base cations.

Bautista-Cruz and del Castilo (2005) reported that as the age of fallow increased, soil available phosphorus concentration had a sharp drop during the first 15 years of forest development and remained relatively stable afterward or further increased in the mature forest. They concluded that effective cation exchange capacity changed significantly with the age of fallow. In a similar vein, Feldspausch *et al.*, (2009), reported that soil phosphorus stocks to 45 cm depth tended to decline with forest age in secondary forest regenerating from degraded pasture in Amazonian (0.66 kg/ha^{-1}year^{-1}), a trend most pronounced within the upper 0-15 cm. They reported that the surface layer represented 46 to 70 % of total soil phosphorus stocks to 45 cm depth, with the younger areas, on average, storing 4.2 kg/ha more phosphorus in the first 15 cm than the oldest areas. They further reported that potassium, calcium, and magnesium stocks remained constant with time after abandonment.

In contrast, other kinds of humid forest showing the opposite trend (Peet, 1992), the nitrogen to phosphorus ratio decreased significantly as forest develop in areas originally occupied by tropical montane forests in southern Mexico. This relation is expected to change during succession due to contrasting difference in biogeochemical cycles of nitrogen and phosphorus. Nitrogen is derived primarily from the atmosphere by microbial fixation, while phosphorus is derived primarily from rock weathering, thus, nitrogen is nearly absent in young soils, but with time, the invasion of nitrogen fixers is expected to increase atmospheric fixation (Gorham *et al*., 1979). By contrasts, the amount and availability of phosphorus is expected to decline during long term soil development due to the demands of the growing vegetation, in such a way that phosphorus is becoming largely bound to secondary minerals or soil organic matter, leading to extremely phosphorus deficient soils.

On the other hand, Bautista-Cruz and del Castilo (2005), observed that phosphorus was very scarce in ecosystems originally occupied by tropical mountain forest in Mexico. At the study sites, the lack of essential minerals containing phosphorus may explain this result (Bautista *et al.*, 2003). In a chronosequences in Krakatau, Indonesia, Schlesinger *et al* (1998) found an excess of accumulation of organic phosphorus relative to the losses of inorganic phosphorus, probably as a result of plant uptake from lower depths. Higher nitrogen and phosphorus loss ratios in Hawaiian tropical montane forests were explained by an efficient phosphorus recycling and high nitrogen throughputs (Hedin *et al*., 2003).

Land-use history has important effects on soil stocks, with type and intensity potentially overriding time since abandonment. A well- replicated study in Ecuador found that the direction of changes in soil carbon stocks following pasture to forest conversion was best explained by the time a site had been under pasture use (de Koning *et al*., 2003). Younger pasture soils (< 10 years) had on average 9.3 Mg/ha more soil carbon than paired secondary forest and plantations sites, while pastures > 20 years had lower soil carbon content than the forested sites. The difference between pasture and reforested soil carbon content decreased with age of pasture before conversion, pastures 20-30 years old had 18.8 Mg/ha less than forests, and pastures > 30 years had 15.8 Mg/ha less than forests (de Koning *et al*., 2003).

The rate and direction of soil change may vary at different stages of succession, and with soil depth. In a cloud forest chronosequences growing on abandoned maize fields Oaxaca, Mexico, soils down to 40 cm had the greatest carbon accumulations rates in the first 15 years of succession, which also coincided with the largest changes in aboveground forest structure. In the next 30 years, the top 20 cm had a net loss of soil carbon, followed by a smaller increase after 45 years of forest cover (Bautista-Cruz and del Castillo 2005). The lower depth (20-40 cm) showed no patterns with forest age during the first 15 years.

In North Carolina, Billings (1938), studied the secondary succession of pine and found that significant changes in soil physical properties could be observed in soils under different stages of pine succession in an area of uniform lithology and climate. His study revealed that only the top 6 inches (15 cm) of the soil profile was significantly modified as a result of succession. He also found that soils under less than 110 year old stand of pine had higher organic matter content and a higher water holding capacity than those under young fallow. Nye and Foster (1960), studied the relative uptake of phosphorus by crops and natural fallow from different parts of their root zone and found that the limit of the visible humic horizons usually lies within the top 20cm of the soil and that nearly all the feeding of the annual crops which replace the fallows takes place within the zone. Studies on the properties of soils under different stages of secondary succession (that is fallows of different ages) revealed that there is an increase in soil nutrient as secondary succession progresses towards the climatic climax (Nye and Greenland, 1959 and 1960; Aweto, 1978; Geuze *et al*., 1996; Knops and Tilman, 2000; Galindo *et al*., 2002; Deborah and David, 2002; Bautista *et al*, 2003). These studies revealed that there is an appreciable increase of soil nutrients as secondary forest increase in age. The work of Areola (1975) in the derived savanna area of South Western Nigeria confirmed that when secondary succession is prevented from running its normal course (for example through grazing and burning) soil conditions may not improve at a rate commensurate with increase in the length of the fallow period.

2.7.2 OVERVIEW OF STUDIES ON SECONDARY FORESTS LITTERFALL AND ABOVEGROUND BIOMASS

Despite the considerable amount of work on changes in vegetation structure during tropical secondary forest development using chronosequences, where sites vary in time since forest regrowth, most studies of litterfall do not use this approach (see Lawrence 2005b). More commonly, studies compare secondary forest of a single age to plantations or to primary forest (Cuevas *et al*., 1991; Lugo, 1992; Li *et al*., 2005), or compile data worldwide across forest ages (Brown and Lugo, 1990). Our understanding of litterfall nutrients inputs to the forest floor and soil during tropical secondary succession seres is therefore limited.

Secondary forests are generally categorized as establishing high rates of litterfall relatively quickly, within the first 25 years of succession (Ramakrishnan and Toky 1983, Brown and Lugo 1990, Guariguata and Ostertag 2001, Lawrence 2005b), and soon after plateau to a production rate of primary forest (Ewel, 1976). Moreover, litterfall mass is likely to reflect development of biomass during succession (Ewel, 1976), with young forests generally having high rates of litterfall in the first 20 years after abandonment (Brown and Lugo 1990, Guariguata and Ostertag, 2001). Litterfall has also been shown to influence forest tree seedling and sapling mortality in mature forests (Clark and Clark 1991, Guariguata 1998, Drake and Pratt 2001, Gilman *et al*. 2004).

Rapid nutrient cycling through the litter can be an important mechanism for conserving and efficiently using essential nutrient that have been depleted in the soil (Chapin, 1980; Jordan and Murphy, 1981). Odum (1969), Proctor *et al*., (1983) and Vitousek (1984) revealed from their studies that nutrient content of litter could be used to gauge the effects of land use change and forest recovery on nutrient cycling.

Studies on the nutrient content and the dynamics of litterfall include those of (Proctor *et al*., 1983; Jordan, 1971; Spain, 1984; Odiwe *et al*., 1993; Vitousek, 1984; Stocker, 1995; Chandreshekera and Ramakrishna, 1994; Odiwe and Muoghalu, 2003, Lawrence, 2005b). Their studies indicate that litter production and the content of litter are affected by intensity of disturbance, seasonal variation and age of fallow.

Vitousek (1984) evaluated the patterns of nutrient cycling in tropical forest ecosystem through litterfall based upon published information from 62 tropical forests. He found that tropical lowland forests generally have more nitrogen and lower dry mass/nitrogen ratios in liltterfall than most temperate forests while nitrogen return in montane tropical forest is comparable to temperate forests. Many tropical forests have little phosphorus ratio in litterfall compared to moist temperate forests – phosphorus appears to be cycled highly efficient.

Julio *et al*., (2007) worked on litter nitrogen and phosphorus dynamics in two secondary tropical dry forests (a 10-year old secondary forest and a 60-year old secondary forest) after relaxation of nutrient availability constraints in the Yucatan Peninsular of Mexico and found that the magnitude of phosphorus fluxes in litterfall in control plots of the Yucata´n sites appears to increase with forest age, when results of both sites are considered. Phosphorus return from litter in late-successional forest are higher than that reported for other dry forests in the tropical region (ranging from 0.2 to 9.2 kg P ha^{-1} year^{-1} and 752 to 1100 mm of annual rainfall; Lugo and Murphy, 1986; Campo *et al.*, 2001) and in the Yucata´n State (2.8–9.2 kg P kg/ha^{-1}year^{-1}and 900–1400 mm of annual rainfall; Read and Lawrence, 2003a). However, the return of this nutrient from litterfall in early successional forest site is comparable to those reported for these other tropical dry forests, despite their similar annual litterfall production to the older counterpart (Campo and Va´zquez-Yanes, 2004). In contrast to P fluxes in litterfall, the amounts of N in litterfall in both forests are similar between them. Nitrogen returns from both sites are three times to an order of magnitude higher than that reported for a Puerto Rican dry forest in infertile soils (ranging from 12 to 49 kg N kg/ha^{-1}year^{-1} and 880 mm of annual rainfall; Lugo and Murphy, 1986) and in the upper bound reported for tropical dry forests in Chamela, Mexico (116 kg N and 750 mm of annual rainfall; Jaramillo and Sanford, 1995) and in Belize (156 kg N and 1030 mm of annual rainfall; Lambert et al., 1980); but within the range reported for seasonal forests in Yucata´n along a rainfall gradient (60–204 kg N ha^{-1} year^{-1} and 900–1400 mm of annual rainfall; Read and Lawrence, 2003a).The phosphorus pool in the forest soil of the 10-year old forest is comparable to those in the older counterpart, despite differences in the magnitude of phosphorus fluxes between forests. In contrast, nitrogen pool in the forest soil appears to decline with forest age, despite similar nitrogen return to soil in both forests. Data of estimated mean residence time (MRT) for organic matter in Yucata´n (calculated as the ratio of the litter standing crop to the annual litterfall production; Vogt *et al.*, 1986) (obviously, MRT in the 10-year old forest is even not stabilized) indicate a faster turnover in control plots of the late-successsional forest (1.5 and 1.8 years for late- and early-successional forests, respectively) (Campo and Va´zquez-Yanes, 2004). Annual nitrogen and phosphorus residence time in the forest floor were 2.4 for both nutrients in the early successional forest, and 2.1 for nitrogen and 1.1 for phosphorus in the late successsional forest. They opined that the higher phosphorus availability in the soil of the late-successional forest than in the soil of the younger counterpart could be explained by the decrease in the nutrient MRT with forest age, and that this suggests that the soil phosphorus availability constraint the nutrient release in the early-successional forest. On the other hand, the residence time of nitrogen in the forest floor was similar in both forests and revealed the slow release of this nutrient in the ecosystem (Julio *et al*. 2007).

On the seasonality of litter nutrient, Julio *et al*. (2007) reported that the seasonal trends in litter nutrient dynamics indicate a strong relation between precipitation and mineral pools in the forest floor. In both the 10-year and the 60-year old secondary forests nitrogen and phosphorus in the forest floor increase during the dry season (by a factor of 2 and 3 in the 10-year old forest, and in the 60-year old forest respectively) , possibly as a result of reduced microbial activity and leaching that occur during the rainless period in tropical dry forest ecosystems (Campo *et al*., 1998), and an increase in the litter standing crop (Campo and Va´zquez-Yanes, 2004). Leaf litter nitrogen concentration changed significantly with season. In both forests, nitrogen concentration was greater in the wet than in the dry season ($P < 0.01$). However, phosphorus concentration variation between seasons was very low and the difference was not significant ($P > 0.05$) (Julio *et al*., 2007).

Wood *et al*., (2009) studied rain forest nutrient cycling and productivity in response to large-scale litter manipulation. They established a large-scale litter manipulation experiment in two secondary forest sites and four old-growth forest sites of differing soil fertility. In replicated plots at each site, leaves and twigs (< 2 cm diameter) were removed from a 400-m^2 area and added to an adjacent 100-m^2 area. This transfer was the equivalent of adding 5–25 kg/ha of organic P to the forest floor. They analyzed leaf litter mass, nitrogen and phosphorus, and nitrogen and phosphorus inputs for addition, removal, and control plots over a two-year period. They also evaluated basal area increment of trees in removal and addition plots. They found that there was no response of forest productivity or nutrient cycling to litter removal; but that, litter addition significantly increased leaf litter production and nitrogen and phosphorus inputs 4–5 months following litter application. They also reported that litter production increased as much as 92%, and phosphorus and nitrogen inputs as much as 85 % and 156 %, respectively. In contrast, litter manipulation had no significant effect on woody growth. The increase in leaf litter production and nitrogen and phosphorus inputs were significantly positively related to the total phosphorus that was applied in litter form.

Neither litter treatment nor forest type influenced the temporal pattern of any of the variables they measured. Wood et al (2009) concluded that factors of the environment such as rainfall drive temporal variability in litter and nutrient inputs, while nutrient release from decomposing litter influences the magnitude. Seasonal or annual variation in leaf litter mass, such as occurs in strong El Niño events, could positively affect leaf litter nutrient cycling and forest productivity, indicating the ability of tropical trees to rapidly respond to increased nutrient availability.

In Yegambi, Belgian Congo (now Democratic Republic of Congo), Bartholomew et al (1953) studied the biomass and nutrient content of a highly weathered oxisol under shifting cultivation. They used the inferential method to study fallows of 2, 5, 6, 17 and 18 years old in the tropical moist forest and grass and found that plant biomass increase with increasing age of forest. Similarly, Aweto (1983 a, b), studied secondary succession and soil fertility restoration in the highly weathered oxisol, of the tropical rain forest of South-Western Nigeria using the inferential method and the concept of soil-vegetation system model. He studied 10 replicate plots of 1, 3, 7, 10 of fallows following shifting cultivation and a mature forest. Aweto's works focused on forest structure and soil nutrient. Aweto (1983 a, b) reported increase in vegetation biomass characteristics and soil nutrient with increasing age of successional fallows.

Jordan (1971), studied the productivity of tropical forest and its relation to world pattern of energy storage. He compared a young plant community and an older mature forest stand. He made comparisons between rates of biomass production in the Luquillo Mountains of Puerto Rico. He observed that annuals have the highest rate of litter production and that leaf and litter production is relatively uniform in perennial herb and grass, and tree communities (Jordan, 1971).

Lugo (1992), compared the structure of and dynamics of small plantation of pines (*pinus caribaea*, of 4 and 18.5 years old) and mahogany *Swietenia macrophylla* of 17 and 49 years old) of similar age and growing adjacent to each other under similar edaphic and climatic conditions. His comparisons included a variety of demographic, production and nutrient cycling characteristics of stands. He found that – plantations had higher aboveground biomass and net above ground biomass production than paired secondary forests. For root densities, he observed that, root densities and biomass were higher in secondary forest as were greater depth of root penetration, high nutrient concentration in root and more micro sites where root grow, than paired plantations. It is therefore likely, that roots of secondary forests immobilized more nutrients than those of plantations.

2.7.3 STUDIES ON NUTRIENT CYCLING IN FALLOW COMMUNITIES AND PLANTATIONS IN NIGERIA

Aweto (1981) used the soil vegetation system model approach to study soil dynamics under fallow in part of tropical rainforest of Southern Nigeria. The major advantage of this approach is that soil and vegetation components of bush fallow are studied as functionally dependent systems that exert reciprocal effects on one another. He modeled the reciprocal relationships between the soil and vegetation components of bush fallows using multivariate statistical techniques. This enhanced the recognition of the characteristics of fallow vegetation that further enhanced the process of soil fertility restoration in fallow soil. The soil-vegetation system model approach represented a distinct advancement over the approach adopted by ecologists, agronomists/pedologists who studied the process of soil fertility restoration and vegetation succession in fallow land independent of one another. Aweto’s study revealed that soil physicochemical properties and vegetation structural properties improve with increasing age of fallow and that soil physicochemical properties exert reciprocal relationships on each other.

Aweto’s (1981) study on secondary succession and soil fertility restoration in south-western Nigeria revealed that (1) soil organic matter increase is confined to the topsoil (0-10cm), (2) nutrient accumulation in fallow soil is largely confined to the topsoil and (3) soil-bulk density decreased while porosity and water-holding capacity increased with age of fallow.

In Oyo state (Nigeria), Adejuwon and Ekanade (1987) found soil organic carbon levels of 26 g/kg under forest and 19 g/kg in the top soils under cocoa. All the major nutrients and the pH were lower under cocoa compared to soils under forest. In southern Nigeria it was found that that soil organic carbon under a secondary forest was about 35 g/kg and 25 g/kg under a 10 year old cocoa farm (Ogunkule and Eghaghara, 1992). Total nitrogen and most other soil properties were about the same under cocoa and secondary forest.

Aweto (1987) studied the nutrient and physical status of soil under rubber (*Hevea brasiliensis)* of different ages (1, 7, 11, 14 and 18 years of age) in South-Western Nigeria. Aweto's study revealed that changes in soil bulk density and total porosity during the first 18 years of rubber plantation establishment were slight. There was no significant increase in soil organic carbon and total nitrogen contents over time. Soil exchangeable calcium and magnesium declined in the 0-10cm and 10-30cm layers of the soils with increasing age of rubber plantation. Decline in the levels of exchangeable potassium was, however, confined to the top 10cm of the soil profiles. Most of the decline in soil mineral-nutrients occurred during the first 11 years following rubber plantation establishment (Aweto, 1987). The data of Aweto (1987) indicated that exchangeable calcium, magnesium and potassium in the 0-10 cm layer of soils under 1-year-old rubber plantation established on oxisols in south-western Nigeria were 20-100 % higher than in the corresponding layer of soil in nearby rain forest, part of which was cleared to establish the plantation. This Aweto attributed to the effect of ash fertilization after forest slash burning prior to rubber plantation establishment.

Though, nutrient cycling in plantations and isolated trees have been studied in broad outline in Nigeria, none of these studies have examined nutrient cycling in secondary forests regenerating from abandoned rubber plantations in Nigeria.

Hence in this study, the author used the inferential method, based on the side by side comparison of soils physicochemical properties, litterfall and the nutrient content of litter, the diversity of plant species and vegetation biomass parameters in secondary forest regenerating from degraded abandoned rubber plantation sites in the southern Nigeria to examine the dynamics of soil, flora and plant litter and their nutrient content with a view to understanding how soil fertility is rejuvenated following the abandonment of rubber plantations.

CHAPTER THREE

METHODOLOGY

A common method for studying above-ground biomass, litterfall and soil dynamics in regenerating secondary forests on abandoned lands is the use of the chronosequences or inferential method. Using this method, forest stands of different ages are selected, using age as a proxy for successional time. An important assumption of this method is that the patterns observed across the chronosequences will be comparable to the patterns occurring at one site over time. Another common method is paired-site comparisons, where secondary forest sites or plantations are compared to primary forests, typically in close proximity. Another method is the direct method which involves the study of the same site over a period of time, during which the changing characteristics of the soil and vegetation are monitored.

The inferential method involves a side by side comparison of soil, above-ground biomass and litter fall in fallow communities of different ages on different sites in a homogeneous zone with no marked variations in climate, geology, topography, land use practice and ecological factors that affect the properties of vegetation (Jenny, 1941; Toky and Ramakrishna, 1983). The same method was adopted in studying ecological succession under natural fallows (Aweto 1978, 1981a, b, c, Brassel and Sinclair, 1983; Edwards 1977, 1980a, b, 1981). This approach has been widely applied because of the constraint of time researchers are faced with in monitoring changes that occur in the properties of the soil on the same site over considerable period of time. However, it must be noted that Pickett (1989), opined that studies using the inferential approach may be confounded with other factors besides time that affect soil and above ground biomass properties in particular those changing locally.

This method involves the study of the same site over a period of time, during which the changing characteristics of the soil and vegetation are monitored. To achieve this, permanent quadrats are established either during the course of succession before the establishment of the climatic climax vegetation or prior to the colonization of a bare surface. Quantitative and qualitative changes in vegetation and soil attributes are examined at regular intervals. Air photographs of the same area taken at different times are also used in monitoring such changes. The qualitative nature of air photo interpretation makes its use of limited value. Fore example, only major structural changes in the vegetation such as changes from herbaceous to a woody plant cover can be detected through air photo-interpretation (Aweto, 1978).

As a result of the long period it takes for complex terrestrial ecosystem, such as forests and woodlands to develop from the pioneer stage to the climax stage, the direct method of monitoring soil and vegetation characteristics through time has not been widely used. Because of this limitation, direct studies of soil fertility restoration in fallow ecosystem have been confined mainly to the first few years fallowing cessation of cropping (Odum, 1960; Juo and Lal, 1977; Adedeji, 1984).

In this study, the inferential method based on side-by-side comparison of soils and litter fall attributes in a homogeneous zone was employed. This is because it was not possible to monitor the changes in the properties of soil and litter fall from the cessation of cropping until a mature forest is established within the available time for this study.

3.1 Data Collection Procedures

Prior to the collection of data, a field survey was conducted in the study area to identify the fallows in different stages of regeneration and a mature forest which has not been cultivated for at least six decades for study. During this field survey, the ages of the secondary forests were ascertained from the local farmers. A selection was made of secondary forests of different age after abandonment but with similar farming practice history and similar soil features. The essence of the field survey is because of the non-availability of suitable air photographs to use as sampling frame for the random selection of the secondary forests for study. The mature forest ecosystem was used as control for the study.

For each secondary forest category and for mature secondary forests (which henceforth shall be referred to collectively as age categories), ten sample plots were chosen for study on the basis of one sample representing 100 acres, using the criterion of Boone *et al.*

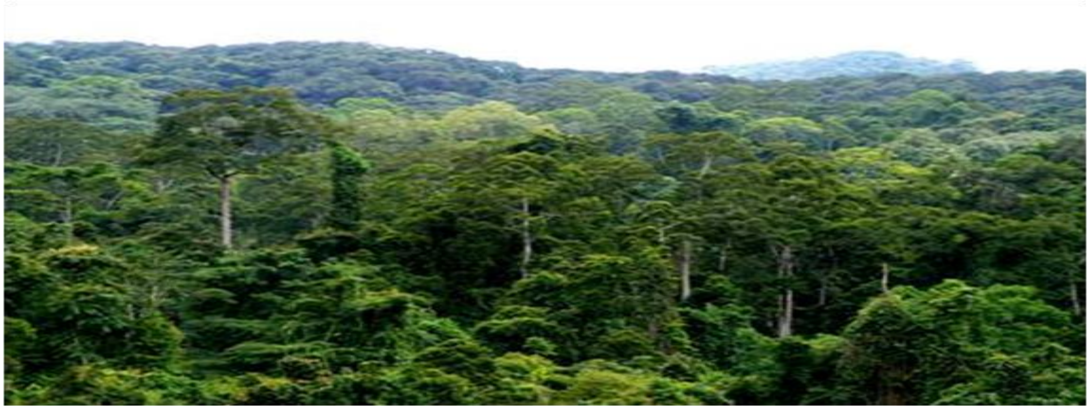
(1999), who opined that in a texturally homogeneous soil a sample of soil analyzed is adequate for 100 acres of land. On the whole, a total of forty sample plots were chosen for study.

The fallows and secondary forest that were studied belong to the following age categories: (1) one year old fallow (2) five year old fallow (3) ten year old fallow and (4) a mature forest (See Plates 3.1, 3.2, 3.3 and 3.4).

The choice of category 1-year and 5-year fallows was largely determined by the traditional practices of shifting cultivation in the study area. Abandoned farmlands are usually left for a period of five years before the land is cultivated, while very few people leave their land for as long as ten years depending on the availability of land for farming. Albeit, the fallows of one-year are not usually cleared for cultivation, they were studied so that they would provide a point of reference for assessing the rate of increase in above-ground biomass, litter fall and soil nutrient status during the first year following cessation of cropping.

The attributes of above-ground biomass, litterfall and soil of a mature secondary forest land which has not been cultivated for at least six decades were also analyzed to provide a standard against which to assess the rate of nutrient turnover and soil regeneration under fallow. This was done because if secondary forest vegetation is left undisturbed for a very long time, it eventually reverts to forest which is the climatic climax of the study area. Iat was pertinent therefore to assess the extent to which fallow vegetation at different successional stages had advanced towards the climatic climax in terms of floristic and above-ground biomass.

The strips of forest studied are secondary in nature as evidenced by the presence of secondary forest species (See Plate 3.1) such as *Scotelia coriacea*, *Tetrapleura tetraptera* and *Irvingia gabonensis* (FEPA 2001). They can be regarded as mature since their structural organization revealed the presence of the three tree layers characteristics of the mature rainforest (Hopkins, 1965).



Mature forest in Orogun

10-year old fallow in Orogun

5-year old fallow in Orogun

1-year old fallow in Orogun

Plate 3.1: A Mature Forest and Fallows in Different Stages of Regeneration

Within each of the secondary forest age categories, ten sample plots of 30 metre X 30 metre sizes were delimited for investigation. Since the focus of this study as far as the above-ground biomass of the mature forest and the fallow vegetation are concerned, is the size of tree individuals and the diversity of the plant species, this plot size is considered adequate (Aweto, 1978). The boundaries of each 30 metre X 30 metre quadrat were delimited by cutting paths through the secondary forest. Each 30 metre X 30 metre quadrat was further divided into thirty six 5 metre X 5 metre quadrats. Five of these sub-quadrats were randomly selected in each plot using table of random numbers. Quantitative measure on vegetation biomass parameters such as tree height, tree diameter and tree density and basal area were taken in each of the 5 metre X metre quadrat delineated within each 30 metre X 30 metre plot in each secondary forest category. In addition aspects of floristic diversity such as number of tree species, number of plant species and species diversity (using Simpson's Index) were also measured using appropriate field techniques.

3.1.1 Tree Basal Area

Tree basal area (TBA) is the cross–sectional area (over the bark) at breast height (1.3 meters above the ground) measured in square meters (m^2). Tree basal area can be used to estimate tree biomass and stand competition.

Tree basal area was measured in this study by using the equation based on the formula for the area of a circle:

$$(A = \Pi r^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4)$$

Where:

A= area

r = radius

$\Pi = 3.142$

And the formula for radius

$$r = \frac{\text{diameter}}{2} = \frac{DBH}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

Therefore:

$$\text{Tree basal area} = \frac{(DBH)^2}{200}\,\Pi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.6)$$

Where

DBH = Diameter at breast height in centimeters.

200 = Conversion factor from centimeters to metres

After calculating the individual tree basal area using the above formula the total tree basal area per hectare was obtained by multiplying the average individual tree basal area by the total number of trees per hectare.

3.1.2 Tree Diameter Measurement

Tree diameters are measured at breast height (termed diameter at breast height or DBH). It is defined as the diameter of the tree at 4½ feet above the ground on the uphill side of the trees. For the purpose of the field investigation, a tree was defined operationally as woody plant of erect habit with a minimum breast height diameter (i.e. at the height of 1.5m above the ground) of 2cm. The circumference of the tree trunks were measured at breast height with flexible measuring tape around the trunk of the trees. The circumference measurements were then converted into diameter values by dividing circumference values by 3.142 (i.e. by Π). The diameters of saplings in the 1-year old secondary forest plots were determined at the ground level (see Aweto, 1978).

3.1.3 Tree Height

The height of trees was measured by measuring the angle of the tree tops and their distance from the point of observation with Abney level and measuring tape respectively (i.e. the angle of the tree was measured using the Abney level while the tape was used to measure the distance from the point of observation to the tree). Based on these measurements, tree height was estimated using the formula:

$H = X \tan \theta$ ………………………………………………………………………….. (3.7)

Where

H = Height of tree

X = Distance of observer from tree

θ = Angle of tree top from observer

For the one year old secondary forest saplings, their height was measured by stretching the metre rule from the base of the saplings to their tops and recording their heights.

3.1.4 Tree Density

The tree density was obtained by counting the number of individual that have attained tree status (Aweto, 1981a). Tree heights, density and diameter were determined for the five (5 meter square) sub-quadrats that were randomly selected within each sample plot (tree density was later converted to tree density per hectare)

3.1.5 Frequency of Plant Species

This refers to the chance of occurrence of a particular plant species in a given number of quadrats. Whittaker (1967), defined species frequency as the percentage of small sub-quadrats within a large sample quadrat in which a given plant species is observed. The measurement of frequency was carried out for the dominant plant species in each secondary forest category to ascertain the variation in distribution of plants among the different secondary forest categories. Ashby (1961), noted that the frequency of a plant species can be measured by recording its presence or absence in a number of quadrats taken at random in an area under consideration, the frequency being equal to the proportion of the total number of quadrats in which the plant species occurred. He further stated that frequency could be seen as a chance of finding the species rooted within a sampled quadrat in any trial.

For the measurement of the tree species in each secondary forest category the presence or absence of the dominant tree species in each 30 meter square quadrats was determined. While for the herbaceous species the presence/absence of the dominant tree species in fifty 1x1 meter sub-quadrat randomly selected from the ten 30 X 30 meters quadrat in each of the secondary forest category were recorded.

The formula for frequency of plant species is given as:

$$\text{Frequency} = \frac{\text{Number of quadrats where a given species occur}}{\text{Total number of quadrats}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

3.1.6 Species Diversity

Species diversity is a measure of how heterogeneous a plant community is with respect to its floristic composition. It is a feature of a natural and well organized community (Hairston, 1964). Usually, a high value of species diversity is an indication of vegetation tending towards the climatic climax or regional stability (Whittaker, 1969).

Different measures of species diversity including those of Ashby (1969), Simpson (1949), Shannon (1963) and Williams (1964), have been proposed. Ashby's index is simply the ratio of the total number of species recorded to the logarithm of the ratio of the total number of species. Ashby's index does not include a measure of equitability (i.e. Evenness in the distribution of individuals) which is an essential component of species diversity (Whittaker 1965). The Williams index is primarily designed for the zoologist and as such not suitable for vegetation studies. Both Simpson's and Shannon's indices are based on the number of species and equitability. In this study, Simpson's method has been used for computing species diversify indices in preference to that of Shannon which is biased in favour of rare species (Odum, 1975). The Simpson's index is computed using the formula.

I = I – D ………………………………………………………………………..(3.9)

Where

I = Simpson index of species diversity

D = $1-\sum\frac{ni}{N}$

The plant species used for the measurement of species diversity were obtained by counting the number of plants species in each sub quadrat and their values were added to give the numbers of species for each quadrat Simpson's index is converted to percentage in the study.

3.1.7 Number of Tree Species and Plant Species

The number of tree species and plant species was recorded by identifying and counting the total number of tree species and plant species (trees and herbaceous species) in each 30 meters square quadrat in each fallow category.

3.1.8 Biomass Estimation

A number of empirically validated regressions e.g. Anon (1978), and Kira (1978) have been used to estimate trunk, branch and (by their addition) total woody biomass. These regressions are not likely to be of general application because of the great variation between stem and crown proportions according to age and stand density (Gray, 1956, 1966). According to Dawkins (1961, 1963), for trees of many species and a wide range of sizes the aboveground wood and bark biomass can be calculated using the formula:

Wood biomass = tree height x basal area x 0.5 (Dawkins, 1961) …………… (3.3)

The calculated value according to Proctor *et al*., (1983) is a theoretically sound figure which agrees with the quadratic paraboloid theory of tree form. Edwards and Grubb (1977), have suggested that by multiplying the wood biomass by a factor of 1.1-1.2, a value for total aboveground biomass (including leaves, small twigs, epiphytes, lianas and other life forms) is obtained. Therefore, for the purpose of estimating the total biomass of the 5-year old and the 10-year old secondary forests and the mature forest, the biomass values (using the Dawkins 1961, 1963 formula above) for wood was multiplied by 1.1 to give a rough estimate of total aboveground biomass. By subtracting the values of the wood biomass from the values of the total biomass, the values for leaves and twigs biomass were obtained. Due to the sampling restriction of not being allowed to cut any tree in the mature forest by the owners of the mature forest, the Dawkins method of measuring biomass was used for the estimation of the 5-year old, 10-year old and mature forest.

The biomass of the herbaceous plants of the 1-year old fallow was determined by the harvest method. During September and October 2010, when most species were at their peak biomass, all plants from the fifty 1 x 1 meter quadrats, selected randomly on the basis of five from each 30 meter by 30 meter quadrant were clipped at ground level and categorized into wood or main stem and twigs as well as leaves. They were dried at 80^0C for 24 hours and weighed. The average biomass value for 1x1 meter was converted to hectare by multiplying by a factor of 10,000. The biomass of the trees in the 1-year fallow was estimated using the Dawkins formula (Dawkins 1963).

3.1.9 Litterfall Collection

Litterfall was collected at monthly intervals using 1m x 1m traps of 30cm deep, and having 1mm nylon mesh base which could retain all particles greater than 1mm and that could allow free drainage of water. Forty litter traps were randomly laid out in all the secondary forest categories on the basis of 10 litter traps in each age category to collect litterfall materials monthly. A total of 480 samples of litter were collected in one year, on the basis of forty samples per month. The monthly collections were oven dried at 80 ^{0}C for 24 hours and weighed, to determine the seasonal pattern of litterfall.

3.1.9.1 Soil Sampling

Soil sampling follows the procedure described by Boone *et al*., (1999). Soil samples were collected from five points which were located randomly within the 30 metre square quadrat at predetermined depths of 0-10 cm and 10-30 cm (i.e. from topsoil and subsoil) using a core sampler. The approach of sampling from predetermined depths was adopted in order to ensure comparability among samples collected from different sample quadrants in geographically separate locations since the thickness of the soil horizons vary from place to place. The limit of the top 30 cm of the soil is chosen for two reasons. Firstly, the limit of the visible humic horizons usually lies here and secondly, numerous observations of root distributions and direct measurement of labeled-phosphorus uptake (Nye and Foster, 1960) indicates that in humid regions nearly all the feeding of the annual crops which replace the fallows takes place within this zone. A total of 100 samples of soil were collected from each age category; 50 samples from topsoil and 50 samples from subsoil using core sampler. These samples of soil were mixed into a composite of 10 composites for each soil depth (on the basis of five samples constituting a composite sample) for chemical analysis. Since there are three age categories and a mature forest, a total of 80 soil composite samples were used for chemical and physical analysis. Eighty composite samples collected were air-dried, crushed thoroughly, mixed and passed through a 2 mm mesh sieve in readiness for analysis.

3.2 Soil and Vegetation Tissue Analysis

The soil properties analyzed are (1) particle size composition (2) bulk density (3) total porosity (4) soil water capacity (5) soil organic matter (6) soil pH (7) total nitrogen (8) available phosphorus (9) exchangeable cations (exchangeable calcium, magnesium, sodium and potassium) and effective cation exchange capacity. These soil properties were measured because they are the major soil properties affecting the fertility of soil.

3.2.1 Particle Size Composition

Two methods (hydrometer and pipette) are normally used to analyze soil particle size composition (Bouyoucous, 1952). The hydrometer method was used in this study because of logistic reasons; quicker than the pipette method and its level of accuracy suffices for this study.

The hydrometer method determines the approximate proportion of sand, silt and clay particles in a soil. Forty grams of air dried soil was shaken for 2 hours with 100 ml of 5 % sodium hexametaphospate (Bouyoucous 1952). The suspension is quantitatively transferred to a sedimentation cylinder and brought to a total volume of 1L with deionised water. After 2 hours temperature equilibration, the suspension was stirred vigorously for one minute to re-suspend the particles. A hydrometer is carefully placed in the suspension and used to take two readings, one at 40 seconds and another at 3 hours. The percentage of sand, silt and clay in the soil was calculated from the resulting hydrometer readings using the formulas below:

Sand = $100-(H1 + 0.2(T_1-68)-2)2$

Clay = $(H_2 + 0.2(T_2-68)-0.2)2$

Silt = 100 – (% sand + % clay)

Where

H1 = Hydrometer reading at 40 seconds

H2 = Hydrometer reading at 3 hours

T1 = thermometer reading at 40 seconds

T2 = Thermometer reading at 3 hours

The results were corrected to a temperature of 68^0 Fahrenheit. For every degree over 68^0 Fahrenheit 0.2 was added to hydrometer reading before computation and for less than 68^0 Fahrenheit 0.2 was subtracted from every hydrometer reading.

3.2.2 Soil Bulk Density and Total Porosity

The bulk density of soil is a measure of the mass (weight) of oven-dried soil sample divided by the bulk volume. It is the ratio between the mass apparent volumes of a given sample of soil. It is a measure of the degree of soil compaction. It affects root penetration and the amount of air and water the soil can hold. It was determined by using the core method (Blake, 1965). To obtain the bulk density using the core method, 3 undisturbed soil samples were collected at 0-10 cm and 10-30 cm soil depths respectively in each of the 30 X 30 metres plots, oven-dried and weighed. The bulk density was thereafter computed using the formula:

Bulk density = dry weight (grams) ÷ volume (cm^3)

Bulk density is an essential item for converting any weight/weight value into weight/volume value.

Total porosity is the percentage of the bulk volume of the soil that is not occupied by soil particles (Vomocil, 1965). Total porosity determines the degree of soil aeration and is positively correlated with nutrient absorption by plants (Grabble, 1966). Total porosity values were calculated from bulk density values using an assumed particle density value of $2.65 g/cm^3$ (Vomocil, 1965).

3.2.3 Soil Water Holding Capacity

Soils hold different amounts of water depending on their texture and structure. How much water soil can hold is very important for plant growth. Soils that can hold a lot of water support more plant growth and are less susceptible to leaching losses of nutrient and pesticides. Not all of the water held by soil is available for plant growth. Two separate laboratory tests are required to determine how much plant available water a soil can hold. The first test on the soil determines how much water the soil can hold at field capacity. The second test determines how much water the soil holds when roots can no longer extract water (wilting point). To determine the soils water holding capacity, 5 soil samples were collected at 0-10 cm and 10-30 cm soil depths respectively in each of the 30 X 30 metres plots, air dried and taken to the laboratory for analysis. The soil water holding capacity was determined as the difference between field capacity (FC) and permanent wilting point (PWC) (See equation below).

Water Holding Capacity = Field Capacity – Permanent Wilting Point …………… (3.0)

3.2.4 Determination of Field Capacity Water Content

The first step in determining the field capacity water content of the soil is to place dry crushed soil samples on ceramic plates. The samples are then saturated with water and left to equilibrate overnight. The next day, the porous ceramic plate was placed on a container that is pressurized with 1/3 atmospheric pressure (about 5 Psi). The slight pressure in the container pushes excess water out of the soil samples and through the ceramic plate. After 24 hours in this chamber, the moisture content in soil sample is said to be at field capacity (Veldkamp, 1994; AGVIS, 2008).

3.2.5 Determination of Soil Wilting Point Water Content

The next thing after determining field capacity water content was to determine how much water the soil can hold when it is so dry that plant roots can no longer remove water (Wilting Point). First, a dry pulverized soil sample was placed on a ceramic plate and saturated with water overnight. The next day the ceramic plate was placed in a container that is pressurized with 15 atmospherics pressure (about 225 Psi). This pressure pushed most of the water out of the soil samples through the ceramic plate. The samples were left in this pressurized container for 48 hours. The samples are then weighed before they are placed in an oven at 105^0C for two hours to remove the remaining water (The weight after oven drying at 105^0C for two hours is the permanent wilting point). The amount of water left in the soil is held too tightly for plants to extract (hygroscopic water). Once this step is completed the soil water holding capacity was calculated using equation 3.0 above AGVIS, 2008).

3.2.6 Soil Organic Matter

Soil organic matter is the major source of plant nutrients such as phosphorus and nitrogen. It affects the major physical and chemical properties of the soil (Lawrence and David, 2002) which influence soil fertility status.

In this study the Walkley-Black method was used to determine the soil organic carbon content, while the soil organic carbon was converted to soil organic matter by multiplying the organic carbon values by a factor of 1.729 (Veldkamp, 1994).

The Walkley-Black method has the advantage of yielding accurate values than the other methods of determining soil organic matter such as the use of hydrogen peroxide or heating.

3.2.7 Soil pH

This is a measure of the alkalinity and acidity of soil. This soil property hinges on the concentration of hydrogen ion in soil solution. Soil pH affects the solubility of nutrients in the soil solution and the absorption of nutrient elements by the roots of plants (Kings, 2009). Soil pH was determined potentiometerically in 0.01M calcium chloride using a soil to calcium chloride solution ratio of 1:2. The main advantage of determining soil pH in 0.01M calcium chloride rather than in water is that the reading obtain truly reflect the degree of soil base saturation (Proctor *et al*., 1983).

3.2.8 Total Nitrogen

Poor crop yield in the forest zone is most of the time due to shortage of nitrogen in the soil (Nye and Greenland, 1960). Soil nitrogen was analyzed by the Kjeldahl's method, which evaluates the total nitrogen content of the soil with auto-analyzer after the soil samples have been digested in sulphuric acid with selenium catalyst. The Kjedahl method's was used because of its precision and reproducibility coupled with the fact that it is the standard method against which all other methods are judged.

3.2.9 Available Phosphorus

Bray and Kurtz (1945), defined "available phosphorus" as those forms of phosphorus that are of immediate significance to crop growth. Adequate supplies of available phosphorus to soil promote or enhance: early root formation and growth, greater flowering and seed production, fruit, vegetable, and grain quality, better growth in cold temperatures, water use efficiency, early maturation of fruit and grain, photosynthesis, respiration and cell division and enlargement.

Available phosphorus was determined by leaching the soil with Bray and Kurtz solution (0.025M HCl to 0.03M NH_4F). The concentration of available phosphorus was determined colorimetrically with “spectronic 20” spectrophotometer after the colour had been developed in soil extract using the ascorbic acid method as described by Molindo, (2008). This method was used because it is widely employed to determine soil available phosphorus and it is proven to show results that are highly correlated with crop response to P fertilization.

3.2.9.1 Exchangeable Cations (Magnesium, Calcium, Sodium, Potassium)

Exchangeable calcium, magnesium, potassium and sodium were extracted with 1N ammonium acetate (neutral). Exchangeable calcium and magnesium were determined by atomic absorption spectrophotometer as described by Aikpokpodion (2010) while potassium and sodium were determined using EEL flame photometer (Molindo, 2008).

3.2.9.2 Exchangeable Acidity

Exchangeable acidity was extracted with 1N KCl and determined by titration with 0.05N NaOH using phenolphthalein indicator. The concentration of exchangeable acidity is calculated from the amount of standard acid needed to back titrate the leachate to the methyl red and bromocresol green endpoint (Gilman and Sumpter, 1986).

3.2.9.3 Effective Cation Exchangeable Capacity (ECEC)

This is defined as a measure of the quantity of sites on soil surface that can retain positively charged ions (cations) by electrostatic forces (Chapman, 1965). It is the capacity of the soil to hold nutrient cations. Soil cation exchange capacity is important for maintaining adequate quantities of plant available calcium, magnesium, potassium and sodium in soils.

Effective cation exchangeable capacity was determined by the summation method (Chapman, 1965). Base cations were extracted by leaching air dried soil with successive aliquots of 1N NH_40AC buffered at pH 7, to total 60 ml. The concentration of the base cations in the leachate are determined by atomic absorption spectrophotometer. The effective cation exchange capacity is calculated from the sum of the base cations and exchangeable acidity. The facts that this method is quicker and cheaper; and the most appropriate method for determining effective cation exchangeable capacity in acidic soil such as exist in the study area make the use of the summation method appropriate.

3.2.9.4 Calculation of Nutrient Storage in Soil per Area

To be able to compare the nutrients stored in soil per hectare to those stored by the above ground biomass and the quantity returned to the soil through litterfall, the formula below was used to convert the soil nutrient concentration (Veldkamp, 1994).

(% and mg kg^{-1}) to soil nutrient content or storage (kg ha^{-1}):

NC (kg ha^{-1}) = (C) x (F) x (M) ………………………………….. (3.1)

Where

NC = Soil nutrient content (kg ha^{-1})

C = Nutrient factor to convert concentration units to a fraction with no units, which equals 10^{-6}kg mg^{-1} in this case

M = Soil mass (kg ha^{-1}) mass is computed with the formula

M = (T) x (Db) x (1-G) x (10^5) …………………………………….. (3.2)

Where

M = Soil mass (kg ha^{-1})

T = Thickness of horizon (cm)

Db= Bulk density (g cm^{-3})

G = Proportion of sand

10^5 = Conversion factor

3.2.9.5 Chemical Analysis of Litterfall

For chemical analysis of litterfall, the ten weighed oven dried litterfall samples collected from each secondary forest category were bulked into three composites (on the basis of 3.33 samples making a composite), ground and analyzed for chemical composition. On the whole a total of 144 composite samples of litterfall were analyzed for chemical analysis for the one year period on the basis of twelve composite samples each month and three composite samples of litter in each age category per month (i.e. 36 composites samples were analyzed in each secondary forest category over the one year period).

Sub-samples of the ground litterfall composite samples were re-dried at 105^0C and wet ash in concentrated nitric acid and analyzed by atomic absorption spectrophotometry for sodium, potassium, calcium and magnesium using method of Allen *et al*., (1974). Total nitrogen and phosphorus were determined colorimetrically by auto-analyzer. No chemical analysis was made of wood over 2cm diameter.

3.2.9.6 Chemical Analysis of Above-ground Tissues

To estimate the aboveground biomass nutrient concentrations (and nutrient stocks on per hectare basis) within each secondary forest category, 50 most common plants species in the studied plots were randomly selected in each forest category and mature, upper canopy leaves were collected using a pruning scissors. From the same trees or plants, we drew two wood billet 10cm long (wood and bark) at 1.3 meter height on opposite sides of the bole. The foliage (leaves and branches) samples were pooled into five sample composites of ten trees per sample for each secondary forest category, oven dried at 80^0C for 24 hours, ground and homogenized and analyzed for nitrogen, phosphorus, potassium, magnesium, calcium and sodium. The wood samples got the same treatment and analysis (on the whole 40 composite samples of above ground biomass were analyzed chemically on the basis of 20 composite samples for wood and 20 composite samples for foliage).

All the different sample composites of plants were subjected to wet digestion method by weighing 0.2 g of each of the composite sample in each age category into a 50ml digesting bottle. To 3ml of concentrated sulphuric acid and 2 ml of hydrogen peroxide were added. This was done under a fume cupboard and then set up on a heating mantle to digest for long with drop wise addition of hydrogen peroxide until a clear digest was obtained. After the digest had cooled down, it was transferred to a 100 ml volumetric flask and made up to mark with deionized water. From this digest nitrogen was determined using a technicon auto analyzer, Phosphorus using the vanadomolybdate method colorimetrically. Potassium and sodium were determined using a flame photometer, while calcium and magnesium were determined on a Perkin Elmer 703 atomic absorption spectrophotometer.

From the concentration of nutrients in the foliage and wood biomass, we estimated aboveground wood biomass nutrient stocks (densities of nutrient stored in above ground wood biomass) by multiplying the above ground wood biomass values by the nutrient concentration of the above ground wood biomass (Feldspauch *et al*., 2010). Similarly, the above ground leaves and branch biomass nutrient stock was estimated by multiplying the above ground leaves and branch biomass values by the nutrient concentration of aboveground leaves and twigs biomass (op cit). The total aboveground biomass nutrients stocks was then calculated by adding the values of nutrient stock of the wood biomass (bole) to that of the leaves and twigs biomass (foliage).

3.2.9.7 Statistical Analysis and Data Presentation

The statistical analysis techniques used in the testing of the various hypotheses include the analysis of variance (ANOVA), stepwise multiple regression and student ‘t’ test. In order to gain a better understanding of the utility of the statistical techniques, it is better to discuss their uses within the context of the various hypotheses they were used to test. Below is a summary of statistical analysis methods used in the testing of the various hypotheses listed in chapter one.

(1) Analysis of Variance: this was used to test hypotheses 1 and 4. Whenever Analysis of variance shows that differences exist, post hoc multiple comparisons of means were carried out with the use of the Least Significant Difference (LSD) to check for statistical differences in soil and vegetation parameters between pairs of secondary forest, and between secondary forests and primary forest.

(2) Pair Wise Student ‘t’ test: this is used to test hypotheses 2 and 3.

(3) Stepwise Multiple Regression: The fifth hypothesis relates to whether vegetation parameters significantly affect individual soil physical and chemical properties. To test this hypothesis Stepwise multiple regression was used. To test the hypothesis, the individual soil nutrient elements and individual soil physical properties were used as the depended variable, while the vegetation aboveground biomass, species diversity and litterfall constitute the independent variables.

CHAPTER FOUR

CHANGES IN SOIL PHYSICO-CHEMICAL PROPERTIS OF SECONDARY FOREST

4.1 Introduction

The harvest of trees at the end of the productive life of the rubber not only disrupts the accumulation of nutrient in the soil, but also constitutes a huge drain on the nutrient resources of the ecosystem. Aside the losses of nutrients from plantations through leaching and erosion, the collection of latex from rubber plantations during their productive years brings about considerable annual nutrient losses from monocultural rubber plantations prior to their degradations and subsequent abandonment.

The changes that take place in soil in secondary forest regenerating from degraded rubber plantations are the reverse of those that take place during the existence of the plantations and essentially they are restorative and result in the regeneration of soil fertility. The changes are:

a. Changes in soil physical properties

b. Changes in soil chemical properties and the build up of soil organic matter and total nitrogen in the soil

This chapter focuses on these changes.

4.2 Soil Particle Size Distribution

The soil textural composition is discussed here briefly, chiefly to throw light on the degree of similarity between the various fallow plots. Appendix 4.1 contains the details of soil particle size distribution.

Table 4.1 presents the summary of particle size distribution data for the sample plots of the different age categories. The soils are predominantly sandy in nature. In the 0-10 cm layer, the proportion of sand exceeds 800 g/kg; hence the amount of clay is small, being usually under 18 g/kg, while that of silt is less than 20 g/kg for the top soil of all the fallow categories. The proportion of sand for the topsoil per sample plot for the 1-year, 5-year and 10-year fallows and for mature forest are 82 %, 840.7 g/kg, 830.5 g/kg and 806.9 g/kg respectively. The corresponding values for the 10-30cm (subsoil) layer are

Table 4.1: Particle size distribution of soil (g/kg) samples from different fallow age categories

	Fallow Age Categories							
	1 – Year		**5 – Year**		**10 – Year**		**Forest**	
Particle Size Distribution	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
Sand	820 (6.3)	800.1 (13.6)	840.7 (1.19)	810.3 (9.7)	830.5 (1.2)	808 (9.3)	806.9 (6.85)	791.8 (10)
Silt	18.5 (9.2)	22.9 (11.4)	11.1 (3.8)	11.8 (6.2)	17.1 (6.3)	12.8 (5.7)	18.1 (10.1)	16.1 (7.9)
Clay	161.5 (5.9)	177.1 (7.4)	148.2(14)	176.9 (7.4)	152.4 (10)	179.3 (7.6)	175.2 (7.3)	192.2 (7.5)

Values in brackets represent standard deviation for each fallows and forest categories,

Source: Author’s fieldwork

800.1 g/kg, 810.3 g/kg, 808.0 g/kg and 791.8 g/kg. The subsoil is also sandy but contains a higher amount of clay than the surface 0-10cm (Table 4.1). The clay fraction of the soil increases down the profile. The mean clay contents of the topsoil for the 1-year, 5-year and 10-year age categories and for mature forest are 161.5 g/kg, 148.2 g/kg, 152.4 g/kg and 175.2 g/kg respectively. The corresponding values for the subsoil are 177.1 g/kg, 176.9 g/kg, 179.3 kg/g and 19.22 kg/g respectively. The silt content of the soil is higher in the topsoil than the subsoil in the 10-year old secondary forest and in the mature forest. While in the 1-year and 5-year old secondary forests the silt content of the topsoil is lower than the subsoil. This indicates that while the silt content of the soil increased down the profile in the younger fallows (1-year and 5-yer old fallows), in the 10-year old fallow and the mature forest the silt decreased down the profile. The higher clay content of the 10-30 cm layer of the soil is likely due to downward eluviation of clay from the topsoil. Despite the differences in the age of the secondary forests, the soils are quite similar texturally. Analysis of variance test revealed that no significant differences existed among soils under the different age categories with respect to proportion of sand, silt and clay at 0.05 confidence level. This indicates that secondary forests do not significantly modify soil particle size composition over time. The composition of soil particle size is inherent in the parent material not dictated or influenced by length of fallow. This also suggests that the soils are similar, having formed from the same parent material under uniform environmental conditions. As such, any observed differences among the soils in respect of chemical or other soils physical properties would be largely due to differences in age of secondary forests.

4.3 Soil Bulk Density

Table 4.2 shows that bulk density tends to decrease with increasing age of secondary forest. This suggests that the soil becomes less compact with increasing age of secondary forest. The value of bulk density in the subsoil was higher than in the topsoil in all the categories of the secondary forests and the mature forest studied. This is due to the overbearing effects of the topsoil. Analysis of variance for soil bulk density revealed that significant differences exist between the soils of the different secondary forest categories and the mature forest (Appendix 4.2). A post hoc comparison of the bulk density of the different age categories with each other and with the mature forest using least significant difference (LSD) revealed that with the exception of the 1-year and 5-year old secondary forest with no significance difference between their mean at 0.05 level of significance, significant differences exist between the mean of all the other secondary forest categories. The bulk densities of the topsoil and the subsoil of the mature forest were significantly lower than those of the 1-year, 5-year and 10-year old secondary forest at $p < 0.05$ of the least significant difference test of means.

The mean values for soil bulk density for the 1-year, 5-year, 10-year and the mature forest are 1.16 g/cm^3, 1.14 g/cm^3, 1.08 g/cm^3 and 1.01 g/cm^3 respectively for the topsoil. Aweto (1978) reported a decrease in soil bulk density with increasing age in fallows following shifting cultivation. This pattern he attributed to the opening up of the soil by plant roots.

The values of bulk density in the subsoil are higher than the topsoil in all the categories of fallow and mature forest studied. The values of bulk density in the subsoil are 1.24 g/cm^3, 1.19 g/cm^3, 1.12 g/cm^3 and 1.19 g/cm^3. The bulk density values in the subsoil follow the pattern of the topsoil.

4.4 Total Porosity

The pattern of total porosity of the topsoil and the subsoil shown in table 4.3 is the opposite of the pattern displayed by the soil bulk density. The total porosity for the 10-year and mature forest are not significantly different from each other. Analysis of variance test shows a significant difference among the various age categories and the mature forest topsoil in terms of total porosity.

Table 4.2: Bulk density values for the topsoil and subsoil in g/cm^3

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	1.14	1.29	1.11	1.06	1.04	1.11	1.02	1.16
2	1.19	1.22	1.16	1.11	1.11	1.10	1.00	1.21
3	1.22	1.21	1.14	1.09	1.06	1.09	1.00	1.19
4	1.12	1.71	1.16	1.11	1.05	1.10	1.04	1.17
5	1.10	1.22	1.13	1.07	1.12	1.12	1.00	1.14
6	1.09	1.20	1.17	1.06	1.21	1.14	1.02	1.19
7	1.16	1.27	1.14	1.11	1.03	1.09	1.01	1.22
8	1.21	1.28	1.15	1.08	1.07	1.16	1.01	1.19
9	1.18	1.21	1.10	1.08	1.04	1.13	1.00	1.24
10	1.22	1.28	1.09	1.09	1.10	1.11	1.00	1.18
Mean	1.16	1.24	1.14	1.09	1.08	1.12	1.01	1.19
S.D	0.05	0.15	0.03	0.02	0.05	0.02	0.01	0.03

A = topsoil, B = subsoil, S.D = standard deviation

Source: Author's fieldwork

Table 4.3: Total porosity for topsoil and subsoil in %

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	56.32	51.32	58.11	56.23	60.75	58.11	61.51	60.00
2	55.09	53.96	56.23	54.34	58.11	58.49	62.26	58.11
3	53.96	54.34	56.98	55.09	60.00	58.87	62.26	58.87
4	57.74	54.34	56.23	55.84	60.38	58.49	60.75	59.25
5	58.49	53.96	55.86	56.98	57.74	57.74	62.26	58.87
6	58.87	57.72	55.84	55.09	54.34	56.98	61.51	58.11
7	56.23	52.08	56.98	53.96	61.13	58.87	61.89	58.20
8	54.34	54.70	56.60	65.09	59.62	56.22	62.26	60.00
9	55.47	54.34	58.49	53.28	60.75	57.36	62.26	58.11
10	53.96	51.70	58.87	55.47	58.49	58.11	61.89	59.25
Mean	56.11	53.55	56.98	55.09	59.13	57.92	61.89	58.87
S.D	1.82	1.84	1.10	3.32	2.06	0.86	0.50	0.75

A = topsoil, B = subsoil, S.D = standard deviation

Source: Author's fieldwork

4.5 Soil Water Holding Capacity

The capacity of the soil to absorb and retain moisture for plant growth during the interval between rainfalls largely depends on its water holding capacity. Table 4.4 shows the water holding capacity values for the topsoil and subsoil of the different age categories of fallows regenerating from degraded rubber plantation and mature forest. The mean water holding capacity values for the 1-year, 5-year and 10-year and for mature forest are 40.29 %, 48.16 %, 51.23 % and 59.35 % respectively for the topsoil, while the corresponding mean values for the subsoil are 46.32 %, 50.77 %, 61.40 % and 64.04 %. This shows that the subsoil of each age categories and the mature forest subsoil have greater ability to hold water than the topsoil. Also the capability of the soil regenerating from degraded plantation to retain water increases with increasing age of fallow. The trend of increase in soil water holding capacity of the soil with age is similar to the pattern displayed by soil organic matter, soil bulk density and total porosity.

The analysis of variance test for soil water holding capacity shows that significant difference exists between the different age categories and the mature forest at 0.05 level of significance.

Table 4.4: Water holding capacity for topsoil (A) and subsoil (B) (in %)

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	40.08	45.75	49.89	51.53	49.88	58.82	57.53	63.85
2	39.40	47.68	47.89	50.65	53.31	61.31	60.17	61.94
3	39.40	46.72	46.94	50.65	50.71	60.07	61.78	63.17
4	40.64	44.74	48.06	50.33	51.27	60.95	57.64	68.47
5	39.11	48.45	46.30	51.34	53.04	62.82	59.74	67.79
6	39.93	45.98	49.92	50.74	49.91	61.42	61.74	69.41
7	43.41	46.77	47.70	50.83	50.68	63.05	57.46	60.91
8	40.07	45.05	48.06	50.18	51.07	61.40	60.14	61.97
9	40.61	47.74	46.93	50.45	49.86	63.13	59.51	61.61
10	40.22	44.34	49.92	50.96	53.04	61.04	57.82	61.31
Mean	40.29	46.32	48.16	50.77	51.28	61.40	59.35	64.04
S.D	1.21	1.38	1.33	0.42	1.37	1.35	1.67	3.25

A = topsoil, B = subsoil, S.D = standard deviation

Source: Author's Fieldwork

4.6 Soil Organic Matter

The build up of soil organic matter was gradual during the first five years in the topsoil, but thereafter it increases rapidly with time (See table 4.5). In the topsoil, the soil organic matter mean value per sample plot for the 1-year, 5-year and 10-year fallow plots and the mature forests are 2.12 %, 3.09 %, 4.74 % and 5.10 % respectively. The corresponding mean values for the subsoil are 1.16 %, 1.52 %, 1.65 % and 1.92 % respectively (see table 4.3). By the tenth year of fallow, the concentration of organic matter in the topsoil has reached 92.9 % of the level of concentration of organic matter in the mature forest. All differences between fallows and between fallows and mature forest organic matter are significant (at $P<0.05$) for the topsoil (Appendix 4.2). Similarly, all the differences between fallows and between mature forests are significant for the subsoil at 0.05 level of significance of F. The means of each age category differ significantly from the forest category and from each other at $p < 0.05$ of the least significant difference test for the topsoil and while for the subsoil the only significant differences between means are those between the 1-year and 5 year old fallows, between 1-year and 10-year fallows and between 1-year fallow and mature forests. This indicates that there is no significant increase in the organic matter content of the subsoil after the fifth year of fallow (Appendix 4.2). An important part of the variation (increase in soil organic matter with age) is most likely a result of increase litter production with age and the dominance of the younger fallow (1-year old fallow) by *Chromolaena odorata* (perennial vagrant forb), and those of the older fallows by woody vegetation which generates more litter than the younger fallow. As would be seen in later part of this work, the total annual production of litter increased significantly with the age of fallow as it is the case of soil organic matter. The study by Lawrence and Foster (2002), on the dynamics of soils following shifting cultivation lends credence to this assertion.

Table 4.5: Soil organic matter content (%) of the topsoil and subsoil

	Fallow age categories							
Samples	1 –year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	2.56	1.08	2.76	1.46	4.88	1.70	4.92	1.93
2	1.20	1.15	2.71	1.74	4.92	1.66	5.03	2.01
3	2.45	1.03	2.81	1.37	5.01	1.59	4.91	1.94
4	2.13	1.17	3.45	1.53	4.61	1.67	5.42	2.03
5	2.66	1.14	3.43	1.48	4.74	1.61	5.11	1.86
6	2.01	1.21	3.21	1.48	3.86	1.63	5.06	1.93
7	1.98	1.13	2.74	1.51	4.93	1.55	4.90	1.78
8	2.33	1.18	3.10	1.56	5.01	1.68	5.22	1.91
9	1.87	1.26	3.31	1.53	4.43	1.63	5.31	1.84
10	2.02	1.23	3.37	1.49	4.96	1.73	5.08	1.96
Mean	2.12	1.16	3.09	1.52	4.74	1.65	5.10	1.92
S.D	0.44	0.07	0.30	0.09	0.36	0.05	0.18	0.08

A= topsoil, B = subsoil, S.D = standard deviation

Source: Author’s fieldwork

It seems that the older fallows (5-year and 10-year fallows) generate more litter than the quantity required to balance the rate of organic matter destruction in the soil. Another part of the significant increase in topsoil organic matter with age may be due to the fact that because the organic matter level in the topsoil of the younger fallow is far below the equilibrium level under the mature forest the build up of organic matter in the topsoil becomes accelerated with increasing age of the fallow to the extent that within ten years of fallow, the level of soil organic matter reached 92.94% of the equilibrium level under the mature forest. According to the equilibrium concept, the effect of fallow on soil organic matter depends as much on the initial organic matter level of the soil in relation to the equilibrium level under the fallow as on the properties of the fallow itself (Nye and Greenland, 1960).

As seen from the table above, it appears that the build up of soil organic matter during the fallow period is higher in the topsoil than the subsoil. This is because leaf litter is the main source of organic matter in forest fallows such as found in the study area. Nye and Greenland (1960) and Lawrence and Foster (2002), opined that where this is the case, the zone of organic matter accumulation is confined to the topsoil.

It is worthy of note that the increase in soil organic matter content in the topsoil after the tenth year of regeneration of fallow from abandoned rubber plantation is not as high as it is immediately after the rubber plantation is degraded and abandoned. This is revealed by the fact that the mean level of soil organic matter in the 10-year fallow regenerating from degraded rubber plantation of 4.74 % is relatively close to that of the mature forest of 5.1% but much higher than that of the 1-year category (2.12 %). This finding support the equilibrium concept and is consistent with those of Aweto (1981), Lawrence and Foster (2005).

The mean level of soil organic matter of 4.74 % obtained for the 10-year old fallow in this study is higher than that of 4.18 % obtained for a 10-year old fallow following shifting cultivation obtained by Aweto (1978) in south-western Nigeria. While the mean value of 5.1 % obtained for this study is relatively close to that of 5.37 % obtained by

Aweto (1978), higher than 4.7 % reported for by Owusu-Seykere *et al*. (2006), but far smaller than the 15.2 % obtained by Deborah and David (2002), following shifting cultivation in a dry tropical forest of the southern Yucatan Peninsula in southern Mexico. This suggests that the level of soil organic matter can build up in soils regenerating from degraded rubber plantation to the equilibrium level, that is, level of soil organic matter in virgin forest if the secondary vegetation is left undisturbed for a long period of time.

The progressive accumulation of soil organic matter during the follow period points to the fact that the accumulation of carbon in fallow vegetation is attained without any decrease in the level of soil carbon. This is because green plants are capable of synthesizing carbon compounds and do not depend directly on soil carbon. Post and Kwon (2000) reviewed the reported trends in soil organic matter build up during forest establishment after agricultural use and could not find a common trend. This study shows a great variation in soil organic matter build up even within the same locality. The build up of soil organic matter seem to be faster in a secondary forest regenerating from abandoned plantation than secondary forest regenerating from shifting cultivation. For instance Aweto (1981a) reported that by the tenth year of fallow soil organic matter has reached 78 % of that in the mature forest and increase in the concentration of the soil organic matter from 2.49 % in 1-year fallow to 4.19 % in 10-year fallow, representing 67 % increase in soil organic matter concentration by the tenth year. While this study shows that by the tenth year of fallow soil organic matter concentration increase from 2.12 % in the 1-year fallow to 4.74 % in the 10-year fallow. This increase represents 124 % increase in soil organic matter by the tenth year. This presupposes that the build up of soil organic matter is more rapid in secondary forest regenerating from abandoned plantation than those regenerating from shifting cultivation. The concentration of soil organic matter in the topsoil is higher than its concentration in the subsoil. Similarly the build up of soil organic matter in the topsoil is more rapid than the subsoil.

4.7 Total Nitrogen

Table 4.6 shows the total nitrogen content of the topsoil and the subsoil of the different age categories and mature forest. The total nitrogen level in the soil (to a depth of 30 cm) increases with increasing forest age. Total nitrogen concentration is highest in the mature forest and least in the 1-year. The build up of total nitrogen both in the topsoil and the subsoil with forest age can be partially explained by external inputs. For example, Fernandes *et al* (1997), Szott *et al*., (1999) reported that nitrogen-fixing plants may contribute 10-15 kg ha^{-1} to soils, while Schroth *et al*., (2001) opined that atmospheric deposition may add 5.5-11.5 kgha^{-1}yr^{-1} to soil, explaining a fraction of the increasing total soil nitrogen. Another reason for the high soil nitrogen accumulation rates with age, is due to rapid return of nitrogen through litterfall. The mean values of total nitrogen for the 1-year, 5-year and 10-year fallows and for mature forest are 0.18 %, 0.22 % 0.34 % and 0.53 % respectively for the topsoil. The corresponding values for the subsoil are 0.11 %, 0.16 %, 0.19 % and 0.31 % respectively.

The pattern of nitrogen concentration in soil is similar to that of its return to the soil through litter fall (nitrogen concentration in litter) and the pattern of increasing soil organic matter with increasing age of fallows. The mean values of soil total nitrogen reported in this study for mature forest are higher than those reported by Aborisade and Aweto (1990), for a rainforest in Gambari Nigeria (0.19%), Greenland and Kowal (1960), for a mature secondary semi-deciduous forest in Kade, Ghana (0.2%). However, the mean values of nitrogen reported in this study fall within the range of values reported by Brassell, Unwin and Stocker (1980) for an undisturbed rainforest 'site 1' and 'site 2' in North eastern Australia – 0.59 % and 0.45 % respectively for 'site 1' and 'site 2' and by Aweto (1981) for Ijebu-Ode area of south-western Nigeria (0.49 %). The mean values reported for the subsoil of the fallows in this study are higher than those reported by Aweto (1981) for fallows following shifting cultivation in south western Nigeria but the topsoil values fall within the range reported by Aweto (1981), and Owusu-Seykere *et al.* (2006), for a primary forest in Ghana. Both the mean values of the topsoil and the subsoil in this study are higher than the values reported by Feldpausch *et al* (2010) for forests regenerating from degraded pastures in Manaus central Amazon Brazil.

Table 4.6: Total nitrogen content (in %) of the topsoil (A) and the subsoil (b)

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	0.16	0.096	0.21	0.15	0.26	0.16	0.46	0.28
2	0.18	0.108	0.24	0.17	0.28	0.17	0.48	0.28
3	0.27	0.162	0.34	0.24	0.24	0.16	0.53	0.31
4	0.19	0.114	0.21	0.15	0.36	0.20	0.52	0.31
5	0.18	0.108	0.21	0.15	0.37	0.21	0.54	0.31
6	0.12	0.102	0.23	0.17	0.38	0.22	0.56	0.32
7	0.19	0.114	0.20	0.14	0.41	0.15	0.54	0.31
8	0.17	0.102	0.22	0.16	0.31	0.19	0.54	0.31
9	0.19	0.114	0.21	0.15	0.39	0.24	0.56	0.36
10	0.16	0.096	0.19	0.14	0.38	0.22	0.55	0.32
Mean	0.18	0.11	0.22	0.16	0.34	0.19	0.53	0.31
S.D	0.04	0.02	0.04	0.03	0.06	0.03	0.03	0.02

A = topsoil, B = subsoil, S.D = standard deviation

Source: Author's fieldwork

Though the mean values of total nitrogen in the topsoil are higher than those of the subsoil for the different age categories and the mature forest, there is a progressive build-up of total nitrogen in both the topsoil and the subsoil. High subsoil nitrogen concentrations in the fallow may be attributable to leaching from topsoil during the productive life of the rubber, followed by a reduced nutrient capture potential of shallow rooted colonizing secondary vegetation. Mature forest also losses nitrate to the subsoil. Toky and Ramakrishnan (1983), opined that leaching of surface nitrogen can be rapid in oxisols because of the high macro-porosity and hydraulic conductivity. Leaching of surface nitrogen (0-10cm) to the subsoil could also explain the increase nitrogen concentration observed in the subsoil with forest maturation. Owusu-Seykere et al. (2006) and Feldspauch *et al*., (2010), attributed increase nitrogen concentration of subsoil to the leaching of surface nitrogen (0-10cm).

The concentration of total nitrogen in the topsoil and the subsoil of this study reached 64 % and 61 % of the mature forest topsoil and subsoil respectively by tenth year. While for a 10-year fallow following shifting cultivation studied by Aweto (1981) in Ijebu-Ode area of western Nigeria it reached 59 % of that of the mature forest. The differences between all the secondary forest categories in terms of nitrogen concentration of the topsoil are significant. Similarly the differences between the concentration of total nitrogen in topsoil of the mature forest and each of the secondary forests categories are significant at $p < 0.05$ of the least significant differences test

This progressive build-up in the concentration of total nitrogen in both the topsoil and the subsoil with increasing age of fallow may be due to the addition through nitrogen fixing plants. Szott *et al*. (1999) reported that nitrogen-fixing plants may contribute 10-150 $kg/ha^{-1}yr^{-1}$ to soils, while Schroth *et al*. (2001) reported that atmospheric deposition adds 5.5-11.5 $kg/ha^{-1}yr^{-1}$ to soil.

High subsoil nitrogen concentration in the fallows may be attributed to the following:

i. Leaching from topsoil during the productive life of the rubber. Toky and Ramakrishnan (1983), opined that leaching of surface nitrogen can be rapid in oxisols because of the high macro-porosity and hydraulic conductivity
ii. Reduced nutrient capture potential of shallow rooted colonizing secondary vegetation.

This reveals that unless deep nitrogen mining with root development occurs, nitrogen losses to the subsoil due to leaching may negatively affect surface fertility of soil regenerating from degraded rubber plantation.

4.8 Available Phosphorus

Nye and Greenland (1960), opined that phosphorus deficiency in forest fallows is a factor that limits crop yield. Therefore, the build up of phosphorus in the soil during the fallow period is of paramount importance. Table 4.7 shows the mean available phosphorus contents of the two layers of soil studied. The mean available phosphorus values for the topsoil in mg/kg are 4.91, 8.81, 4.57 and 11.60 for the 1-year, 5-year, 10-year and the mature forest respectively. While the corresponding values for the subsoil are 1.27, 4.53, 1.34 and 5.80 for the 1-year, 5-year, and 10-year fallows and for the mature forest respectively. The trend of available phosphorus concentration in the soil in decreasing order is mature forests > 5-year old secondary forest > 1-year old fallow > 10-year old secondary forest.

The difference among all the age categories and the mature forest taken together is significant at the 0.05 level of significance of the F distribution for both the topsoil and the subsoil. The concentration of topsoil available phosphorus reached 76 % of the level of concentration of available phosphorus in the mature forest by the fifth year of fallow. The difference between the 1-year old and the 10-year old secondary forest is not significant at 0.05 level of significance of the least significant differences test while the differences between pairs of the other secondary forest categories on the one hand and between them and the mature forest are significant at 0.01 significant level of the least significant differences test

Compared to the mature forest phosphorus concentration in soil, the 1-year, 5-year and 10-year age categories have less phosphorus in soil than the mature forest. Available phosphorus in the soil increased rapidly in the first five years after the abandonment of the plantation, but also declined rapidly from 8.81 mg/kg to 4.57 mg/kg by the tenth year. This pattern may be attributed to increasing tree density as age increases during the fallow period with its concomitant relocation of available soil phosphorus from below (soil) to above ground (vegetation) pools. Plants appear to be taking up more soil phosphorus than is available in the 10-year age category due to the high density of trees in the 10-year fallow. The net reduction in soil available phosphorus with increasing forest age, indicates inadequate replacement of available soil phosphorus with plant phosphorus uptake, a trend also observed elsewhere (Johnston *et al*., 2001, Feldpeusch *et al*., 2010). Feldpausch *et al*. (2010) observed that should this trend continue, phosphorus may become limiting to growth unless other factors such as (a) reduce phosphorus uptake by plants (b)increase phosphorus uptake from subsoil, or (c)increase in the rate at which unavailable forms of soil phosphorus shift to plant available phosphorus forms to replenish immobilized plant available soil phosphorus.

The findings on phosphorus in this study are in consonance with those reported by Aweto (1981b) and (2001), Lehmann *et al*. (2001a), Feldspauch *et al*. (2010), but not consistent with those of Angelica *et al*., (2005) and Toky and Remakrishnan (1983) whose works on fallows following Slash and burn agriculture showed consistent increase in phosphorus with time as against fluctuating pattern of nutrients concentration with time reported in this study. However, the values reported for the concentration of available phosphorus in this study fall within the range reported for the tropical region by Aweto (1981b, 1987), Aborishade and Aweto (1990), Aweto and Iyanda (2003), Owusu-Seykere *et al*. (2006), Molindo (2008) and Aikpokpodion (2010).

Table 4.7: Available phosphorus content of the topsoil (A) and subsoil (B) in mg/kg

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	6.0	1.23	8.67	4.29	4.81	1.95	12.10	6.02
2	4.76	1.11	8.74	4.33	4.67	1.02	11.89	5.95
3	5.11	1.96	8.91	4.39	4.31	1.83	11.47	5.71
4	4.83	1.20	8.82	4.40	4.42	1.86	12.13	6.03
5	4.91	1.36	8.76	4.42	4.58	0.98	11.26	5.57
6	5.01	1.29	8.93	4.60	4.21	1.05	11.32	5.63
7	4.82	1.18	9.01	5.85	4.96	0.99	11.42	5.68
8	4.93	1.22	8.77	4.29	4.82	1.21	12.01	5.68
9	3.96	0.96	8.62	4.41	4.86	1.12	10.98	6.01
10	4.78	1.18	8.90	4.29	4.01	1.03	11.13	5.46
Mean	4.91	1.27	8.81	4.53	4.57	1.34	11.6	5.80
S.D	0.49	0.26	0.12	0.47	0.32	0.40	0.42	0.21

A = topsoil, B = subsoil, S.D = standard deviation

Source: Author's fieldwork

The pattern displayed by available phosphorus may be due to increasing tree density as fallow age increases with its accompanying relocation of available soil phosphorus from below (soil) to above-ground (vegetation) pools. The density of trees is highest in the 10-year fallow. It appears that trees are taking up more soil phosphorus than is available in the 10-year age category soil. The net reduction in available phosphorus with increasing forest age, indicates inadequate replacement of available soil phosphorus with plant phosphorus uptake, a trend also observed by Johnston *et al*., (2001). Feldspauch *et al*., (2010) opined that should this trend continues, phosphorus may become limiting to growth unless other factors such as:

i. Reduce phosphorus uptake by plants
ii. Increase phosphorus uptake from subsoil or
iii. Increase in the rate at which unavailable forms of soil phosphorus shift to plant available phosphorus forms to replenish immobilized plant available soil phosphorus.

4.9 Exchangeable Cations

This section deals with the changes in the levels of exchangeable magnesium, calcium, sodium and potassium.

Tables 4.8, 4.9, 4.10 and 4.11 respectively show the concentrations of exchangeable calcium, magnesium, sodium and potassium in the topsoil and subsoil of the sample plots. The pattern of variation shown by magnesium and calcium in the course of soil regeneration is the same, while the pattern of variation shown by sodium and potassium is the same. There is a gradual increase in the level of exchangeable cations in the soil (topsoil and subsoil) during the first five years of the fallow period after which a decline occurs by the tenth year. Though, decline occurs by the tenth year for all the exchangeable cations, it must be noted that the concentration of sodium and potassium in the 10-year fallows is more than that of the 1-year fallow category, but for magnesium and calcium the concentration is more in the 1-year category than the 10-year category (see Table 4.9 and Table 4.10). The increase in the concentrations of nutrients cations in the soil during the first five year is due to the fact that at this period, the rate of return of exchangeable cations to the soil through the fall and mineralization of litter exceeds the rate of uptake by plants and loss through leaching or run off.

After the fifth year, the rapid decline in exchangeable cations concentration of the soil by the tenth year may be due to immobilization by the rapidly developing vegetation or high uptake by the growing vegetation after abandonment. The higher concentrations of exchangeable magnesium and calcium in the 1-year fallow category than the 10-year category may probably be due to the consequence of the burning of the 1-year fallow, which releases these elements to the soil or translocation of nutrients to the soil before the rubber experienced die back: otherwise, these cations are expected to be lost by leaching given the heavy rains in the study area, and low vegetation and litter cover, in the 1-year fallows.

Table 4.8: Concentrations of exchangeable magnesium in the topsoil (A) and in the subsoil (B) in mg/kg

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	228.1	110.1	318.7	137.0	231.0	113.2	370.0	101.5
2	217.9	130.2	334.2	121.2	208.2	108.4	405.1	131.6
3	301.1	106.4	298.5	103.1	271.1	111.3	381.7	123.4
4	232.2	122.3	291.6	98.4	254.3	106.1	333.6	119.3
5	256.3	116.1	326.1	101.2	266.4	110.6	384.5	117.8
6	268.8	128.1	343.6	126.3	219.7	121.1	376.1	133.5
7	243.4	122.3	328.7	117.0	209.3	102.3	364.3	119.4
8	261.6	130.3	331.4	120.4	232.3	106.4	398.9	126.2
9	258.7	119.4	322.7	111.6	266.1	114.2	401.3	114.6
10	287.4	106.3	316.4	99.3	234.3	107.9	396.4	121.3
Mean	255.6	119.2	321.2	113.6	239.3	110.2	381.2	120.9
S.D	26.20	9.22	15.91	13.03	23.77	5.24	21.69	9.06

A = topsoil, B = subsoil, S.D = standard deviation

Source: Author’s fieldwork

Ewel *et al*., (1981); Aweto (1981b), Adedeji (1984); Bautista-Cruz and del Castilo (2005) and Feldspauch *et al*., (2010), observed fluctuating pattern in the concentration of exchangeable cations in the top 10 cm of the soil with the 1-year old fallow having higher concentration of exchangeable cations (magnesium and calcium) than the 10-year old secondary forest.

When a secondary forest has reached the climax stage, the optimum level of nutrient cations is immobilized and stored in the standing crop of vegetation, consequently when more nutrients are absorbed from the deeper layer of soil, they are returned to the topsoil through the fall and mineralization of litter and through rain-wash. This explains why the levels of exchangeable cations under mature forest are higher than under the fallow categories.

The difference in the concentration of exchangeable cations in the topsoil of the different age categories and the mature forest are significant at the 0.05 significant level of the F distribution. Similarly the differences in the concentration of exchangeable cations (magnesium, potassium, calcium and sodium) are significant at the 0.05 level of significance of the F distribution for the subsoil of the different age categories and the mature forest.

The concentrations of exchangeable cations in the topsoil of the different categories of fallows and the mature forest are higher than those of their respective subsoil (Tables 4.8, 4.9, 4.10 and 4.11). With the exception of sodium, the concentration of exchangeable cations in the subsoil of the mature forest was lower than the topsoil of the 1-year fallow. By the 5th year of fallow the level of exchangeable magnesium, calcium, potassium and sodium for the topsoil reach 84.26 %, 77.85 %, 56.17 % and 75.82 % of those of the mature forest respectively, while by the fifth year the build up of exchangeable sodium and potassium in the subsoil reached 191.78 % and 56.83 % respectively of their level in the mature forest as against 75.82 % and 56.17 % for sodium and potassium respectively in the topsoil. Similarly, while sodium increased by 54.35 % in the topsoil by the fifth year of secondary forest regeneration, it increased by 55.22 % by the fifth year in the subsoil, while when potassium increased by 36.22 % in the topsoil by the fifth year of

Table 4.9: Concentrations of exchangeable calcium in topsoil (A) and subsoil (B) in mg/kg

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	589.4	410.1	711.8	298.36	617.4	214.2	891.8	294.1
2	612.3	380.4	689.9	346.5	624.5	227.6	918.5	244.2
3	631.5	378.2	746.1	317.5	624.5	254.3	944.8	317.1
4	592.6	383.5	718.9	322.3	611.2	209.2	899.2	296.3
5	609.2	286.3	700.3	309.4	619.6	211.4	936.4	311.2
6	628.4	268.1	736.2	348.2	622.3	225.3	919.1	276.1
7	591.3	276.2	713.0	299.9	602.5	203.9	921.5	301.4
8	611.2	323.1	699.1	292.6	611.6	206.3	913.8	240.6
9	626.5	341.2	726.4	307.3	624.0	252.7	897.4	286.3
10	604.2	273.4	696.2	294.2	613.1	211.2	940.1	306.4
Mean	610.2	332.1	714.7	313.7	617.1	221.6	918.3	287.4
S.D	15.6	53.9	18.3	20.2	7.3	18.4	18.4	26.5

A = Topsoil, B = Subsoil, S.D = Standard deviation

Source: Author's fieldwork

Table 4.10: Concentrations of exchangeable sodium in topsoil (A) and subsoil (B) in mg/kg

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	21.4	24.1	48.5	50.1	44.1	18.3	28.1	65.7
2	22.6	21.2	51.7	38.9	43.7	19.4	29.1	64.8
3	26.5	20.3	52.9	39.9	42.8	24.2	21.2	71.7
4	22.3	21.6	47.8	43.3	43.3	22.6	27.3	66.3
5	24.1	22.1	53.2	50.3	44.6	19.7	24.2	68.4
6	26.3	21.3	52.4	49.6	42.4	20.3	26.3	65.2
7	24.6	21.7	49.3	51.3	44.3	18.8	28.6	67.4
8	23.4	22.0	52.1	54.2	42.6	21.3	25.4	64.7
9	25.3	21.6	50.3	53.2	44.2	22.4	22.3	69.3
10	21.7	19.2	49.9	49.6	42.7	24.3	21.8	66.5
Mean	23.18	21.5	50.8	48.04	43.5	21.13	25.05	67.0
S.D	1.84	1.26	1.91	5.40	0.81	2.17	2.93	2.24

A = Topsoil, B = Subsoil, S.D = Standard deviation

Source: Author's fieldwork

Table 4:11 Concentrations of Exchangeable Potassium in Topsoil (A) and in Subsoil (B) in Mg/Kg.

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	26.6	10.7	36.3	14.6	28.1	11.4	61.4	24.5
2	23.4	9.6	32.7	13.2	27.6	11.3	63.8	25.4
3	25.8	10.5	34.8	14.0	29.3	12.0	59.7	23.8
4	25.6	10.5	36.5	14.7	27.2	11.1	61.3	24.4
5	24.7	10.1	33.3	13.4	28.4	11.6	60.4	24.1
6	26.2	10.7	34.9	14.1	29.1	11.9	62.6	24.9
7	23.4	9.6	32.6	13.3	28.2	11.6	61.2	24.5
8	26.1	10.7	35.8	14.4	29.4	12.0	63.7	25.6
9	25.3	10.3	34.2	14.0	27.5	11.3	59.3	23.6
10	26.4	10.8	34.7	14.1	29.0	11.9	62.7	25.0
Mean	25.4	10.4	34.6	13.98	28.38	11.6	61.6	24.6
SD	1.17	0.45	1.40	0.53	0.79	0.33	1.57	0.62

A = Topsoil, B = Subsoil, S.D = Standard deviation

Source: Author's fieldwork

secondary forest regeneration from abandoned rubber plantation, it increased by 34.42 % in the subsoil by the fifth year. This suggests that though the concentration of exchangeable sodium is higher in the topsoil than the subsoil, its build up over time is more rapid in the subsoil than the topsoil. This finding contradicts that of Aweto (1978) who reported that the build up of nutrient sodium and exchangeable cations is confined to the topsoil but agrees with that of Feldpausch *et al*. (2010).

The mean levels of exchangeable calcium, magnesium and sodium are lower in the subsoil of the 10-year age category than in the 1-year category. This situation is the reverse of that which occurs in the topsoil and suggests that the leaching of nutrients from the topsoil to the subsoil is more rapid in the young fallows than the older fallows. In addition, it also suggests that the roots of the woody fallows of the older fallows are more efficient than those of the *Chromolaena odorata* (forb fallow) which characterize the 1-year fallow, in transferring nutrients from the subsoil to the topsoil.

The mean concentration of exchangeable calcium and sodium for the subsoil of the 5-year fallow of 313.7 and 48.04 mg/kg for calcium and sodium respectively are higher than the mean values of 287.4 and 25.05 mg/kg respectively for calcium and sodium of the subsoil of the mature forest. This again lends support to the idea that the leaching of exchangeable cations from the topsoil to the subsoil is more rapid in the younger fallows than mature forest.

The results on exchangeable cations show that when compared with the values reported in the literature for southern Nigerian soils the values reported for exchangeable calcium for the mature secondary forest in this study fall within the range reported by Aborishade and Aweto (1990) (971.9 mg/kg), Aweto and Iyanda (2003) (953.9 mg/kg) and Aikpokpodion (2010) (1024 ppm) but lower than the values reported by Aweto (1978) (1392.8 ppm) and Ukpong (1994) (2144.3 ppm) and higher than the values reported by Aweto (1987) (100 ppm) Molindo (2008) (90.18 ppm) and Molindo *et al*. (2009) (12.85 ppm). The values reported for the concentration of calcium in the fallows of the 1-year and 10-year old fallows are slightly lower than the values reported by Aweto (1978) for fallows of similar age in Ijebu-Ode area of south-western Nigeria, while the value reported for the calcium concentration of the 5-year fallow in this study (714.7 mg/kg)) is similar to the value reported for a three-year fallow (708.6 ppm) regenerating from swidden fallow studied by Aweto (1978). Comparatively, the concentration of magnesium in the soils of this study are higher than the values reported by Aweto and Iyanda (2003) (102.1 mg/kg), Aweto (1987) (60 mg/kg), Molindo (2008) (27.96 mg/kg), Molindo *et al*. (2009) (60.78 mg/kg), lower than the values reported by Aborishade and Aweto (1990) (384.1 mg/kg), Cuevas, Brown and Lugo (1991) (2114.97 mg/kg) and Ukpong (1994) (2144.28 mg/kg), but similar to the values reported by Aweto (1978) (212-359 ppm) as against 255.6-381.2 ppm for this study. The concentration of potassium of the topsoil of this study area ranged from 25.4 mg/kg – 61.6 mg/kg, while Aborishade and Aweto (1990) and Aikpokpodion (2010), reported values of 234.6 ppm and 218.9 ppm for the topsoil. This suggests that potassium may become a limiting factor to plants growth in secondary forest regenerating from degraded rubber plantation.

4.10 Soil pH

One would have expected a rise in the level of soil pH with increasing age of fallow following the build-up of exchangeable nutrient bases in the soil. In both the 0-10 cm layer and 10-30 cm layer of the soils, there is a decline in soil pH during the first ten years of the regeneration of secondary forest from degraded abandoned rubber plantation. The mean pH values of topsoil per sample plot for the 1-year, 5-year and 10-year age categories and for mature forest are 6.14, 5.81, 5.3 and 6.0 respectively. While the corresponding values for sub-soils are 5.70, 5.45, 4.66 and 5.24 respectively (Table 4.12). The differences observed in soil pH in the various age categories and the mature forest is proven to be statistically significant at the 0.001 level of the F distribution (Analysis of variance).

The decrease in soil pH with age may be due to the uptake of nutrient cations by the growing vegetation of the older secondary forest. This agrees with Feldpausch *et al*., (2010), that the uptake of nutrient cations by rapidly growing vegetation of secondary

Table 4.12: pH values of the topsoil and the subsoil

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	6.0	5.6	6.0	5.9	5.7	5.0	6.2	5.8
2	6.1	6.0	6.4	5.4	4.4	4.4	6.0	5.5
3	6.4	6.4	5.0	6.0	5.8	5.7	5.8	5.4
4	6.2	5.2	5.8	5.1	5.3	4.9	6.1	4.9
5	6.0	5.8	5.6	5.0	4.8	5.1	6.1	6.0
6	6.3	6.2	6.2	6.0	5.8	5.8	5.9	5.3
7	5.9	5.4	5.9	5.0	5.6	4.9	5.6	4.9
8	6.1	6.0	5.3	5.3	5.0	4.9	5.6	4.9
9	6.1	5.1	6.1	5.8	5.4	4.9	6.1	5.2
10	6.3	5.3	5.8	5.0	5.2	5.0	6.0	4.8
Mean	6.14	5.7	5.81	5.45	5.30	4.66	6.0	5.24
S.D	0.16	0.45	0.42	0.43	0.46	0.41	0.21	0.41

A = topsoil, B = subsoil, S.D = standard deviation

Source: Author’s fieldwork

forest regenerating from degraded pasture in Central Amazonian resulted in decrease in soil pH with increasing age of secondary forest. Each sample is formed by composite of five sub-samples from each depth.

It is likely that the higher concentration of base cations in the topsoil helps to raise the level of soil pH. Hence, the forest plots have relatively high pH values as compared to those of the older fallows.

The general pattern of pH values in subsoil is similar to that of the topsoil. There is decrease in the value of pH with depth. This is chiefly the result of decrease in the concentration of base cations with depth down the profile of the soil. Generally, the soils were slightly acidic. This is normal for this type of humid soils which are subject to leaching by bases (Alloway, 1996).

4:10 Effective Cation Exchange Capacity

Effective cation-exchange capacity changed or differs significantly with the age of the fallow. The lowest concentration of effective cation exchange capacity (ECEC) is found in the 1-year fallow, reached a higher value of 9.07 cmol/kg in the 5-year fallow and increased to 10.18 cmol/kg in the mature forest.

Table 4.13 shows the mean values of ECEC for both topsoil and subsoil of the different age categories of fallow and the mature forest. The mean values for the topsoil of the 1-year, 5-yer and 10-year fallows and for mature forest are 7.14, 9.07, 8.04 and 10.18cmol/kg respectively. The corresponding values for the subsoil are 5.14, 6.22, and 6.09 and 5.79 cmol/kg for 1-year, 5-year and 10-year fallows and for mature forest respectively. This pattern is similar to the pattern displayed by soil organic matter. It is most probable that soil organic matter has more influence on effective cation exchange capacity than any other factor (Agboola and Corey 1973, Aweto 1981).

Albeit the mean clay contents of the subsoil are higher than those of the topsoil, the topsoil has higher ECEC than the subsoil. This suggests that on sandy soils derived from sandstones such as in the study area the soil organic matter content is more important in contributing to the ECEC of the soil than the clay content does.

Table 4.13: Effective cation exchange capacity values for the topsoil and the subsoil in centimoles per kilogram of soil (cmol/kg)

Samples	Fallow age categories							
	1-year		5-year		10-year		Forest	
	A	B	A	B	A	B	A	B
1	7.10	5.74	9.03	6.40	8.75	6.07	9.98	5.69
2	6.80	5.73	9.10	6.35	8.60	6.10	10.37	5.69
3	7.61	5.54	9.05	6.09	9.12	6.29	10.33	5.95
4	6.85	5.69	8.85	6.89	8.91	6.00	9.70	5.84
5	7.10	5.17	9.05	5.82	9.05	6.04	10.30	5.89
6	7.32	5.16	9.38	6.46	8.67	6.11	10.14	5.85
7	6.91	5.15	9.11	5.91	8.50	6.01	10.07	8.85
8	7.16	5.45	9.10	6.15	8.74	5.98	10.30	5.62
9	7.22	5.45	9.14	6.14	9.07	6.29	10.25	5.73
10	7.32	4.99	8.94	5.97	8.75	6.04	10.42	5.79
Mean	7.14	5.41	9.07	6.22	8.04	6.09	10.18	5.79
S.D	0.25	0.27	0.14	0.32	0.21	0.11	0.22	0.98

A = Topsoil, B = Subsoil, S.D = Standard deviation

Source: Author's fieldwork

Effective cation-exchange capacity increased significantly with the progress of the fallow. Analysis of variances test for the differences among the fallow categories and the mature forest showed that there was significant difference among them at $p < 0.05$ significant level of the F distribution with respect to ECEC for both the topsoil and the subsoil. Also the differences between each fallow category and the mature forest is significant at the 0.05 level of significant of the least significance difference post hoc multiple comparison test of mean.

One of the objectives of this study is to assess the differences in soil physical and chemical properties related to soil fertility in secondary forests regenerating from degraded abandoned rubber plantation. The hypothesis which states that in an area of homogenous topography and regional climate, differences exist in the characteristics of soils under secondary forests in different stages of secondary succession was used to achieve that objective. A summary of the analysis of variance test (ANOVA) of the hypothesis is presented in appendix 4.2. as is to be expected the test reveals that significant differences exist in both the physical properties and chemical properties of soils under secondary forests in different stages of regeneration from degraded abandoned rubber plantations. The differences between the different age categories are proven to be significant at the 0.05 significant level of the F distribution.

However, despite the existence of significant differences in the characteristics of soils under secondary forests in different stages of secondary succession, a post hoc test of the differences between the different age categories and the differences between the various age categories and the mature forest shows the following:

i. No significant difference between the bulk density of the 1-year fallow and the 5-year fallow for the topsoil (Appendix 4.3)

ii. Total porosity of the 1-year fallow and the 5-year fallow is not significantly different for the topsoil. This is probably due to the similarity in bulk density of the 1-year and the 5-year fallows.

iii. The concentrations of exchangeable calcium, magnesium, potassium and available phosphorus of the topsoil of the 1-year fallow are not significantly different from that of the 10-year fallow for the topsoil (Appendix 4.3).

iv. The effective cation exchange capacity of the 1-year and 10-year fallows is not significantly different (Appendix 4.3).

v. The pH of the 1-year fallow and the mature forest on the one hand, and the 5-year fallow and the mature forest on the other hand are not significantly different (Appendix 4.3).

This chapter has concentrated chiefly on the dynamics of soil in secondary forests regenerating from degraded abandoned rubber plantation. As noted earlier, the investigation was based on an inferential approach which involved comparison of both the physical and chemical attributes of soils under secondary forest of different ages in a monolithologic zone of sandstone parent materials. The different plots have similar history of cultivation, thereby eliminating the distortion of estimates of the rate of change in soil properties that may have arisen from different histories of cultivation and variation in land use intensity.

CHAPTER FIVE

CHANGES IN SECONDARY FORESTS VEGETATION ABOVE-GROUND BIOMASS PARAMETERS, VEGETATION FLORISTIC PARAMETERS AND LITTERFALL

5.1 Introduction

This chapter focuses on the pattern of litter production and the nutrient content of litter in secondary forests regenerating from degraded abandoned plantation. In addition the attributes of the vegetation that influence litter production are discussed with a view to providing an insight to how these vegetation parameters could provide explanation for the pattern of litter production in secondary forest.

The parameters of vegetation discussed are those relating to above-ground biomass and abundance of predominant species. The vegetation parameters discussed are tree height, tree diameter, tree density, tree basal area, estimated vegetation above ground biomass, total numbers of plant and tree species, species diversity, density of predominant plant species, frequency of predominant plant species, tree cover litter fall, litter quality (measured by the concentration of nutrient elements in litter fall), elements returned to the soil through litter fall, biomass quality (measured by the concentrations of nutrient elements in the above ground biomass) and the biomass nutrient storage.

5.2 Changes in Vegetation Above-ground Biomass Parameters

This section focuses on vegetation aboveground biomass parameters (tree density, tree height, tree diamer, tree basal area and estimated aboveground biomass).

5.2.1 Tree Density

The number of trees per unit area has an important bearing on litter production. Consequently, tree regeneration or increase in tree density is quintessential to soil fertility restoration during the fallow period (Aweto, 2000).The means tree density per hectare for the 1-year 5-year and 10-year age categories and for the mature forest are 70.3, 1472, 2834 and 2168 trees respectively (Table 5.1). This shows that the density of trees increases linearly with age of the secondary forest up to the tenth year but declined later in the mature forest. The density of trees in the 10-year old secondary forest is more than

Table 5.1: Tree density (number of trees DBH > 2 cm /ha) per hectare

Sample	Fallow age categories			
	1-year	5-year	10-year	Mature forest
1	32	1920	2880	2400
2	16	2560	2800	2720
3	16	1280	2880	2080
4	48	1280	2880	2160
5	80	1200	2880	2080
6	32	1120	2740	1760
7	48	800	2800	2000
8	175	1280	2640	2080
9	208	1760	2960	2240
10	48	1520	2880	2160
Mean	70.3	1472	2834	2168
S.D	66.9	497.7	91.4	254.2

S.D = Standard deviation

Source: Author’s fieldwork

that of the mature forest. These may be due to competitive elimination of some trees in the forest ecosystem due to inter-specific competition of tree species or probably due to higher mortality rates than ingrowths in the mature forest. Kennard (2002), opined that higher tree density in recent fallows is expected because the open areas favour the rapid establishment of seedlings, while d ‘Oliveira (2011) opined that the rate of mortality is higher in the mature forest than the rate of ingrowths, thereby decreasing density of trees in the mature forest. Stenninger (2000), Alves *et al*. (1997) reported a gradual replacement of pioneers by shade-tolerant species. Analysis of Variance and the Least Significant Difference tests revealed that significant differences existed between tree densities under the different forest categories at $p < 0.05$.

The tree density of the secondary forest was comparable to similar-age forests growing in the tropical forest life zone of the same age. d‘Oliveira *et al*. (2011), reported values of 641 to 745 trees per hectare for trees > 5 cm DBH for a primary forest in southern Brazilian Amazon, Aweto (2001), reported the density of 510 trees (girth at breast height of at least 10 cm) per hectare for a shifting cultivation farm in Ibadan area of Nigeria.

5.2.2 Tree Cover

Tree cover is the proportion of the ground occupied by the perpendicular projection of the aerial parts of the trees (Whittaker and Gimmingham, 1963). The mean tree cover of 1-year, 5-year and 10-year old fallows and for the mature forest are 1.91 %, 39.46 %, 78.61 % and 89.97% respectively. This shows that there is linear increase in the abundance of tree species with age. Table 5.2 shows the mean percentage tree cover for the different sample plots. By the tenth year of fallow the secondary forest percentage tree cover has reached 87.37% of the value of the mature forest percentage tree cover.

The differences between tree cover for all the pairs of secondary forest are significant at 0.05 probability level of the F distribution. Significant increase in tree cover with increasing age of secondary forest was reported by Aweto (1978), Guriguata and Osterg (2001) and Feldpausch *et al*., (2005).

Table 5.2: Tree cover in percentage

Sample	Fallow age categories			
	1-year	5-year	10-year	Mature forest
1	0.8	49.3	81.5	91.3
2	3.2	45.6	79.3	96.4
3	1.7	38.1	86.4	88.7
4	2.6	39.4	73.5	90.4
5	2.4	37.8	81.1	82.9
6	1.9	33.2	69.2	84.3
7	1.1	31.8	77.7	91.6
8	1.5	38.3	76.6	88.7
9	1.8	41.6	79.3	94.1
10	2.1	39.5	81.5	91.3
Mean	1.91	39.46	78.61	89.97
S.D	0.71	5.19	4.76	4.08

S.D = Standard deviation

Source: Author's fieldwork

5.2.3 Tree Height

Table 5.3 shows the mean tree heights for the different fallow and the mature forest. The means per sample plot for the 1-year, 5-year, 10-year fallows and mature forests are 1.74m, 4.18m, 6.44m and 8.71m respectively. The tree sizes as measured by the tree height increase significantly with increasing age of the secondary forest chiefly because of cumulative increase in size of trees over time.

The pattern of increase in tree height as secondary forest age increases is consistent with what is reported in the literature (Aweto 1981a, Toky and Ramakrishnan 1983, Guriguata and Osterg 2001, Feldspauch et al. 2005, Erika *et al*., 2008).

5.2.4 Tree Diameter

Table 5.4 shows the mean tree diameter per sample plot. The means per sample plots for the 1-year; 5-year, 10-year fallows and forest are 1.03cm, 4.75cm, 9.23cm and 20.65cm respectively. The diameter of trees in the mature forest was significantly larger than those of the secondary forest (Appendix 2).The larger diameter of the secondary forest resulted in a basal area that is four times higher in the mature forest than the oldest fallow (10-year old fallow) despite the higher tree density of the oldest secondary forest. Similarly, the least significant difference comparison of the means of the secondary forests revealed that the differences between their means are significant at $p < 0.05$ (Appendix 2).

By the tenth year of secondary forest regeneration from degraded abandoned rubber plantation, the height of the trees in the secondary forest and tree diameter have reached 73.9 and 44.65 % respectively of the height and diameter respectively of trees in the mature forest. Linear increase in tree heights and tree diameter with increasing age of secondary forest in the study area is as a result of cumulative increase in the height and diameter of the trees over time. A similar trend of increase in tree height and tree diameter with increasing age of forest regeneration was reported by Aweto (1981a), Marin-Spiottal *et al*. (2007) and Raphael *et al*. (2010). This indicates that secondary forest is capable of regenerating to mature forest level if left undisturbed for a long period of time.

Table 5.3: Tree height per 5m square quadrant per sample plot in meters

Sample	Fallow age categories			
Plots	1-year	5-year	10-year	Mature forest
1	1.80	4.07	6.45	8.45
2	1.77	4.21	6.33	8.02
3	1.79	4.19	6.39	9.25
4	1.77	4.20	6.47	8.94
5	1.74	4.19	6.44	8.43
6	1.65	4.21	6.46	8.79
7	1.79	4.21	6.46	8.77
8	1.64	4.20	6.41	8.63
9	1.68	4.17	6.43	9.21
10	1.75	4.19	6.38	8.64
Mean	1.74	4.18	6.44	8.71
S.D	0.06	0.04	0.04	0.37

S.D = Standard deviation

Source: Author's fieldwork

Table 5.4: Mean tree diameter (in cm) per sample plot

Samples	Fallow age categories			
	1-year	5-year	10-year	Mature forest
1	2.4	5.3	8.2	20.4
2	1.2	4.5	9.6	18.6
3	0.9	5.3	8.8	17.4
4	0.7	4.8	9.3	20.2
5	0.6	4.3	9.3	24.0
6	1.1	4.6	10.3	22.2
7	0.9	4.4	8.6	23.6
8	0.8	4.7	8.2	19.9
9	0.3	4.9	9.7	19.6
10	1.4	4.7	9.5	20.8
Mean	1.03	4.75	9.23	20.67

5:2.5 Basal Area

The basal area of trees is the cross-sectional area of a tree's trunk at 1.3 meters above the ground, which is approximately chest height. The basal area is used to determine the volume of trees, the productivity of the forest and competition between trees for resources. Table 5.5 shows the mean basal area of tree per hectare for each of the fallow categories and the mature forest. There is a rapid increase in the tree basal area after the fifth year of fallow. The mean values of the tree basal area of the 1-year, 5-year and 10-year fallow and for the mature forest are 0.16 m^2, 2.76 m^2, 18.21 m^2 and 72.99 m^2 per hectare respectively.

With the exception of the difference between the means of the basal area of the 1-year and the 5-year old secondary forests which is not significant at $p = 0.05$, the differences between the means of tree basal area between all the other forest categories are significant at $p< 0.05$ of the F statistics and the Least Significant difference comparison of means.

A large increase in tree basal area with increasing age of secondary forest was noted. The values are similar to the range given for many tropical and subtropical forests (e.g. Brown and Lugo 1984). The higher tree basal area of the mature forest than the 10-year secondary forest despite the higher tree density of the latter is as a result of the higher tree diameter of the trees in the mature forest.

5:2.6 Vegetation Biomass

The standing biomass in the successional communities and the mature forest increased significantly ($P<0.05$) with increasing age of the fallows, reaching a maximum of 349.02 tons per hectare in the mature forest (Table 5.6). Herbs accounted for some 90 % of the biomass in the 1-year fallow while trees and shrubs accounedt for more than 90 % of the biomass of the 10-year fallow and the mature forest.

The mean values of the total abov- ground biomass per hectare for the 1-year, 5-year and 10-year fallows and for the mature forest are 5.11 tons, 30.14 tons, 74 tons and 349.02 tons respectively. There is a pronounced difference between the mature forest and the oldest secondary forest (10-year fallow). Although the density of tree is higher in the 10-

Table 5.5: Mean basal area per sample plot (m^2ha^{-1}) plots

Plots	Fallow age categories			
	1-year	5-year	10-year	Mature forest
1	0.36	4.24	15.32	78.47
2	0.05	4.07	20.26	73.94
3	0.03	2.82	17.64	49.49
4	0.05	3.47	20.38	69.23
5	0.01	1.74	23.24	95.04
6	0.03	1.86	22.50	69.68
7	0.33	1.23	16.27	87.49
8	0.28	2.22	13.73	63.37
9	0.26	3.32	22.17	69.40
10	0.18	2.64	20.56	74.76
Mean	0.16	2.76	18.21	72.99
S.D	0.14	1.01	3.27	12.53

S.D = Standard deviation

Source: Author's fieldwork

Table 5.6: Estimated Above-ground biomass per sample plot (converted to tons per hectare)

Plots	Fallow age categories			
	1-year	5-year	10-year	Mature forest
1	5.9	30.52	59.16	364.69
2	5.51	30.40	76.94	326.15
3	4.58	29.76	67.63	251.78
4	5.44	29.51	79.12	340.40
5	4.74	35.12	89.80	440.65
6	4.0	24.64	89.22	336.87
7	4.34	29.96	63.06	422.01
8	5.04	30.42	52.81	300.79
9	5.50	30.83	85.54	351.55
10	6.05	30.27	78.71	355.26
Mean	5.11	30.14	74.00	349.02
S.D	0.68	2.50	12.91	54.30

S.D = Standard deviation

Source: Author's fieldwork

year fallow than the mature forest (7.1 and 5.42 trees per 5 meter square respectively), the mature forest above ground biomass is 4.72 times greater than the 10-year fallow. This suggests that compared to tree density, tree basal area and tree height are better indicators of vegetation biomass.

The values reported for aboveground biomass in the study fall within the range reported in the literature for tropical areas (e.g. d ‘Olivera 2011, Kennard 2002, Feldspauch et al 2005, Toky and Ramakrishnan 1983). Guriguata and Ostertag (2005) reported that the success rate of secondary forest regeneration depends on a multitude of factors, including prior land use, available seed source, and soil fertility. While early secondary succession can be fast, with biomass accumulations estimated up to 25-50 t/ha on 5-year old-sites, and up to 75-150 t/ha on 15-year sites throughout tropical Amazon basin (Neeff 2005). Silver *et al*. (2000a) found that overall aboveground biomass had significantly faster biomass accumulation during the first 20 years of succession (6.17 Mg ha^{-1} yr^{-1}) than subsequent 60 years. Nonetheless, tropical forests generally show relatively fast aboveground growth, up to 70 % of mature forest height and basal area can be reached in 25 years, as observed on prior agricultural land in dry Bolivian forests (Kennard, 2002).

5:2.7 Nutrient Concentrations in Above-ground Biomass

The concentrations of nitrogen, phosphorus and magnesium declined with fallow age, with an average reduction of 23.6 %, 55.9 % and 49.3 % in foliage nitrogen, phosphorus and magnesium respectively from the 1-year fallow to the mature forest foliage biomass. Similarly the concentrations of nitrogen, phosphorus and magnesium in wood biomass decline by 47 %, 75 % and 57.5 % respectively from the 1-year to the mature forest. Compared to wood, concentration of nitrogen is 4.9 times, 5.8 times, 7.5 times and 7 times more in the foliage biomass than the wood biomass in the 1-year, 5-year and 10-year fallows and for the mature forest respectively. The concentration of phosphorus in the foliage biomass is 2.8 times, 2.5 times, 3.2 times and 5 times more than in the wood biomass of the 1-year, 5-year and 10-year fallows and the mature forest respectively. For magnesium, the concentration is 2.4 times, 4.3 times, 4.2 times and 3.3 times higher in the foliage biomass than the wood biomass of the 1-year, 5-year and 10-year fallows and the mature forest respectively.

The concentration of calcium in the foliage biomass decreases with fallow age (see table 5.7). The mean values of the concentrations of calcium for the 1-year, 5-year and 10-year old fallows and for the mature forest are 9.18, 8.38, 5.81 and 5.16 g/kg respectively. While the corresponding values for the wood biomass are 4.09, 2.06, 4.32 and 2.46 g/kg for the 1-year, 5-year and 10-year fallows and for the mature forest respectively. The concentrations of calcium in the foliage biomass are higher than those of the wood biomass in all the fallow categories and the mature forest.

The values reported for calcium concentration in foliage and wood biomass in this study fall within the reported range in the literature. Feldspauch et al. (2010) reported calcium concentration (in g/kg) of 7.25, 6.42, 5.28, 6.59 and 7.86 for the foliage of 0-2, 2-4, 4-6, 6-8 and 12-14 years old fallow regenerating from degraded abandoned pasture in Brazil, while for wood biomass he reported the calcium concentration (g/kg) of 4.05, 2.76, 2.01, 2.33 and 2.51 for 0-2, 2-4, 4-6, 6-8 and 12-14 years old fallows respectively.

The sodium concentrations of wood and foliage biomass decrease with increasing age of fallows up to the tenth year of fallow and increase in the mature forest relative to the 10-year fallow. The mean values of the concentration of sodium for the 1-year, 5-year and 10-year fallow and for the mature forest are 0.54, 0.32, 0.27 and 0.3g/kg respectively for foliage biomass while the corresponding mean values for the wood biomass are 0.19, 0.13, 0.09 and 0.1g/kg for the 1-year, 5-year, 10-year fallows and the mature forest respectively. The concentration of sodium is higher in the foliage than the wood in all the fallow categories and the mature forest.

The concentration of potassium in the foliage increases with increasing age of fallow a trend which is opposite of those of the other elements discussed previously. In the wood biomass the concentration of potassium increases with age up till the tenth year of fallow and declines insignificantly in the mature forest. The mean concentrations of potassium in the foliage biomass are 2.3, 3.03, 3.13 and 3.22 g/kg for the 1-year, 5-year and the 10-

Table 5.7: Mean nutrient concentrations in foliage and wood biomass (in g/kg) in fallows in different stages of regeneration

Fallow categories	Nutrients (g/kg)					
Foliage	N	P	K	Ca	Mg	Na
1-year	17.07	1.02	2.30	9.18	6.15	0.54
5-year	16.55	0.64	3.03	8.38	5.21	0.32
10-year	15.19	0.55	3.13	5.81	5.09	0.27
Forest	13.04	0.45	3.22	5.16	3.61	0.30
Overall mean	15.46	0.67	2.92	7.13	5.02	0.36
Wood						
1-year	3.51	0.36	1.51	4.09	2.59	0.19
5-year	2.87	0.26	2.24	2.06	1.22	0.13
10-year	2.02	0.17	2.34	4.32	1.20	0.09
Forest	1.86	0.09	2.19	2.46	1.10	0.10
Overall mean	2.57	0.22	2.07	3.23	1.53	0.13

*Each mean nutrient concentration value represents n=5 samples of ten tree composite in each fallow.

Source: Author’s fieldwork

year fallow and for the mature forest respectively. While the mean concentrations of potassium in the wood biomass for the 1-year, 5-year and 10-year fallows and for the mature forest are 0.19 g/kg, 0.13 g/kg, 0.09 g/kg and 0.10 g/kg respectively. The concentration of potassium is higher in the foliage than wood in all the fallow categories. Marin-Spiottal *et al*. (2007) and Feldspauch *et al*. (2010) reported higher concentration of potassium and phosphorus in foliage biomass than wood biomass. 2.75 g/kg-5.59 g/kg for foliage biomass potassium concentration was reported by Feldspauch *et al*. (2010), while for wood biomass, they reported potassium concentration of 1.19 g/kg-2.23 g/kg.

The concentrations of nutrients in the foliage biomass are ranked in the order of N>Ca>Mg>K>P>Na in all the fallow categories and the mature forest. The order of rank of the concentrations of nutrients in the wood biomass in the 1-year fallow is Ca>N>Mg>K>P>Na, that of the 5-year fallow is ranked in the order of N>K>Ca>Mg>P>Na, the 10-year fallow nutrient is ranked in the order of Ca>K>N>Mg>P>Na while for the mature forest the nutrient content of wood is ranked in the order of Ca>K>N>Mg>Na>P.

5:2.8 Nutrients Stored in Aboveground Biomass Foliage and Wood Biomass

Table 5.8 shows the mean of the various nutrients elements stored in foliar biomass and wood biomass for the various fallow categories.

The quantity of elements in the aboveground biomass increased with the age of the secondary forests. Leaves and twigs (foliage) contained a higher proportion of nitrogen (57.2 %) than wood in the first year (Table 5.8). Generally in the first year of fallow the leaves and twigs (foliage) contained 44.6 % of the total nutrients stored in the aboveground biomass of the 1-year fallow while the wood biomass contained 55.4 % of the total nutrient immobilized by the aboveground biomass of the 1-year fallow. In the 5-year fallow 44 % of the nutrient immobilized by the aboveground biomass are stored in the foliage while 56 % are stored in the wood biomass. However, the proportion of nitrogen stored in the foliage of the 5-year fallow is greater than the proportion of nitrogen in the wood biomass. In the mature forest, 75.3 % of the nutrients immobilized by the aboveground biomass are stored in the wood biomass while 24.7 % are stored in the leaves and twigs. This shows that the proportion of nutrients in foliage biomass to that in wood biomass decreased with increasing age of secondary forests.

Feldspauch *et al*. (2010), reported decrease in the proportion of nutrients in foliage biomass to that in wood biomass with increasing age of secondary forest regenerating from degraded abandoned pasture in Brazil.

The nutrients stored in the aboveground biomass are ranked in the order of N>Ca>Mg>K>P>Na in the 10-year fallow, and N>Ca>K>Mg>P>Na for the 5-year fallow, Ca>N>K>Mg>P>Na for the l0-year fallow and N>Ca>K>Mg>P>Na for the mature forest. Nitrogen and calcium are the nutrients that are mostly immobilized by the aboveground biomass in all the fallow categories and the mature forest, while sodium and phosphorus are the least immobilized by the aboveground biomass.

The quantity of nutrients immobilized by the aboveground biomass of the mature forest is 3.3 times greater than that of the 10-year fallow. This shows that the mature forest immobilized more nutrients in the aboveground biomass than the younger fallows 1-year, 5-year and 10-year fallows.

The amount of nutrients stored in the aboveground biomass of the secondary forests and the mature forest studied in this work fall within the range reported in the literature for other tropical and subtropical forests. Some values reported in the literature are shown in table 5.9 below.

The quantity of phosphorus and potassium in the aboveground biomass of the 10-year old fallow of this study are lower than those of the 10-year fallow following shifting cultivation reported by Toky and Ramakrishnan (1983) (Table 5.9) while the quantities of nitrogen, calcium and magnesium in this study are higher than the values reported for the aboveground biomass of the 10-year old secondary forests reported by Toky and Ramakrishnan (1983). Although, the quantity of potassium in the soil of a mature forest studied by Bernhard-Reversat (1976) in Cote d’Ivoir is more than 15 times higher than the quantity of potassium of the mature forest of this study (160 kg/ha as against 10.56 kg/ha for this study), the quantity of potassium in the aboveground biomass of this study is higher than the quantity of aboveground biomass of the mature forest studied by

Table 5.8: Quantities of nutrients stored in aboveground (foliage and wood) biomass for 1-year, 5-year, 10-year fallows and for a mature forest (kg/ha)

Fallow categories	Nutrients (kg/ha)					
Foliage	N	P	K	Ca	Mg	Na
1-year Foliage	18.89	0.98	2.50	10.00	6.67	0.59
1-year Wood	14.12	1.45	6.03	16.43	10.34	0.76
Total	33.01	2.43	8.53	26.43	17.01	1.36
5-year						
Foliage	83.91	3.24	15.46	41.19	26.41	1.62
Wood	71.96	6.52	56.16	51.79	30.59	3.25
Total	155.87	9.76	71.62	92.98	57.0	4.87
10-year						
Foliage	188.77	6.80	38.91	72.21	62.91	3.36
Wood	124.56	10.48	144.30	266.62	74	5.55
Total	313.33	17.28	183.21	338.83	136.91	8.91
Mature forest						
Foliage	410.88	14.28	102.17	163.83	114.51	9.52
Wood	594.5	28.56	697.15	780.52	350.23	31.73
Total	1005.38	42.84	799.32	944.35	464.71	41.25

Source: Author’s fieldwork

Table 5.9 Nutrients contents for some Tropical and Subtropical forests (in kg/ha) above-ground biomass

Forest type	Location	N	P	K	Ca	Mg	Na	Authors
Mature rainforest	Banco, Ivory Coast	1400	100	600	1200	530	-	Bernhard-Reversat, (1977)
40-year secondary forest	Kade, Ghana	1690	112	753	2370	320	-	Greenland and Kowal (1960)
1-year old secondary forest	India	30	10	40	10	20	-	Toky and Ramakrishnan (1983)
5-year old secondary forest	India	140	20	190	80	70	-	Op cit
10-year old secondary forest	India	190	30	540	160	90	-	Op cit
20-year secondary forest	India	490	60	138	440	230	-	Op cit
1-year old fallow	Orogun, Nigeria	33.01	2.43	8.53	26.43	17.01	1.36	This study
5-year old fallow	Orogun, Nigeria	155.87	9.76	71.62	92.98	57	4.87	This study
10-year old secondary forest	Orogun, Nigeria	313.33	17.28	183.21	338.83	136.91	8.91	This study
Mature forest	Orogun, Nigeria	1005.38	42.84	799.32	944.35	464.71	41.25	This study

Bernhard-Reversat (1976). Despite the fact that the aboveground biomass of the forest studied by Bernhard-Reversat (1976) is higher than the aboveground biomass of the mature forest of this study, the aboveground biomass of the mature forest of this study has more potassium.

The quantities of the other nutrients (nitrogen, phosphorus, calcium and magnesium) stored in the aboveground biomass of this study fall within the range reported by Bernhard-Reversat (1976), (Table 5.9). Similarly, though the secondary forest regenerating from degraded abandoned rubber plantation accumulation of aboveground biomass is more rapid than that of secondary forests following shifting cultivation, the secondary forests regenerating from abandoned plantation stored lesser nutrients in the aboveground biomass than secondary forests following shifting cultivation (Table 5.9).

It is often assumed that forest biomass is related to soil nutrient status; this study corroborates that assumption as revealed by the significant correlation between aboveground biomass and all the elements in the soil. However, this assertion should be taken with caution. It is noteworthy that, despite its huge biomass, the 10-year fallow has soils that have lower concentration of nutrients whilst the soils under the small aboveground biomass 5-year old secondary forest have comparatively high concentrations of soil nutrients probably due to rapid nutrient immobilization by the growing vegetation that is associated with transition from pseudo-woody fallow by the fifth year to woody secondary forest by the tenth year. In contrast the mature forests have comparatively higher aboveground biomass and soil nutrients than both the 10-year and 5-year old secondary forests. Many factors, including different patterns of regeneration, might influence forest biomass. A proportional relationship between soil nutrient concentrations and forest biomass would be more likely in young secondary forests (as long as other factors are not limiting) than in mature secondary forests with efficient nutrient cycling and long term nutrient accumulation in living matter from the soil and rainwater. This finding agrees with that of Ramakrishnan and Toky (1983), who reported rapid depletion of soil nutrients by the 10th year of fallow.

There is pronounced difference between the above-ground biomass of mature forest and the 10-year secondary forests sampled. This finding is consistent with those of Aweto (1981a), Lawrence and Foster, (2002); Toky and Ramarishnan (1983); Ewel (1976), Odum (1969) and Feldpausch *et al*., (2010).

Among the elements (nutrients) in the aboveground biomass, the concentration of potassium increases with the age of the secondary forests while the other elements show the reverse trend. The higher concentration of potassium in the older fallows and the mature forest aboveground biomass may be due to its fast accumulation by the tree species which replace the herbaceous species of the 1-year fallow. In the secondary forests studied here, nitrogen is predominant over other elements in aboveground biomass a trend which is consistent with that reported by Lawrence and Foster (2002), and Feldpausch *et al* (2010), but not in agreement with the finding of Toky and Ramakrishnan (1983) who reported the predominance of calcium over nitrogen.

With the development of the secondary forest, the amount of nutrients in the aboveground biomass increased due to a increase in biomass with age. A similar observation was made by Golley *et al*., (1975); Grubb and Edwards (1982), Toky and Ramakrishnan (1983) in India, Lawrence and Foster (2002), Feldspauch *et al* (2010) in Brazil.

The percentages of nutrients in the plant compartment of the total nutrients in the mature forest total ecosystem (nutrients in soil+nutrients in litterfall + nutrients in aboveground biomass) are nitrogen 49.3 %, phosphorus 95.4 %, calcium 87.7 %, magnesium 89.6 %, sodium 79.4 % and potassium 98.8 %. These results lend credence to the conventional idea of a tropical rainforest with about 90 % of the nutrient capital in the plants.

The high rate of nitrogen immobilization in vegetation without corresponding decrease in soil nitrogen storage over time in this study can be explained by at least two factors;

1 Atmospheric deposition, and

2 Addition through nitrogen fixing plants to the soil nitrogen stock

The rapid rate of nutrients immobilization in vegetation and decrease in soil exchangeable nutrients in this study indicates (1) soils inadequacy in replenishing immobilized nutrients from unavailable forms and/or (2) the vegetation is withdrawing more than it is returning nutrients to the soil. Vitousek and Sanford (1986), Schroth et al (2001) and Feldpausch *et al* (2010) opined that addition of nitrogen through nitrogen fixing plants and atmospheric deposition result in the increase of nitrogen in both the vegetation aboveground biomass and soil. The higher amounts of nutrients in the aboveground biomass (except total nitrogen) than the top 30cm reported in this study is consistent with the findings of Vitousek and Sanford (1986), Schroth *et al* (2001) and Feldpausch *et al* (2010), who reported higher amounts of nutrients in the aboveground biomass than the top 30 cm of the soil but inconsistent with that of Toky and Ramakrishnan (1983), who reported higher densities of nutrients in the top 40 cm of the soil than the vegetation.

Although only 21.3 %, 16.8 % 16.8 % and 9.1 % of the aboveground biomass of the 1-year, 5-year, 10-year old fallows and mature forest respectively are accounted for by the foliage biomass (leaves and twigs), this component of aboveground biomass contains 44.6 % of the nutrients in the aboveground biomass of the 1-year old fallow, 44 %, 33.4 % and 24.7 % of the nutrients in the aboveground biomass of the 5-year and 10-year old fallows and the mature forest respectively. In contrast, the wood biomass (bark + wood) which constitutes 78.7 %, 83.2 %, 83.2 % and 90.9 % of the aboveground biomass of the 1-year, 5-year and 10-year old secondary forest and the mature forest respectively, contains 55.4 %, 56 % 66.6 % and 75.3 % of the nutrients in the 1-year, 5-year and 10-year old fallows and the mature forest aboveground biomass respectively. In the event of clear felling, the nutrients in the foliage (branches and leaves) will be retained within the ecosystems, while that in the barks and wood) will be lost in the harvest. In real amounts the loss of 55.54 %, 56 %,66.6 % of the nutrients in the aboveground biomass of the 1-year, 5-year and 10-year old secondary forests in harvest is very substantial in each of the different age categories, for example, a clear felling of the vegetation with removal of the wood only will result in the removal of the following amounts of nutrients (in kg ha^{-1}) – nitrogen (124.5), phosphorus (10.5), potassium (144.3), calcium (266.6), magnesium (74) and sodium (5.6kg/ha) in the 10-year old secondary forests and the following amounts of nutrients in the 5-year old secondary forests – nitrogen (72), phosphorus (6.5), potassium

(56.2), calcium (51.8), magnesium (30.6) and sodium (3.3 kg/ha). These losses become noteworthy especially in the case of phosphorus and potassium in view of the very low level of these nutrients in the soil.

5.3 Changes in Vegetation Floristic in Secondary Forest Regeneration in Degraded Rubber Plantation

The floristic properties of vegetation discused in this subsection are: are abundance of dominant plant species, species diversity, number of plant species, and number of tree species

5.3.1 Abundance of Dominant Plant Species and Diversity of Plant Species

In the 1-year old fallow weeds and herbaceous species dominate the fallow. *Chromolena odorata* dominates the 1-year and 5-year fallow categories. In the one year fallow category C*hromolena odorata* has 100 % frequency of occurrence with density of 159500 per hectare, representing 94.63 % of the total density of the dominant species of plants in the 1-year old fallow. Other herbaceous species and weeds that are found in the 1-year fallow include *Elusine indica*, *Panicum maximum, Ageratum conyzoides,* and *Aspilia africana. Havea brasilliensis and Elaeis guineensis* survive in the one year old secondary forest as relics of past cultivation.

In the 5-year old secondary forest C*hromolena odorata* also dominates. *Chromolena odorata* has 100 % frequency of occurrence and density of 6000 per hectare in the 5-year old secondary forest (Appendix 5.1*)* and accounts for 71.89 % of the total density of the dominant plant species in the 5-year old secondary forest. Other dominant species in the 5-year fallow are small woody plants, shrubs and trees. They include *Maesobotrya barteri, Cnetis feruginea*, *Pentaclethra macrophylla*, *Baphia nitida, Blighia sapida, Antiaris toxicaria, Anthonatha macrophyla, Purshia tridenta, Lecaniodiscus cupaniodes, Microdesmis puberula*, *Elaeis guinensis*, *Hevea brasiliensis*, *Triplochiton scleroxylon, Macaranga barteri*, *Harungana madagascariensis and Rauvolfia vomitoria.*

In the 10-year old secondary forest, *Anthonata macrophylla* is the most dominant plant species. *Anthonata macrophylla* has 100 % frequency of occurrence and density of 1440 trees per hectare in the 10-year fallow and accounts for 57.54 % of the total densities of the dominant plant species. Other species found in the 10-year fallow are *Berlinia grandiflora, Albizia adianthifolia, Nauclea dederrichii, Triplochiton scleroxylon, Scottellia coriacea, Milicia excelsa and Funtumia elastica*. Apart from these species, all the other tree species, woody plants and shrubs found in the 5-year fallow are also found in the 10-year old secondary forest.

The mature forest is very diverse in tree species. No species of plant has up to 24 % of the total density of the dominant species of plants. The following tree species are confined to the mature forest *Piptadeniastrum africanum, Cleistopholis patens, Celtis africana, Sterculia tragacantha, Ricinodendron heudelotti and Alstonia boonei*. With the exception of *Rauvolfia vomitoria, Harungana madagascariensis, Lecaniodiscus cupaniodes, Microdesmis puberula and Cnetis feruginea* all the other plant species found in the 10-year old secondary forest are also found in the mature forest.

Some species do not have clear-cut affinity with any stage of secondary forest regeneration. Such species include *Maesobotrya barteri, Elaeis guineensis, Triplochiton scleroxylon* which are found in all the categories of secondary forest and in the mature forest. Some species are confined to the younger secondary forest; they include *Chromolena odorata, Elusine indica, Panicum maximum and Ageratum conyzoides, Cnetis fegruginea, Lecaniodiscus cupaniodes, Microdesmis puberula, Macaranga barteri, Harungana madagascariensis and Rauvolfia vomitria* are confined to the 5-year old and 10-year old secondary forests.

5.3.2 Number of Plant Species

The total number of plant species increased gradually during the course of secondary forest regeneration. The mean number of plant per sample plot is 24.4, 35.7, 42.5 and 53.0 (Table 5.10) for 1-year, 5-year, 10-year fallows and primary forest respectively. These results suggest that number of plant species increases with the progress of the succession. Significant differences exist between all the pairs of fallow categories, and between each of the fallow categories and the mature forest in terms of number of plant species (N = 40, F = 29.53, P = 0.001; p values for mean comparison ranged from 0.028 to 0.001).

The difference between the number of plant species of the 5-year old regrowth fallow and the 10-year old fallow is significant at p = 0.05, while the differences between all the other pairs of fallows and between each of the fallow categories and the mature are significant at p = 0.01 Least Significant Mean comparison (Appendix 5.2).

5.3.3 Number of Tree Species

Table 5.11 shows the number of tree species per sample plot. The number of tree species increase with the age of the secondary forest. The mean number of tree species per sample plot for the 1-year, 5-year and 10-year fallows and the mature forest are 1.2, 13.6, 15.2 and 23.4 respectively. The increase in the total number of plant species and tree species with the age of the secondary forest may be due to the invasion of some plant and tree species to the older fallows and the mature forest later in the successional sequence.

The mean number of tree species varies significantly between the 1-year old fallow and the other fallow categories (5-year old and 10-year old fallows), and also between the 1-year old fallow and the mature forest (significant at p =0.001 of mean comparison). Similarly, the variations in the number of tree species are significant between the mature forest and 10 year old fallow and between the mature forest and the 5-year old fallow at p = 0.05 and p = 0.001 (of Least significant mean comparison) respectively, while the variation in the number of tree species is not significant between the 5-year fallow and the 10-year old fallow (see appendix 5.2).

Although, there were no visible environmental differences among the studied secondary forest (e.g., water availability, climate, aspect and topography), the result of the census of the total number of tree species and total number of plant species in each fallow categories and in the mature forest indicate that after the degradation and abandonment of the rubber plantation and the subsequent colonization of the area occupied by the rubber plantation by secondary forest, significant linear increase in the total number of plant species and total number of tree species occur.

Table: 5.10: Total number of plant species per sample plot

Plots	Fallow age categories			
	1-year	5-year	10-year	Mature forest
1	22	39	38	56
2	26	36	53	62
3	22	30	47	64
4	18	35	49	46
5	33	34	48	52
6	26	38	35	42
7	24	36	40	52
8	28	34	39	54
9	23	37	43	49
10	22	38	37	52
Mean	24.4	35.7	42.5	53
S.D	4.12	2.63	6.03	6.67

S.D = Standard deviation

Source: Author's fieldwork

Table 5.11: Number of tree species per sample plot

Sample	Fallow age categories			
	1-year	5-year	10-year	Mature forest
1	1	13	18	27
2	1	11	10	22
3	1	15	16	21
4	1	13	14	21
5	1	17	11	25
6	2	14	18	21
7	1	13	19	26
8	1	14	17	22
9	2	12	21	27
10	1	14	18	22
Mean	1.2	13.6	15.2	23.4
S.D	0.4	1.6	3.5	2.5

S.D = Standard deviation

Source: Author's fieldwork

This finding is consistent with what was reported by Aweto (1981) for Ijebu Ode area of South-western Nigeria, and those reported by Feldspauch *et al*. (2005), d 'Oliveira *et al*. (2011). In plantation agriculture of rubber, when a forest is converted to cultivable land, not only is its original forest destroyed, but the site is subjected to continued perturbations due to introduction of rubber tree and its concomitant shading of the undergrowth, soil nutrient depletion during the harvest of rubber latex and annual bush fire. These result in a progressive reduction in the total number of tree species and plant species and consequently early colonizing secondary forest after the degradation of rubber plantation and its subsequent abandonment, contain few species but the number increases gradually as the secondary forest community develops.

5.3.4 Species Diversity

Species diversity is very low in the first year; it increased considerably by the 5th year and showed further but less increase (when compared to the rate of increase between 1-year and 5-year fallows) in the tenth year and also in mature forest (Table 12). By the 5th year of forest regeneration the secondary forest has reached 96.48 % of the level of species diversity of the mature forest. Conversely, dominance was maximal in the early phases of succession and decreased sharply with the age of fallow. The index is computed using Simpson's formula. The mean species diversity indices per sample plot for the 1-year, 5-year, and 10-year fallow and for the mature forest are 36.71 %, 68.88 %, 71.30 % and 71.39 % respectively.

Though significant differences exist between the 1-year old fallow and all the other fallow categories (5-year and 10-year fallows) at p = 0.05 of Least significant mean comparison of the mean of plant species diversity, no significant difference was observed between the mean of the five year and 10-year old fall and between the mean of the 5-year old secondary forest and the mature forest at p = 0.05. Similarly, species diversity is not significantly different between the mature forest and the 10-year old fallow.

Table 5.12: Mean Species Diversity per Sample Plot

Sample	Fallow age categories			
	1-year	5-year	10-year	Mature forest
1	33.30	61.34	71.22	73.20
2	38.03	58.11	74.13	70.65
3	32.71	72.63	73.24	72.33
4	31.52	73.20	74.45	70.76
5	32.08	68.14	72.36	72.73
6	43.39	71.24	70.14	71.19
7	41.75	69.17	73.23	63.36
8	37.14	74.31	69.91	71.42
9	38.51	72.15	71.19	72.01
10	38.62	68.54	63.10	71.21
Mean	36.71	68.88	71.30	71.39

Source: Author's fieldwork

The diversity of plant species stabilizes by the 10th year of secondary forest regeneration- a trend which is consistent with what was reported by Aweto (1981a) but incongruous with what was reported by Toky and Ramakrishnan (1983). Aweto (1981a), reported stabilization in species diversity by the 7th year of forest succession while Toky and Ramakrishnan reported continuous increase in species diversity beyond the 15th year of fallow regeneration. A multiplicity of strategy is adopted by successional species among which stump, root and rhizome sprouts and invasion through seeds are frequent. The relative importance of different plant species and their strategies could vary depending upon the length of the farming period, the species composition and the structure of the vegetation before they were cleared for cultivation, and the previous land use history. In secondary forests under 5 years of regeneration from soils that were subjected to decades of intensive monocultural cultivation of rubber (*Hevea brasiliensis*) as in the present case, *Chromolaena odorata* is the predominant component of the secondary forest. The production of large number of seeds, which are light in weight and wind dispersed, aids it to thrive as an early invader. The significance of this was emphasized by Hayashi and Numata (1968) and Raynal and Bazzaz (1973), while Salisbury (1942), stressed that species with lightweight, highly mobile seeds, often colonize highly perturbed ecosystems whereas species with heavier seeds are often animal disseminated and usually enter the secondary forest at a later stage. This early species adopts an exploitative strategy (Grime, 1974); are able to achieve dominance in fields that are temporarily with nutrients and radiant energy (Toky and Ramakrishnan 1983). This suggests that if the five-year fallow period as is presently practiced in the study area is continued the regeneration of the secondary forest to a mature forest with diverse tree species will be arrested at the weed stage with *Chromolaena odorata* dominating the community. In the early stage of secondary forest regeneration herbaceous plants and forbs dominates the spatial structure but are eventually replaced by woody species such as *Albizia adianthifolia, Antiaris toxicaria, Anthonata macrophyla, Balphia nitada,* and *Pentacletra macrophyla* as the secondary forest becomes older. This suggests that if secondary forest regenerating from degraded abandoned rubber plantation is left long enough to fallow it is capable of regenerating to mature forest and performing both the environmental and non environmental functions being performed by mature forest.

5:4 LITTERFALL

The total annual production of litter increased significantly with the age of the fallow. The values for the total annual litterfall for the 1-year, 5-year and 10-year fallows and for the mature forests are 1114.9 kg/ha^{-1}year^{-1}, 7146.8 kg/ha^{-1}year^{-1}, 11184 kg/ha^{-1}year^{-1} and 11324 kgha^{-1}year^{-1} respectively (Table 5.13). All differences between the fallows are significant ($P<0.001$) Also the differences between the younger fallows (1-year and 5-year fallows) and the mature forest were significant, while the difference between the 10-year fallow and mature forest was not significant ($P<0.05$). *Chromolena odorata* contributed more than 90% of the total litter in the 1-year old fallow. In the 5-year fallow about 60% of the litter produced came from C*hromolena odorata,* while *Maesobotrya barteri, Pentaclethra macrophylla, Baphia nitida and Antiaris toxicaria* contributed the remaining 40% of the litter produced in the 5-year fallow.

Litter from trees increased with fallow age and accounted for about 70 % and 90 % in the 10-year old fallow and mature forest respectively. In the 10-year fallow *Anthonota macrophylla* contributed about 58 % of the litter produced while *Berlinia grandiflora, Albizia adianthifolia, Nauclea dederichii and Pentaclethra macrophylla* contributed the remaining parts of the litterfall. In the mature forest, *Milicia excelsa, Alstonia boonei, Maesobotrya barteri, Nauclea dederichii, Baphia nitida* and *Pentaclethra macrophylla* were the sources of litterfall.

The quantity of litter produced in the fallows reached 98.8 % of the values of litter produced in the mature forest by the tenth year. Tree cover seems to play a significant role in influencing the dynamics of litter production than tree density. Litter production follows a pattern that is akin to that of tree cover (Tables 5.1 and 5.13 above) in the fallows. In the 1-year fallow the litter produced is exclusively accounted for by leaf litter,

Table 5.13: Mean total annual litterfall (kg/ha)

Sample	Fallow age categories			
	1-year	5-year	10-year	Mature forest
1	81.10	385.0	639.3	470
2	70.3	342.3	624.40	385
3	83.0	424.50	817.4	490.9
4	71.4	346.1	602.6	391.7
5	72.8	400.3	732.9	631.1
6	83.0	352.3	650.2	504.8
7	92.9	398.1	708.0	560.8
8	167.2	796.2	1032.7	1123.2
9	204.2	851.8	1197.3	1912.0
10	82.6	1439.1	2404.8	3092.1
11	42.8	996.2	1093.1	1201.3
12	63.6	414.9	681.7	561.1
Total	1114.9	7146.8	11184	11324

Each sample is a mean of collection from 10 litter traps

Source: Author's fieldwork

Table 5.14: Annual litterfall ± 95% confidence limits (Gm^{-2}year^{-1}) in successional communities in Orogun, developed in secondary forest regenerating from degraded abandoned plantation

Litter types		Fallow categories		
	1-year	5-year	10-year	Mature forest
Leaves	111.49 (100%)	645.99 (90.4%)	970.15 (86.7%)	916.79 (80.8%)
Twigs	-	68.69 (9.6%)	147.85 (13.2%)	215.6 (19.2%)
Total	111.49	714.68	1118.4	1132.4

Source: Author's fieldwork

there was no input from twigs. Leaves accounted for 90.39 %, 86.78 % and 80.96 % of the litter produced in the 5-year fallow, 10-year fallow and the mature forest respectively while twigs accounted for 9.61 %, 13.22 % and 19.4 % of the litter produced in the 5-year old fallow, 10-year old fallow and mature forest respectively (Table 5.14). The proportion of twigs contributed to the litterfall in the mature forest is 31.42 % greater than that of the oldest fallow (10-year fallow). This implies that twigs fall contributed a significant larger proportion to the total litterfall in the mature forest than the fallow.

Percentage leaf litter decreased from 100 % in the 1-year old fallow to 86.78 % and 80.96 % in the 10-year old fallow and mature forest respectively while that of twigs increased from 0 % in the 1-year fallow to 13.22 % and 19.04 % in the 10-year fallow and mature forest respectively.

The total litterfall and the percentage contribution of the different litter fractions (leaves and twigs), obtained in this study fall within the range reported for other tropical lowland rainforests (Bernhard 1970; John 1973; Songwe *et al.* 1988, 1995; Odiwe and Muoghalu 2003; Christopher *et al*. 2004; Owusu-Seykere *et al*. 2006; Ostertag *et al*. 2011; Toky and Ramakrishnan 1983; total litter fall 9.1 – 14.1 t ha-yr-1, leaf 61 – 81%, wood 10 – 38%, reproductive 4 – 12%).

The total litterfall in the mature forest and the 10-year old fallow was surprisingly similar (11.2 t ha^{-1}year^{-1} in the 10-year old secondary forest and 11.47 t ha^{-1}year^{-1} in the mature forest) in view of the large differences between the mature forest and 10-year old fallow in aboveground biomass and the physicochemical properties of their soils. The similar values of litter production in the mature forest and the 10-year old fallow in this study may be due to the fact that in the 10-year old secondary forest, a number of tree species are deciduous, while in the mature forest many tree species are evergreen. The fact that the total litterfall in the mature forest and the 10-year old secondary forest is nearly equal reinforces the assertion by Proctor *et al.,* (1983) that litterfall is not closely related to ecosystem nutrient status.

The highest measured litterfall value in lowland tropical forests (excluding plantations) is that for *Macrolobium* forest in Zaire where Laudelout and Meyer (1954), recorded 15.3 t $ha^{-1}year^{-1}$. Four African studies have shown higher litterfall values: 12.4-15.3 t $ha^{-1}year^{-1}$ for four forests in Zaire (Laudelout and Meyer 1954), 13.4 t $ha^{-1}year^{-1}$ in a forest in the Ivory Coast (Bernhard 1970); 12.45 t $ha^{-1}year^{-1}$ in a forest from Gabon (Hladink 1978), 12.45 t $ha^{-1}year^{-1}$ in a lowland secondary forests affected by fire in Ile-Ife (Muoghalu and Odiwe 2003). However, these values may be misleading since the authors do not give size limits for the twigs fraction (except Muoghalu and Odiwe 2003).

5.4.1 Seasonality of Litterfall

Total litter production showed a marked seasonal peak which coincide with a peak maximum temperature and low minimum temperature (i.e. period of low humidity) due to water stress at this period. In all the fallow categories and the mature secondary forest litter production is relatively stable throughout most of the year, at 6-8.5 g/m^2 /month in the 1-year fallow, 35-42.5 g/m^2/month in the 5-year fallow, 65-82 g/m^2/month in the 10-year fallow and 38-63.5 g/m^2/month in the mature forest (between May and December). Thirty three percent of total annual litter production in the 1-year fallow fell during the peak, between January and February and 54.5 % fell from December to April. In the 5-year fallow, 34 % of total annual litter production fell during the peak in January and February and 63 % fell from December to April. Thirty two percent of total annual litter production in the 10-year fallow fell during the peak in March and February while 58 % fell from December to April. Forty four percent of total annual litter production in the mature forest fell during the peak in March and February and 56 % fell from December to April. The least quantity of litter was produced in July in all the fallows categories while in the mature forest the least quantity of litter was produced in September. Minimum litter production coincided with the period of maximum rainfall.

The highest values of monthly litterfall in the 1-year, 5-year and 10-year fallows and for the mature forest are 20.42 g/m^2, 143.91 g/m^2, 240.48 g/m^2 and 309.21 g/m^2 respectively. While the corresponding values for the least monthly litterfall in each fallow category and the mature forest are 4.28 g/m^2, 34.23 g/m^2, 60.26 g/m^2 and 38.5 g/m^2 respectively

(Fig. 5.2). This shows that the fall of litter responded to seasonal drought from December to April (i.e. litterfall in the study area is strongly tied to the timing of precipitation). The total litterfall shows significant monthly variation in the mature forest and all the fallow categories and the mature forest.

In the mature forest monthly litter production increased eight fold in February at the peak of the dry season, while in the fallows it increased four fold in the dry season showing that litter production is more rapid in the dry season in the mature forest than the 1-year, 5-year and 10-year old fallows. The differences between the litterfall in the dry and rain season is significant at P<0.001 of the ‘T’ distribution for all the fallow categories.

The strong seasonality in the amount of litter fall, which is the highest amount during the dry season and lowest amount during the rain season, has been reported for West African tropical rain forest (Hopkins 1966; John 1973; Songwe *et al.*, 1988; Muoghalu *et al.* 1993, Odiwe and Muoghalu 2003, Owusu-Seykere *et al.*, 2006). Leaf litterfall is responsible for this because no other litter fraction showed significant monthly variation in litter fall in this study. Water stress and the deciduous habit of many tree species in this forest are probably responsible for the peak litterfall during the dry season (November – March) because there is little or no rainfall at that time and a low humidity. Therefore, the high evapotranspiration exceeds rainfall leading to water stress.

As to be expected the seasonality in the amount of litterfall, which is highest amount during the dry season and lowest amount during the rain season in all the secondary forests studied in this study, agrees with what was reported by other authors in West Africa tropical rain forest (Hopkins 1966; John 1973; Songwe *et al*., 1988; Muoghalu *et al*., 1993, Odiwe and Muoghalu, 2003). Water stress and the deciduous habit of many tree species in these secondary forests are probably responsible for the peak litterfall during the dry season (November – March) because the humidity and rainfall at this time is low. Therefore, the high evapotranspiration exceeds rainfall leading to water stress. Many deciduous species which occur in the secondary forests shed their leaves between December and March. They bring out new leaves (flush) with the onset of rain in April and attain full canopy leafiness between June and September. Some species are leafless by December. The high twig litter fall recorded in the mature forest is due probably to the absorption of water by dead branches on the trees during the rainy season which increases

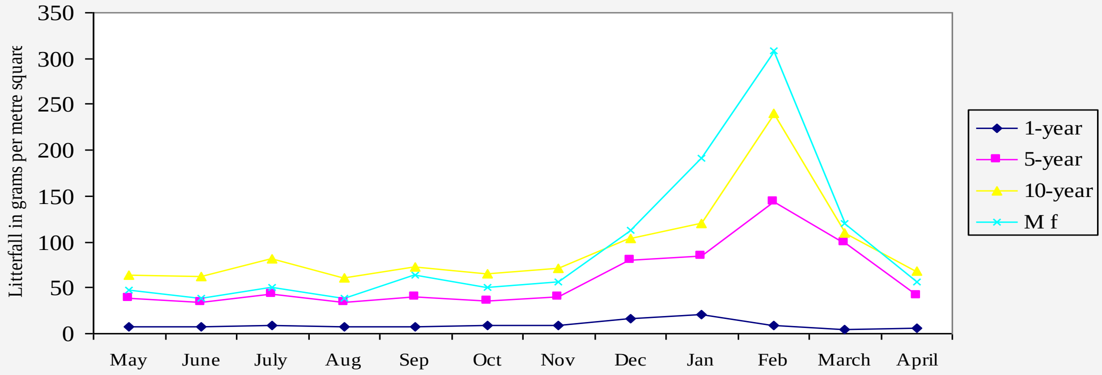


Fig. 5.2: Seasonality of Litterfall

their weight and their subsequent abscission and removal from crowns of trees by the force of the strong winds which accompany rains during the rainy season.

The increase in litterfall with increasing age of secondary forest supports the assertion of Chandrashekera and Ramakrishnan (1994) that litter production and nutrient cycling patterns are likely to change during succession and may be affected by the intensity of disturbance and age.

5.4.2 NUTRIENT CONCENTRATION IN LITTERFALL

The concentration of the nitrogen, calcium, potassium, magnesium, phosphorus and sodium in litterfall in the different fallow categories and the mature secondary forest changes over time and this is discussed below.

5:4.3 Nitrogen Concentration in Litterfall

The concentration of nitrogen in litterfall is highest in the 1-year fallow. The concentration of nitrogen in litterfall decreases with age. The average values of the concentration of nitrogen in the 1-year, 5-year and 10-year fallows and for the mature forest are 12.22 mg/g, 10.41 mg/g, 5.24 mg/g and 8.12 mg/g respectively. The difference between all the fallow categories and between the fallow categories and the mature forest (except between 10-year and mature forest) is significant ($P<0.05$). This shows that litter of the younger fallows is richer in nitrogen than the older fallow and the mature forest (Fig. 5.3).

Nitrogen dynamics followed trends in annual precipitation in all the fallows and mature forest. Nitrogen concentration increased significantly with increasing precipitation but the trend is not significant (Fig 5.3) for the 1-year fallow. The highest concentration of nitrogen in litterfall was experienced in September in the 1-year old fallows, 10-year old secondary forest and the mature forest and in August in the 5-year old secondary forest, while the lowest concentration of nitrogen was observed in February in all the fallows and the mature forest. This shows that nitrogen concentration in litterfall is tied to seasonal precipitation gradient (Fig. 5.3).

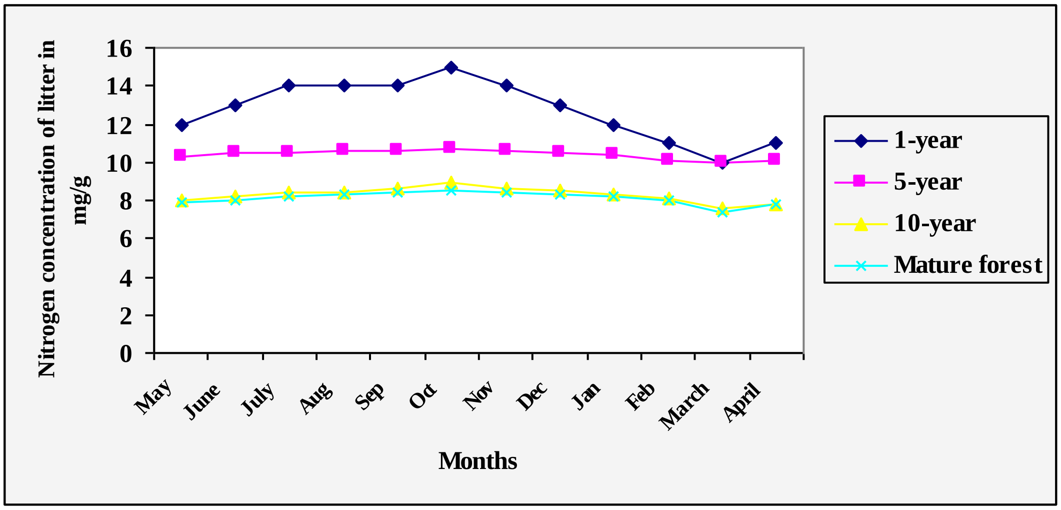


Fig. 5.3: Seasonal Changes in Nitrogen Concentration of Litter Produced by Secondary Forest of Different Age Categories and Mature Forest (mg/g)

The concentration of nitrogen in litterfall reported for this study is smaller than the range reported by Owusu-Seykere *et al*., (2006) (21 mg/g-21.77 mg/g) but fall within the range reported by Campo *et al*., (2007) 13.5 mg/g for dry season and 19.7 mg/g for rainy season in early successional fallow, and 13.9 mg/g for dry season and 22.7 mg/g for rainy season in the late successional fallow. Bernhard-Reversat *et al*., (1978) reported the concentration of 17.4mg/g in litterfall of a mature forest in Ivory Coast, Toky and Ramakrishnan (1983) reported nitrogen concentration of 8.75 mg/g for a 5-year old fallow and 8.73 for a 10-year old fallow in India. In the study by Julio *et al.,* the concentration of nitrogen in litterfall was higher in the rain season than in the dry season. Julio *et al.,* (2007), reported that the concentration of nitrogen in litterfall of the late successional fallow is higher than that of the early successional fallow, but this study shows the reverse and agree with what was reported by Owusu-Seykere *et al.* (2006), and Toky and Ramakrishnan (1983), that the concentration of nitrogen in litterfall is higher in the early successional fallows than the late successional fallows.

5:4.4 Concentration of Calcium in Litterfall

The concentration of calcium in litter decreases with the age of secondary forests. The average values of the concentration of calcium in the litterfall of the 1-year, 5-year and 10-year fallows and for the mature forest are 8.89 mg/g, 7.69 mg/g, 5.46 mg/g and 4.92 mg/g respectively (Fig. 5.4). The difference between all the fallow categories and between the fallow categories and the mature forest (except between the 10-year fallow and the mature forest) is significant at ($P<0.05$). This indicates that the youngest fallow litter is richer in calcium than the older fallows and the mature forest.

There is significant variation in the seasonal concentration of calcium in litter between the rainy and dry season for the mature forest but this variation is not significant for the 1-year old forest. The concentration of calcium in the litter produced in the study area is highest in October in all the categories of fallows and the mature forest while it is lowest in the month of February (Peak of the dry season) in all the fallow categories and the mature forest (Fig. 5.4)

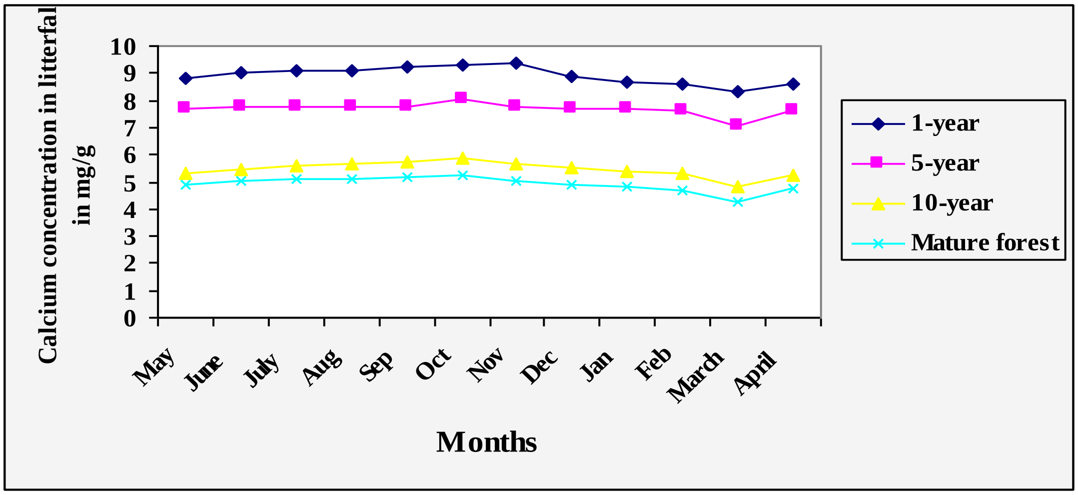


Fig. 5.4: Seasonal Changes in Calcium Concentration of Litter Produced by Secondary Forest of Different Age Categories and Mature Forest (mg/g)

This indicates that the concentration of the calcium in litter fall is higher in the rainy season than the dry season. The dynamics of litter calcium concentration followed trends in annual precipitation in all the fallows and the mature forest.

Owusu-Seykere *et al*., (2006), reported calcium concentration of 19.82 mg/g for a primary forest litterfall and calcium concentration of 15 mg/g for a secondary forest litterfall in Ghana are higher than the values reported in this study, while the values reported in this study fall within the range reported by Toky and Ramakrishnan (1983) for successional fallows in India (7.5 mg/g-5.21 mg/g). Nye and Greenland reported 19.56 mg/g for a 40-year old secondary forest in Kade Ghana.

5:4.5 Concentration of Magnesium in Litterfall

There is decline in the concentration of magnesium in litterfall with increasing age of secondary forest (Fig. 5.5). The mean values of the concentration of the magnesium for the 1-year, 5-year and 10-year fallows and for the mature forest are 5.99mg/g, 5.10mg/g, 5.01mg/g and 3.54mg/g respectively. The differences between all the fallow categories (except the difference between the 5-year fallow and the 10-year fallows) and between the fallow categories and the mature forest litter magnesium concentration are significant ($P<0.05$). The youngest fallow is richer in magnesium than the 5-year and the 10-year fallows and also the mature forest. The concentration of magnesium in litter declines gradually with increasing age of the fallow. The concentration of magnesium in the mature forest is just 59 % of the value of the mean concentration of magnesium in the 1-year fallow. This indicates that the younger fallows litter is richer in magnesium than the mature forest and the older fallows. Though, the concentration of magnesium in litter is higher in the rainy season in all the fallow categories and the mature forest, the seasonal variation in the concentration of magnesium in the litter is significant only for the 5-year and 10-year old secondary forests. The highest concentration of magnesium in litter is in October in all the fallow categories and the mature forest, while the lowest concentration of magnesium in litter is in March in all the fallow categories and the mature forest (Fig. 5.5). This indicates that the magnesium content of litter is higher in the rainy season than the dry season.

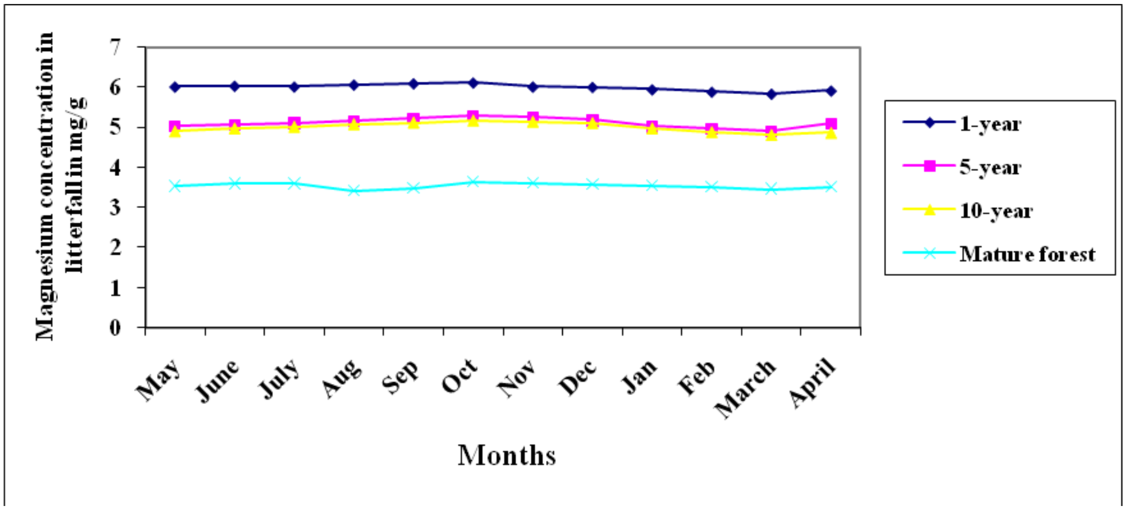


Fig. 5.5: Seasonal Changes in Magnesium Concentration of Litter Produced by Secondary Forest of Different Age Categories and Mature Forest (mg/g)

Higher magnesium concentration in litterfall in the rainy season than the dry season was reported in the literature by previous researchers (Proctor *et al.*, 1983, Morel to 1992, Muoghalu *et al.*, 1994 and Owusu-Seykere *et al.*, 2006). Magnesium concentration in ltterfall in this study is higher than what is reported by Klinge (1974), in Malaysia.

5:4.6 Concentration of Potassium in Litterfall

Just like all the other elements discussed earlier, the concentration of potassium in litterfall declines with increasing age of secondary forest. The mean values of the concentration of potassium in the litter of the 1-year, 5-year and 10-year fallows and for the mature forest are 7.91 mg/g, 7.07 mg/g, 7.19 mg/g and 6.57 mg/g (Appendix 5.11) respectively. The mature secondary forest has up to 83 % of the value of the mean concentration of potassium in the litter of the 1-year fallow. This indicates that the concentration of potassium in litter decreases with age but the rate of decrease is not as high as that of magnesium, which decreases to 59 % of the value of the 1-year fallow in the mature forest. The differences between all the fallow categories (except the difference between the 5-year and 10-year fallows) are significant ($P<0.05$). Also the differences between all the fallow categories and the mature forest are significant at ($P<0.05$).

Seasonal dynamics of potassium followed trends in annual precipitation in all the fallows and mature forest. For the 1-year old fallow the concentration of potassium dropped by 11.52 % in the dry season from the highest value of concentration of potassium observed in the rainy season (dropped from 8.25 mg/g in September to 7.30 mg/g in February). In the 5-year old secondary forest the concentration of potassium dropped from 7.32 mg/g in September (rainy season) to 6.82 mg/g in February (dry season). For the 10-year old secondary forest, the concentration of potassium dropped from 7.50 mg/g to 6.82 mg/g in March (dry season), representing a decrease of 9.7 %. Similarly, in the mature forest, the concentration of potassium dropped by 9.7 % in the dry season (it dropped from 6.82 mg/g in September to 6.28 mg/g in February). This indicates that the concentration of potassium in the dry season is lower than the rainy season. However, this seasonal variation in litter potassium concentration is not significant for the 1-year fallow. Figure 5.6 shows the seasonal variation of the potassium content of litter of the different fallow

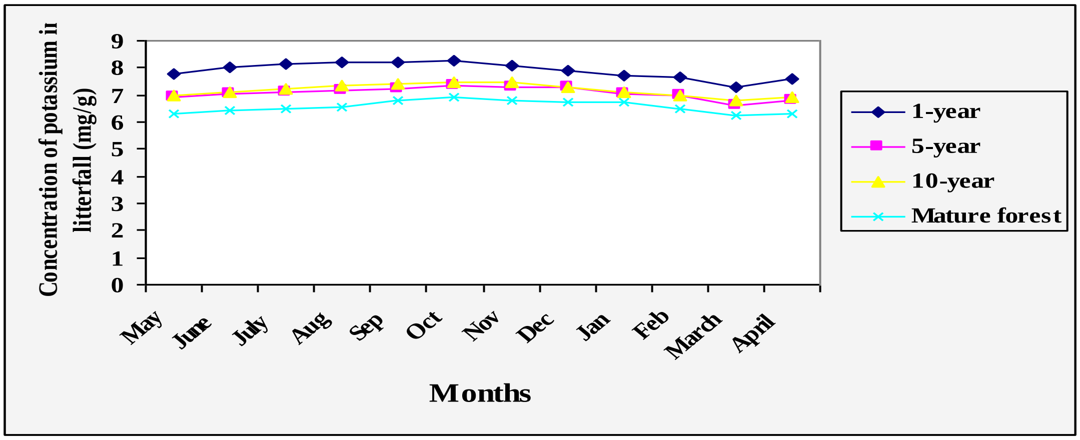


Fig. 5.6: Seasonal Changes in Potassium Concentration of Litter Produced by Secondary Forest of Different Age Categories and Mature Forest (mg/g)

categories and the mature forest. The highest concentration of potassium in litter is in September in all the fallow categories and the mature forest while the lowest concentration is in March for the 10-year old secondary forest and February for the other forest categories.

The values obtained were higher than 2mg/g, 2.2 mg/g, 5.2 mg/g, 4 mg/g and 5.6 mg/g previously reported by Ewel (1976) for a Guatemelia rainforest, Brasell *et al*. (1980) for an Australia rainforest, and Owusu-Seykere *et al*. (2006) for a Ghana primary rainforest and secondary forest respectively. Bernhard-Reversat *et al*. (1978) obtained 8.8mg/g for an Ivory Coast mature forest which is higher than the values obtained for this study. Nye and Greenland (1960) in Kade Ghana, *Brasell et al*. (1980) in Australia, Toky and Ramakrishnan (1983) in India, recorded 6.5 mg/g, 7.3 mg/g and 7.2 mg/g respectively for potassium concentration in litterfall, which fall within the values reported in this study.

5:4.7 Concentration of Phosphorus in Litterfall

The phosphorus content of litter decreases with increasing age of fallows. The decrease in the phosphorus content of litter is very rapid in the first five years of fallow, after which the decline becomes moderate. The mean values of the phosphorus content of litter are 0.98 mg/g, 0.49 mg/g, 0.40 mg/g and 0.37 mg/g for the 1-year, 5-year and 10-year fallows and for the mature forest respectively. Litter phosphorus concentration was reduced by 62.2 % of the mean value of the 1-year fallow in the mature forest (i.e. litter phosphorus content of the 1-year fallow is 62.2 % higher than that of the mature forest. The differences between all the fallow categories and between the fallow categories and the mature forest (except the difference between the 10-year fallow and the mature forest) phosphorus content of litter are significant at ($P<0.05$).

The phosphorus content of litterfall is higher in the rainy season than the dry season. The phosphorus content of litter is highest in August and September and lowest in February in the 1-year old fallow, 5-year old fallow and the mature forest (Fig 5.7). In the dry season, litter phosphorus concentrations were reduced by 32.7 %, 33.3 %, 32.6 % and

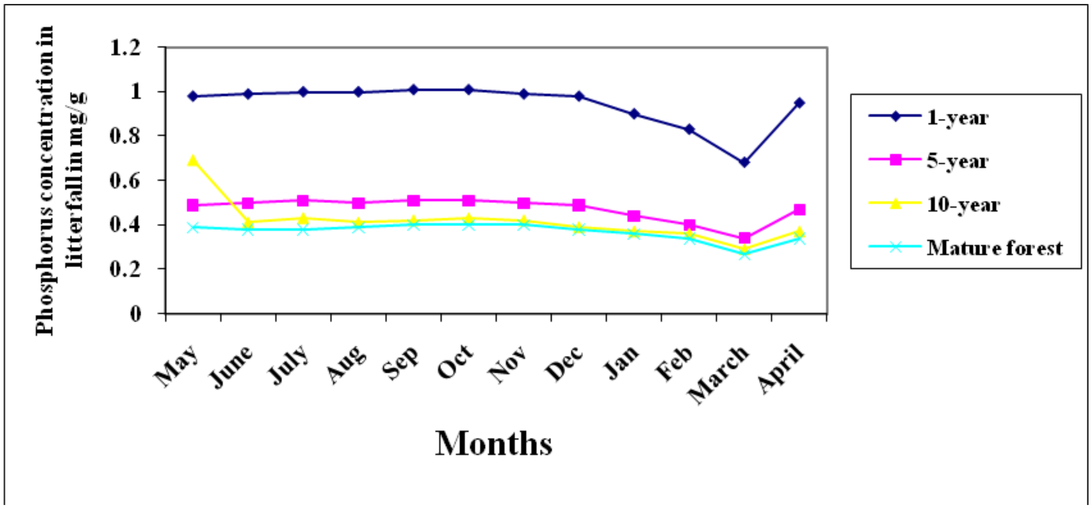


Fig. 5.7: Seasonal Changes in Phosphorus Concentration of Litter Produced by Secondary Forest of Different Age Categories and Mature Forest (mg/g)

32.5 % from the maximum observed in the 1-year, 5-year and 10-year fallows and the mature forest respectively. The seasonal variation in the phosphorus content of litterfall is not significant between the dry and rainy season for any of the secondary forest categories.

Julio *et al* (2007) recorded higher phosphorus concentration in the dry season than in the rain season, and this they attributed to the leaching of phosphorus from the leaves prior to litterfall in the rainy season. Owusu-Seykere *et al*. (2006) reported higher litterfall phosphorus concentration in the rain season than the dry season and higher concentration of phosphorus in the primary forest than the secondary forest.

5:4.8 Concentration of Sodium in Litterfall

Of all the elements studied sodium has the least concentration in litter. The sodium content of litter decreases with increasing age of fallows. The mean values of the sodium content of litter for the 1-year, 5-year, and 10-year fallows and for the mature forest are 0.47 mg/g, 0.24 mg/g, 0.18 mg/g and 0.15 mg/g respectively. This shows that the 1-year fallows litter sodium concentration almost triples the value of the mean litter sodium concentration of the mature forest. The differences between the fallow categories (except the differences between 5-year and 10-year fallows) are significant ($P<0.05$), while the differences between the mature forest and the fallows (except the difference between the 1-year fallow and the mature forest) are not significant ($P<0.05$).

In February (dry season) the sodium content of litter dropped by 12 %, 15 %, 20 % and 19% from the maximum observed in the 1-year, 5-year, 10-year fallows and the mature forest respectively. Though, there is seasonal variation in the sodium content of litterfall, the seasonal variation is not significant. Like the other elements discussed earlier the sodium content of litterfall is higher in the rainy season than the dry season (Fig. 5.8).

Most studies on litterfall nutrient dynamics did not consider the concentration of sodium in litterfall. However, the available data in the literature for the concentration of sodium in litterfall recorded 0.5 mg/g and 0.26 mg/g (Brasell *et al*., 1980) for some Australian rainforests which are within the range observed in this study.

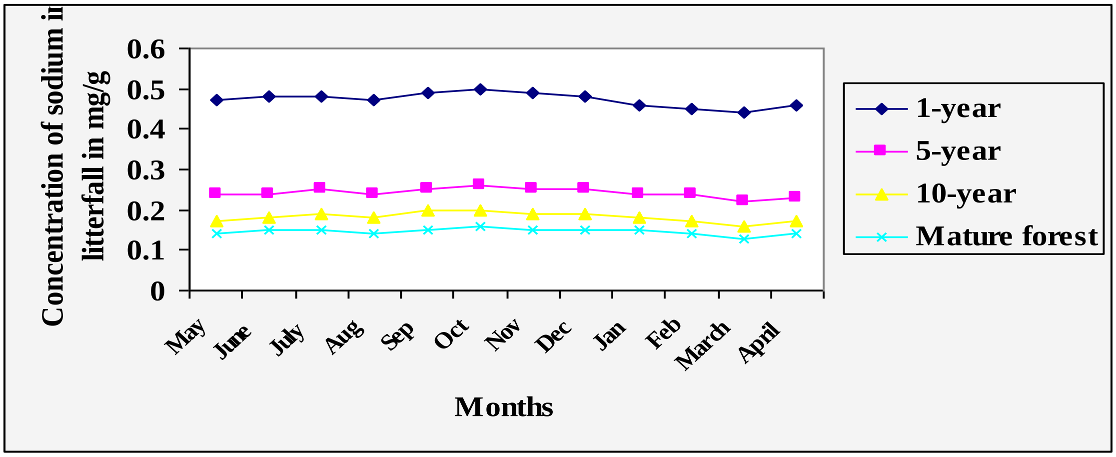


Fig. 5.8: Seasonal Changes in Sodium Concentration of Litter Produced by Secondary Forest of Different Age Categories and Mature Forest (mg/g)

In the 1-year and 5-year fallows the relative ranking of nutrient concentrations in litterfall are in the order of N>Ca>K>Mg>P>Na. While in the 10-year secondary forest and the mature forest the relative ranking of nutrient concentration of litterfall are in the order of N>K>Ca>Mg>P>Na. Sodium concentration of litterfall in all the fallow categories and the mature forest appeared to follow the same trend, that is in all the secondary forest categories, litterfall are low in sodium concentration. However, nitrogen is highest in all the secondary forest categories. The highest concentration of nitrogen, calcium, magnesium, phosphorus, potassium and sodium in litterfall was recorded during the rainy season.

Hypothesis 1 states that in an area of uniform regional climate, differences exist in the nutrient content of litterfall under secondary forests in different stages of secondary succession. Analysis of variance is used to test the hypothesis and the result is shown in table 5.16 below.

Table 5.16 below shows that there are significant differences in the nutrient content of litter produced by secondary forests in different stages of secondary succession. This is because the calculated values of F are greater than the F table value at 0.01 probability level. Thus hypothesis 1 above is accepted. Since there are significant differences in the nutrient content of litter of all the fallow categories taken together as shown by the F test, there is the need to carry out post hoc test to ascertain specifically which of the means of the fallow categories are significantly different from each other. The concern here is to determine which of the means of the four fallow categories are significantly different from others. To achieve this post hoc multiple comparison test was carried out using the least significant difference (LSD) test developed by Fisher. The result of the test is shown in appendix 4.

Looking at appendix 5.5 it can be seen that the differences among the means of the different fallow categories for all the elements are significant at different probability levels between the differen. The differences between the 1-year fallow and the 5-year fallow, 1-year fallow and the 10-year fallow and between the 1-year fallow and the

Table 5.15: Mean element concentrations (mg/g^{-1} in oven dry matter) of litterfall in secondary forest of different age categories

Age categories	Elements					
	N	P	K	Mg	Na	Ca
1-year	12.92	0.94	7.91	5.99	0.47	8.89
5-year	10.41	0.47	7.19	5.10	0.24	7.69
10-year	8.28	0.39	7.07	5.01	0.18	5.46
Forest	8.12	0.37	6.57	3.54	0.15	4.92

Source: Author's fieldwork

Table 5.16: Summary table of the results obtained by analysis of variance for litter nutrient content

Nutrient name	Source of variation	Sum of squares	MSE	F. Calculated value	F. probability	DF	Decision
Calcium	Between samples	125.72	41.91			3	
	Within samples	8.78	0.20	210.01	0.0000	44	Significant
Nitrogen	Between samples	173.76	57.9			3	
	Within samples	26.56	0.56	102.65	0.0000	44	Significant
Potassium	Between samples	10.98	3.66			3	
	Within samples	2.51	0.06	64.16	0.0000	44	Significant
Magnesium	Between samples	37.14	12.38	12.38	0.0000	3	Significant
	Within samples	0.44	0.01			44	
Phosphorus	Between samples	2.92	0.9733			3	
	Within samples	0.06	0.0015	716.22	0.0000	44	Significant
Sodium	Between samples	0.85	0.282			3	
	Within samples	0.12	0.003	103.89	0.0000	44	Significant

mature forest are significant at the 0.001 level of significance for all the elements in litterfall. The differences between the nutrient concentration of the 5-year and the 10-year fallows are significant at $P \geq 0.01$ for sodium.

Apart from the differences, between the nutrient concentration of the 5-year and 10-year fallows which are significant at $P \geq 0.1$ for sodium and potassium and the differences between 10-year fallow and mature forest which are significant at $P \geq 0.01$ for sodium, potassium and nitrogen the differences between all the other fallow categories in terms of nutrient concentration in litterfall are significantly different at $P \leq 0.05$. This lend credence to the hypothesis that in an area of uniform regional climate, differences exist in the nutrient content of litter fall under secondary forests in different stages of secondary succession.

Generally, for all the elements in litterfall studied their concentrations in litterfall decline with the age of the fallow (Table 5.15). The litter from the younger fallows is richer in nutrient than those of the older fallows and the mature forest. The 1-year fallow has the highest concentration of nutrient in litterfall, followed by the 5-year fallow, 10-year fallow and the mature forest. It is most likely that because the 1-year fallow and 5-year fallow litter fall came from herbaceous species hence the better quality of litter from them when compared to those of the older fallow and litter from the mature forest which came from woody species which immobilized greater amount of nutrient in the wood tissues. It is also most likely that the herbaceous species have more nutrient than the woody plant species which have woody tissues, hence the higher nutrient content of the younger fallows than the older fallows and the mature forest.

The quality of the litterfall, measured as the nutrient concentration in litterfall, decreased with the age of the secondary forest. The mature forest and the 10-year old secondary forest are dominated by woody plants with larger tissues where most of the nutrients taken from the soil are immobilized, while the younger forest (1-year and 5-year old secondary forest) are dominated by herbaceous species with smaller tissues hence the concentration of nutrients in the younger fallows biomass are more than the concentration of nutrients in the 10-year old and the mature secondary forest biomass. This finding agrees with that of Chandreshekera and Ramakrishnan, (1994).

There was variation in the monthly concentrations of nutrients elements in litterfall in all the secondary forest categories and the mature forest. All the nutrient elements were evidently higher during the wet months than the dry months. Lower nutrient concentrations in the dry season have been reported elsewhere as well, in both wetter and drier forests (Swift *et al*., 1981, Muoghalu *et al*., 1993, Wieder and Wright 1995, McGrath *et al*., 2001 and Lawrence and Foster 2002). This evidence suggests that the trees reabsorbed essential nutrients prior to massive litterfall in the dry season. Oladoye *et al*., (2005) reported maximum concentration of potassium, phosphorus and magnesium in the dry season. The higher potassium content in the dry season was ascribed to the leaching of potassium by rainwater from leaves during the rainy season (this was also the opinion of Egunjobi, 1971; Egunjobi and Fasehun, 1992; Muoghalu *et al*., 1993). The maximum concentration of these elements in this study in the rainy season is due to the fall of fresh leaves which have not experienced nutrient withdrawal due to water stress prior to their fall in the rain season.

High concentration of nitrogen, calcium and potassium in litterfall is as a result of the high concentration of these elements in the aboveground biomass of the secondary forests studied. More nitrogen is contained in the litterfall in this study than any other elements. Toky and Ramakrishnan (1983), Muoghalu *et al*., (1993), Hermansah *et al*., (2002), Foster and Lawrence (2002), Oladoye et *al*. (2005), and Owusu-Sekyere *et al*., (2006), reported higher concentration of nitrogen than any other nutrient in litterfall. High concentration of nitrogen associated with litterfall is an important component of the internal nitrogen cycle of a forest ecosystem. The concentration of plant nutrients in litterfall is important because it influences both the rate of decomposition and the amount of nutrient released to the soil during such decomposition. Therefore, the quality of litterfall was probably affected by the concentration of nutrients in the aboveground biomass and the soil.

Having established that there is significant difference in the nutrient content of litterfall under secondary forests in different stages of secondary succession in this section, the next section looks at the rate of return of nutrients to the soil through litter fall in the different fallow categories and ascertain whether there are significant differences in the rate of return of nutrient through litter fall among the different fallow categories.

5:5 RETURN OF NUTRIENTS THROUGH LITTERFALL TO SOIL

The annual rate of return of nutrients through the litter fall increased with the age of the fallow. The seasonal variation and variation with age of the rate of return of the various nutrients through litter fall are discussed in this section.

5:5.1 Return of Nitrogen to the Soil through Litterfall

The return of nitrogen to soil through litterfall increases with increasing age of fallow (Fig. 5.9). The total values of nitrogen returned to soil through litterfall are 13.97 kg/hectare/year, 73.51 kg/hectare/year, 90.56 kg/hectare/year and 89.44 kg/hectare/year for the 1-year, 5-year and 10-year fallows and the mature forest respectively. The highest quantity of nitrogen was returned in the 10-year fallow while the lowest quantity was returned in the 1-year fallow. The differences between the fallow categories (except between 1-year and 5-year and between the 1-year 10-year, fallows) and between the fallow categories and the mature forest (except the difference between the 1-year and mature forest) are not significant ($P<0.05$) (Appendix 5.6). This shows that though the return of nitrogen to soil through litter fall is higher in the older fallows and the mature forest, by the fifth year of secondary forest regeneration from abandoned plantation of rubber (*Hevea brasiliensis*) there seems to be no significant increase in the rate of addition of nitrogen to the soil through litterfall with increasing age of fallows.

The return of nitrogen to the soil through litterfall is higher in the dry season in all the fallow categories (a trend which is opposite to that of nitrogen concentration of litterfall). Quantitatively, all the fallow categories and the mature forest tend to contribute more nitrogen to the soil through litterfall during the dry season than the wet season.

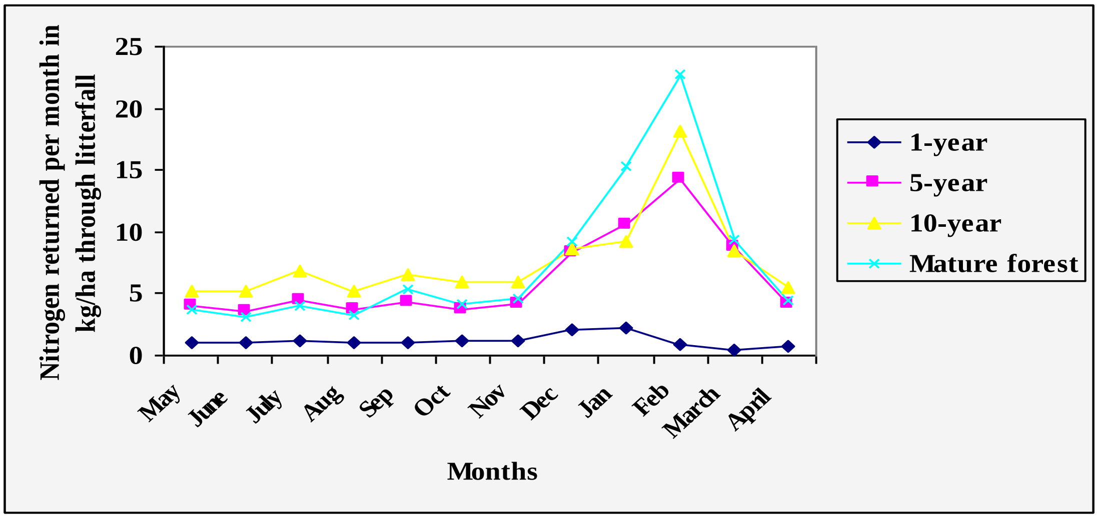


Fig. 5.9: Seasonal Changes in Return of Nitrogen to Soil through Litterfall (kg/hectare)

In the 1-year fallow the highest quantity of nitrogen was returned to soil through litterfall in the month of January, while in the 5-year and 10-year fallows and the mature forest the highest quantity of nitrogen was returned in February a period which coincides with that of lowest nitrogen concentration in litter fall. The lowest quantity of nitrogen was returned to soil through litter fall in March in the 1-year fallow and in October in the 5-year fallow while in the 10-year fallow and the mature forest the lowest quantity of nitrogen was return to the soil through litterfall in June and April respectively (Fig. 9). The difference in the seasonal variation in the rate of return of nitrogen to soil through litter fall is significant (Appendix 5.6).

5:5.2 Return of Calcium to the Soil through Litterfall

Figure 5.10 shows the seasonal rate of return of calcium in soil through litterfall. The annual rate of return of calcium to the soil through litter fall increased with the age of the secondary forest. The total annual values of calcium returned to the soil through litterfall are 9.85 kg/hectare, 54.2 kg/hectare, 59.73 kg/hectare and 54.55 kg/hectare for the 1-year, 5-year and 10-year fallows and for the mature forest respectively. The 10-year fallow returned the highest quantity of calcium to the soil through litter fall. Thus, the 10-year fallow returned higher quantity of calcium to soil through litter fall than the mature forest.

The return of calcium through litterfall to the soil is lowest in the month of March (commencement of the wet season) in the 1-year fallow, while in the 5-year fallow and the mature forest, the return of calcium to soil through litterfall is lowest in July. For the 10-year fallow the return of calcium to soil through litter fall was lowest in September. This shows that the return of calcium to the soil through litterfall was lowest in the older fallows and the mature forest during the period of peak rainfall a period which coincides with the period of highest concentration of calcium in litter and minimal litterfall.

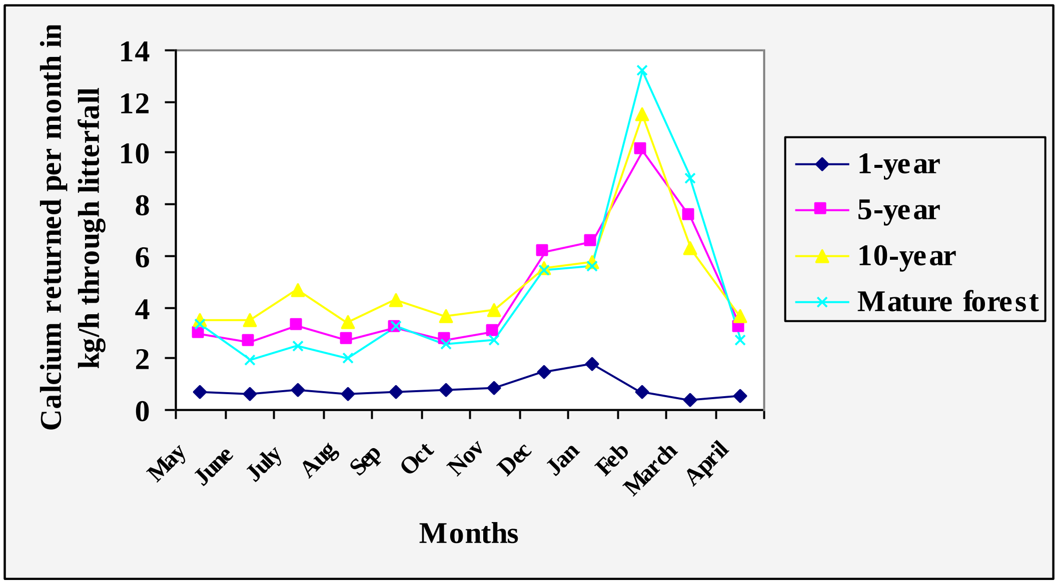


Fig. 5.10: Seasonal Changes in Return of Calcium to Soil through Litterfall (kg/hectare)

Quantitatively, the highest amount of calcium was returned to the soil through litter fall in February in the 1-year fallow and in March in the 5-year and 10-year fallows and the mature forest (dry season). This period coincides with the period of highest maximum temperature and peak litterfall.

5:5.3: Return of Potassium to the Soil through Litterfall

Both the concentration of potassium in litter and the quantity of potassium returned to the soil through litterfall increase with increasing age of fallows. The highest quantity of potassium was returned to the soil in the mature forest (Fig. 5.11).

The annual total quantity of potassium returned to soil through litter fall for the 1-year, 5-year and 10-year fallows and for the mature forest are 7.33 kg $h^{-1}year^{-1}$, 50.77 kg $h^{-1}year^{-1}$, 79.42 kg $h^{-1}year^{-1}$ and 87.20 kg $h^{-1}year^{-1}$ respectively. This indicates that the return of potassium to the soil increases with increasing age of secondary forests.

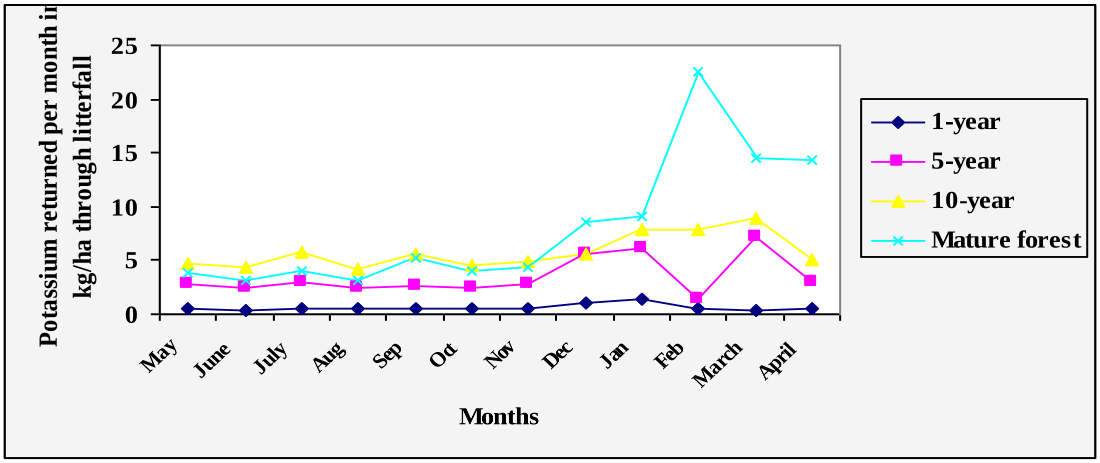


Fig. 5.11: Seasonal Changes in Return of Potassium to Soil through Litterfall (kg/hectare)

Higher amount of potassium was returned to the soil through litterfall in the dry season than the wet season. Between November 2010 and March 2011, 55.3 %, 53.5 %, 51.2 % and 56.1 % of the total annual amount of potassium returned to the soil in the 1-year, 5-year and 10-year fallows and the mature forest respectively through litter fall were returned at this period. Though, the wet season is longer than the dry season the quantity of potassium returned to the soil through litter fall is higher in the dry season than the wet season.

The highest amount of potassium was returned in January in the 1-year fallow and February in the 5-year and 10-year fallows and the mature forest. The lowest quantity of potassium was returned to soil through litterfall in March for the 1-year fallow, October for the 5-year fallow and in August for the 10-year fallow and the mature forest. The concentration of potassium in litterfall is lower in the wet season than the dry season. It seems that most of the potassium in litter was washed off prior to falling in the wet season.

5:5.4: Return of Magnesium to the Soil through Litterfall

The return of magnesium to the soil through litter fall increases rapidly during the first five years of the fallow period after which the increase becomes gradual up till the tenth year of fallow. After the tenth year of fallow a decrease in the rate of return of magnesium to the soil occurs hence the quantity of magnesium return to the soil through litter fall is lower in the mature forest than the 10-year old secondary forest. The higher rate of return of magnesium in the 10-year old secondary forest than the younger fallows (1-year and 5-year old fallows) is due to the fact that litter production in the 10-year old secondary forest is higher than the production of litter in the younger fallow. While the higher concentration of magnesium in the litter produced by the 10-year old secondary forest than those of the litter of the mature forest is responsible for the higher rate of return of magnesium in the 10-year old secondary forest than the mature forest.

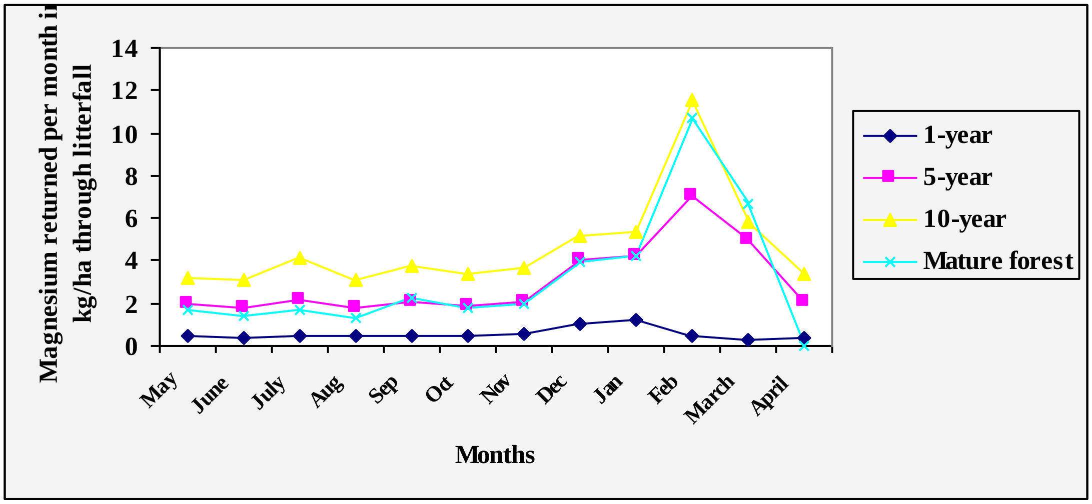


Fig. 5.12: Seasonal Changes in Return of Magnesium to Soil through Litterfall (kg/hectare)

The differences in the seasonal variation of the rate of return of magnesium to the soil through litter fall are significant. The return of magnesium to soil through litterfall is more in the dry season (56.2 %, 53.2 %, 52.3 % and 57.1 % for the 1-year, 5-year, 10-year fallows and the mature forest respectively) than the wet season (43.8 %, 46.8 %, 47.7 % and 42.9 % for the 1-year, 5-year, 10-year fallows and the mature forest respectively of the total annual return of magnesium through litterfall). The period of peak return of magnesium through litter fall coincides with the period of maximum litterfall.

The rate of magnesium return to soil through litterfall is least during the rainy season because litterfall in the rainy season is minimal.

5:5.5 Return of Phosphorus to the Soil through Litterfall

The return of phosphorus to soil through litter fall increases with increase in the length of the fallow period. However, the later part of forest regeneration is characterized by a slight decline in the rate of return of phosphorus to soil through litter fall. Fig. 5.13 shows the annual and seasonal rate of return of phosphorus to the soil through litter fall of the 1-year, 5-year, 10-year fallows and the mature forest. The total annual phosphorus of 1.15 kgh^{-1}, 3.18 kgh^{-1}, 4.18 kgh^{-1} and 4.02 kgh^{-1} were return to the soil through litterfall in the 1-year, 5-year, 10-year fallows and the mature forest respectively (Table 5.16).

The difference between the 1-year old fallow and the mature forest is significant at the 0.05 level of significance. The differences between the 5-year and 10-year fallow categories and the mature forest were not significant due to higher concentration of phosphorus in the younger fallows which offset the higher litter production but lower phosphorus content of the older fallows and the mature forest (Fig. 5.13) litter.

The total phosphorus returned to soil through litter fall during the one year observation period showed notable peak in December and January in the 1-year fallow and December to March in the older fallow categories and the mature forest. The January to March peak corresponds to the dry season and account for 37.39%, 37.12%, 35.17% and 45.27% of total phosphorus returned to soil through litter fall in the 1-year, 5-year, 10-year fallows and the mature forest respectively.

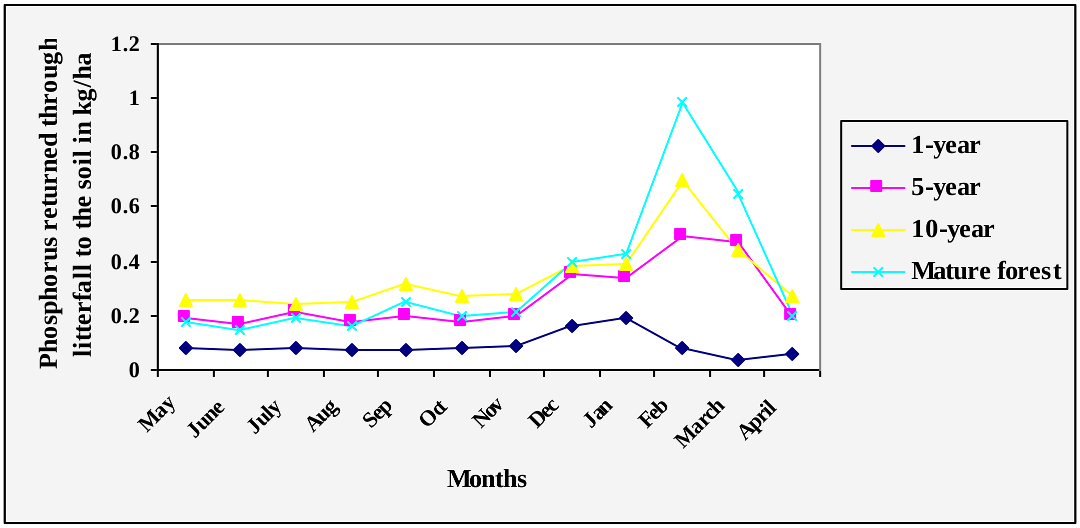


Fig. 5.13: Seasonal Changes in Return of Phosphorus to Soil through Litterfall (kg/hectare)

Quantitatively 52.2 %, 49.1 %, 48.3 % and 55.5 % of the total phosphorus returned to soil through litterfall in the 1-year, 5-year, 10-year fallows and the mature forest respectively are returned in the dry season. This indicates that higher proportion of phosphorus is returned in the dry season in the 1-year fallow and the mature forest while in the 5-year and 10-year old fallows higher proportion of phosphorus is returned in the rainy season. However, the seasonal variation in the return of phosphorus to soil through litterfall is not significant (Appendix 5.7).

5:5.6 Return of Sodium to the Soil through Litterfall

Figure 5.14 shows the annual and seasonal return of sodium through litterfall 0.52 $kgh^{-1}year^{-1}$, 1.71 $kgh^{-1}year^{-1}$, 1.93 $kgh^{-1}year^{-1}$ and 1.60 $kgh^{-1}year^{-1}$, sodium was returned to soil through litterfall in the 1-year, 5-year, 10-year fallows and the mature forest respectively. This shows that the return of sodium to soil through litterfall increased rapidly in the first to soil through litterfall increase rapidly in the first five year of fallow after which the increase in the rate of return of sodium to soil through litterfall becomes gradual up till the tenth year and much later in the mature forest there is a decline in the quantity of sodium return to the forest soil through litterfall. The amount of potassium returned to soil through litterfall increased continuously (though non significantly) with the age of secondary forest, while the amount of the other nutrients return to soil through litterfall reached their maximum by the tenth year of fallow and declined below the amount returned to the 10-year old secondary forest later in the mature forest. Thus, potassium cycling increases during the process of forest recovery. Older forests produced significantly greater amounts of litter, but returned insignificant higher (lower amount for sodium) amount of nutrients (except potassium) through litterfall to the soil. This is due to decline in litter nutrients concentration with increasing age of fallows. This suggests that nutrient use efficiency (except potassium) declined, if it changed at all, as a function of age. This finding is consistent with that of (Lawrence and Foster, 2005) and also in agreement with that of Toky and Ramakrishnan (1983), who reported increase in the inputs of nitrogen, magnesium, calcium, potassium and phosphorus to soil through litterfall with the age of secondary forests up to 20-year of fallow.

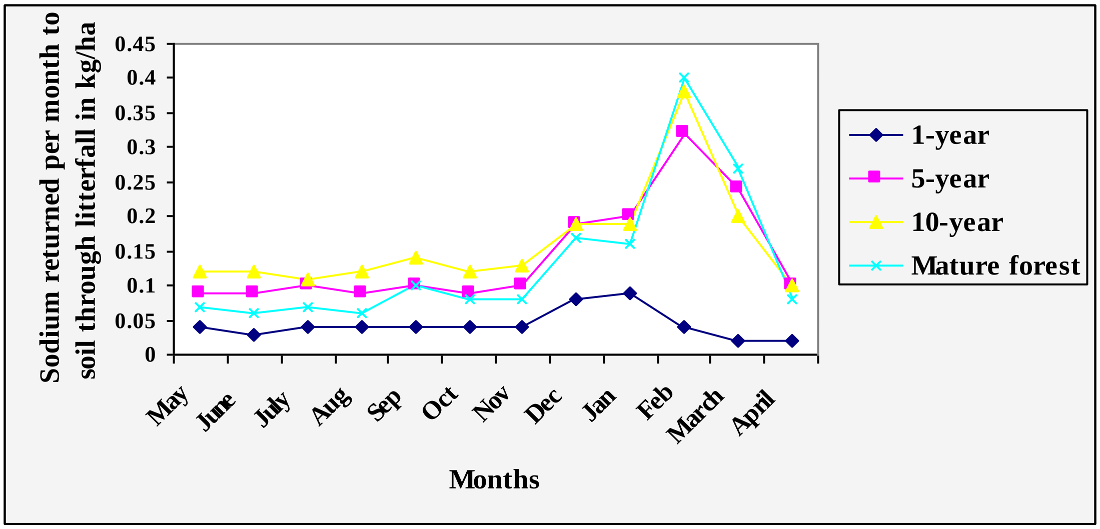


Fig. 5.14: Seasonal Changes in Return of Sodium to Soil through Litterfall (kg/hectare)

The values of the quantities of elements in the litterfall reported in this study are comparable to the published range recorded for tropical and subtropical mature forests (table 5.17). The quantities of nitrogen, phosphorus and calcium returned to soil through litterfall in the mature forest in this study are lower than the values reported by Bernhard-Reversat *et al*., (1978) and Ewel (1976), (Table 5.17) but higher than what was reported by Salas and Khana (1976). The values of potassium and magnesium returned to the soil through litterfall are higher than the values reported by Bernhard-Reversat *et al*., (1978), Salas and Khanna (1976), but magnesium is lower than what was reported by Ewel (1976). The secondary forests in this study returned higher values of the different nutrient elements than secondary forests following shifting cultivation of comparable ages studied by Toky and Ramakrishnan (1983) and lower amounts of nutrients than that of the 40-year old secondary forest studied by Nye and Greenland (1960) in Ghana.

The low rate of return of phosphorus in litterfall to soil may be due to the low concentration of phosphorus in the soil and rapid withdrawal of this element by the aboveground biomass prior to litterfall. A comparison of the nutrient contents in the litterfall and above-ground biomass shows that the latter has more nutrients than the former. This indicates that as to be expected, not all the elements taken up by the plants are returned to the forest floor (soil) through litterfall- a finding which agrees with what was reported by Toky and Ramakrishnan (1983) and Nwoboshi (1981).

The nutrient content of the whole ecosystem (soil, aboveground biomass and litterfall put together) increased significantly with the age of the secondary forest with most of the nutrients immobilized in the aboveground biomass in the older fallows (5-year and 10-year old fallows) and the mature forest than the top 30cm of the soil and litter compartments. This finding is congruent with that of Lawrence and Foster (2002).

Table 5.17: Nutrient returned to the soil through litterfall in a range of lowland tropical forests (in kg/ha^{-1})

Forest type	Location	Litterfall	N	P	K	Ca	Mg	Na	Authors
Mature rainforest	Banco, Ivory Coast	9180	160	14	81	85	36	-	Bernhard-Reversat, Huttel and Lemil (1978)
Rainforest	Colombia	9500	110	2.4	19	53	18	-	Salas and Khanna (1976)
Rainforest	Akyaakrom Ghana	7900	166	7.2	31.6	156.6	23	-	Owusu-Sekyere (2006)
10-year old Forest	Akyaakron Ghana	7900	172	5.6	44.1	118.6	19.4	-	Op Cit (2006)
Rainforest	Guatemalia	9000	170	5.8	20	88	64	-	Ewel (1976)
Rainforest	Australia	9900	120	10	51	160	34	5	Brasell, Unwin and Stocker (1980)
10-year old secondary forest	India	7100	62	3	51	37	36	-	Toky and Ramakrishnan (1983)
Mature forest	Orogun, Nigeria	11324	89.59	4.02	87.20	54.55	39.82	1.60	This study

5:5.7 Quantities of Elements in the Soil, Above-ground Biomass and Litterfall Components of the Ecosystem

The quantity of nitrogen in the soil (to a depth of 30cm) increased with increasing age of the secondary forest, while the quantities of calcium and magnesium in the top 30cm of the soil decreased with increasing age of the secondary forest. The amount of available phosphorus, exchangeable sodium and potassium increased for the first five years and decline to the levels relatively close to that of the 1-year fallow (Table 5.18) by the tenth year. However, the quantities of all the elements in the soil, litterfall and aboveground biomass (total ecosystem) put together increased with increasing age of the secondary forests. The relative ranking of the total quantities of nutrients of the 1-year, 5-year and 10-year old fallows are in the order of N>Ca>Mg>K>Na>P, while for the mature forest the amounts of all the nutrients in the whole ecosystem are ranked in the order of N>Ca>K>Mg>Na>P.

The quantities of all the nutrients (except available phosphorus and potassium for 5-year old fallow) are higher in the top 30cm of the soil than they are in the above-ground biomass in the 1-year and 5-year fallows (Table 5.18). For the 10-year old secondary forest, the amounts of nitrogen and sodium are higher in the top 30cm of the soil than they are in the aboveground biomass while the amounts of potassium, magnesium, calcium and phosphorus are higher in the aboveground biomass than the top 30cm of the soil (table 5.18). With the exception of nitrogen, the quantities of all the other nutrients (potassium, calcium, sodium, magnesium and phosphorus) are higher in the aboveground biomass than the top 30cm of the soil of the mature forest. The quantities of all the nutrients returned through litterfall to the soil are lower than the quantities of nutrients immobilized in the aboveground biomass in all the secondary forest categories. This indicates that bulk of the nutrients in the secondary forests studied is locked up in the vegetation tissues.

Table 5.18: Quantities of nutrients (in kg/ha^{-1}) in the above-ground biomass, soil and litterfall in secondary forests regenerating from degraded rubber plantation in Orogun Southern Nigeria

Ecosystems	Nutrients	Age categories			
		1-year	5-year	10-year	Mature forest
Soil	Nitrogen	930.24	1124.8	1479.34	2368.54
AGB	Nitrogen	33.01	155.87	313.33	1005.38
Litterfall	Nitrogen	13.97	73.51	90.56	89.59
Soil	Phosphorus	1.67	3.65	1.41	4.88
AGB	Phosphorus	2.43	9.76	17.28	42.84
Litterfall	Phosphorus	1.15	3.18	4.18	4.02
Soil	Calcium	294.79	272.22	207.61	307.79
AGB	Calcium	26.43	92.98	338.83	944.35
Litterfall	Calcium	9.85	54.20	59.73	54.55
Soil	Magnesium	113.45	109.96	90.84	128.50
AGB	Magnesium	17.01	57.0	136.91	464.71
Litterfall	Magnesium	6.64	36.06	16.98	24.33
AGB	Sodium	1.36	4.87	8.91	41.25
Soil	Sodium	15.68	30.99	16.98	24.33
Litterfall	Sodium	0.52	1.71	1.93	1.60
Soil	Potassium	10.55	12.63	10.15	23.08
AGB	Potassium	8.53	71.62	183.21	799.32
Litterfall	Potassium	7.33	50.77	79.42	87.20
TE	Nitrogen	977.22	1354.18	1883.23	3463.51
TE	Phosphorus	5.25	16.59	22.87	51.74
TE	Calcium	400.471	419.4	606.17	1284.26
TE	Magnesium	137.10	203.02	283.32	1284.26
TE	Sodium	17.56	37.57	27.82	67.15
TE	Potassium	26.41	135.02	272.78	909.6

TE = Total Ecosystem, AGB = Above-ground Biomass, P = Available Phosphorus

5:5.8 Nutrients Turnover

The annual turnover of the different nutrients for the top 30 cm of the soil and the vegetation is shown in Table 5.19. The annual percentage turnover of all the nutrients in the soil tended to increase with increasing age of secondary forest. This finding is consistent with findings of Toky and Ramakrishnan, (1983). The percentage annual turnover of the phosphorus, potassium and sodium decreased with increasing age of secondary forest while the percentage annual turnover of nitrogen, calcium and magnesium fluctuate with increasing age of secondary forest (see table 5.19). The implications of the above are:

i. The older the secondary forest the greater is the draining effect of the vegetation on the soil nutrients (i.e. the older the age of the secondary forest the higher the amount of nutrients removed from the soil by the vegetation).
ii. Greater proportions of the nutrients removed from the soil by the vegetation are stored in the vegetation.
iii. The older the secondary forests the smaller is the proportion of nutrients leaving the vegetation compartment to that held in the vegetation compartment.

These are expected because of the marked increase in uptake by the developing vegetations and increased storage in the living plants which is proportionately higher than the rate of release through litter. Nutrient cycling varies according to the supply from the soil. For example, in certain Amazonian forests (Klinge and Rodrigues, 1968a) the podzols contain low elements concentrations. As a consequence, the concentrations of elements in plants are much greater than in the soil and the elements released from the litter are rapidly taken up by the vegetation.

Since there is significant difference in the rate of nutrient return between the different fallow categories and between the fallows and the mature forest at $P \leq 0.01$, as shown in Appendix 5.6 there is therefore the need to carry out a post hoc multiple comparison test

TABLE 5:19: The fractional turnover of nutrients of soil and vegetation in the various secondary forests categories in Orogun southern Nigeria.

	N		P		K		Ca		Mg		Na	
Age categories	Soil	Veg	Soil	Veg	Soil	Veg	Soil	Veg	Soil	Veg	Soil	Veg
1-year	3.55	42.3	145.51	47.3	80.8	85.9	7.26	37.3	14.99	39	8.67	38.2
5-year	13.85	47.2	267.39	32.6	567.06	70.9	34.16	58.3	51.84	63.3	15.71	35.1
10-year	28.18	28.9	1225.53	24.2	1743.2	43.3	163.21	17.6	150.7	40.6	52.47	21.7
Forest	42.45	8.91	877.87	9.4	3463.3	10.9	330.9	5.8	361.6	8.6	169.5	3.9

to ascertain whether these differences which exist for all the pairs of fallow and for the fallows and the mature forest are significant between all the pairs of fallow categories.

Appendix 5.8 shows that though significant differences exist between the 1-year fallow and the 5-year, 10-year fallows and the mature forest respectively at $P \leq 0.05$ for all the nutrients elements returned to soil through litterfall, there are no significant differences between the 5-year and the mature forest in terms of nutrient return to soil through litter fall. Similarly there is no significant difference between the 10-year fallow and the mature forest in the rate of return of nutrient to soil through litter fall at $P=0.05$.

This shows that though, the production of litter significantly increases with increasing age of fallow, the rate of return of nutrient through litterfall does not follow this pattern of increase. In fact, looking at the pattern of return of nutrient through litterfall in Fig. 5.9 – 5.14 it would be observed that with the exception of potassium whose rate of return through litterfall follows a steady increase with increasing age of fallows, the return of the other nutrient elements through litterfall reach their peak in the 10-year fallow after which it decreases later in the mature forest.

For the 1-year fallow the difference between the rainy season and the dry season in the rate of return of nutrient to the soil through litterfall is not significant for any of the elements. For the 5-year and the 10-year fallows the differences in the rate of return of calcium potassium nitrogen and magnesium to soil through litterfall are significant at 0.05 level of significance of the T-test between the rain season and the dry season while the difference in the rate of return of phosphorus and sodium to soil through litterfall is not significantly different between the rainy and the dry season for the 5-year and the 10-year fallows.

In the mature forest the differences between the rate of return of calcium, potassium and nitrogen to soil through litterfall are significant between the rain and dry season while the differences for magnesium, sodium and phosphorus are not significant between the rain and dry season.

CHAPTER SIX

MODELING THE RELATIONSHIP BETWEEN SOIL AND VEGETATION

6.1 Introduction

One of the objectives of this study is to examine the relationships between soil properties and vegetation parameters. To achieve this objective simple correlation and stepwise multiple regression analysis were used.

In modeling the relationship between two or more sets of data, it is desirable to inquire whether observed relationships or differences between the sets of data are statistically significant. The inferences arrived at using these tests (Snedecor's F. and the t test) are only valid if the data sets are normally distributed (Yamane, 1964). It is therefore, appropriate to carry out tests of normality on the raw data and if need be, perform appropriate transformation of the raw data.

If data possess skewed distribution, whether positive or negative, they can be transformed in such a way as to eliminate the skewness and make them tend towards normal distribution.

The raw data was tested for significant departure from normality using computer SPSS 2003 Programme (SPSS for windows Version 11.0). Four of the vegetation parameters- litterfall, aboveground biomass, tree diameter and tree basal area were positively skewed and therefore normalized through logarithmic transformation. Out of the soil parameters used for the regression analysis, two (exchangeable calcium and magnesium) were positively skewed, and were transformed through logarithmic transformation to normalize them for the regression analysis.

6:2 Stepwise Multiple Regression Analysis of the Relationships between Soil Properties and Vegetation Parameters

Stepwise multiple regression analysis is used to explain or predict the functional relationships between a dependent variable and a set of predictor or independent variables such that the independent variables are used to explain the variation in the dependent variable. In general, the model is used not only to evaluate the joint contribution of all the independent variables (vegetation parameters in this case) in explaining the variation in the dependent variable (soil physico-chemical properties vegetation parameters in this case) but also the significance of each of the independent variables.

One of the major advantages of a step-wise multiple regression models is that it enables us to examine quickly not only the magnitude and significance of the joint contribution made to the variance explained by all independent variables taken together but also that made by each individual independent variable.

In a stepwise multiple regression, the independent variables are entered into the regression equation step by step based on the strength of their individual relationship with the dependent variable, in an equation of the form:

$Y = a + b1x1 + b2x2 + bnxn + \epsilon$ ………………………………… (Equation 6.1)

In this formulation, a is called the constant term, x is any one of the independent variables that contributes most significantly to the variance explained while b1, b2 …..bn are the regression coefficients and ϵ is called the error term representing the errors that enter our model as a result of other variables which we could not specify or have inappropriately measured as well as other random effects errors (Ayeni 2000). In stepwise multiple regression we compute in the first step $Y = a + bx$…………………. (Equation 6.2)

This means thus that x is the variable that has the highest correlation with the dependent variable Y. In the next step, step two, we enter the next variable and compute $Y = a + bx + b^*x^*$

Where x^* is the independent variable that makes the next highest reduction in the error sum of squares or the variable that makes the highest additional contribution to variance explained after the first variable entered.

There are two types of stepwise multiple regression - the forward selection and the backward elimination. In the forward selection procedure, variables are added one by one on the basis of their partial correlations with the dependent variable. The independent variable with the highest partial correlation with the dependent variable is entered into the equation first. The independent variable which accounts for the greatest proportion of residual variance is entered next and so on. At each stage, an F-test is performed to ascertain whether the contribution of the independent variable just entered to the explanation of the variance of the dependent variable is significant. More variables are entered into the equation until the most recently entered variable does not account for a significant proportion of the variance in the dependent variable. In the backward elimination procedure, the coefficients of the independent variables are assumed to be zero (i.e. they do not need to be in the equation). The variables for which this hypothesis is accepted are dropped from the regression equation (Hauser, 1974).

One of the objectives of this study is to provide explanation for the functional relationships between the parameters of soil and vegetation parameters. Therefore this section is devoted to the explanatory modeling of the relationships between soil and vegetation properties with the use of stepwise multiple regression analysis.

6:3 Multicollinearity – A Problem in Multiple Regression Analysis

One of the assumptions of stepwise multiple regression is that the independent variables should be mutually statistically independent. This means that the independent variables should not be highly correlated. If there is a high correlation between any two of the independent variables it is said that there is the problem of collinearity. However, if more than two of the independent variables are highly correlated, we say that the problem of multicollinearity exists. In all these a correlation coefficient in excess of 0.8 is usually taken as indicating serious problem of colinearity or multicollinearity.

If the problem of multicollinearity exists, there are at least two main consequences. Firstly, it introduces unusually high standard errors in the regression coefficients. This of course means that the variance of the regression coefficients will become very large and the precision of the estimated value becomes imprecise. Secondly, it becomes difficult to decide which independent variable to reject. In this case, relevant variables may be discarded erroneously. Thus when multicollinearity is observed in a data set, one is advised to delete variables that are grossly suspected to be derivable from the others; or use some other techniques such as principal components analysis to derive independent dimensions of the data set (Ayeni, 2000).

6:4 Test for Multicollinearity

Different methods have been suggested to examine the presence of multicollinearity in data. Among these are the eigenvalues criterion (Tinther 1945, 1965) and those which entail examining pairwise correlation among the independent variables (Klein, 1962, Hauser, 1974). The major constraint of the eigenvalues method is the identification of those variables which are interdependent (Hauser, 1974). There is no unanimous agreement as regards the extent of collinearity which if present, will seriously affect the estimates of the regression parameters. Hauser (1974) posited that pairwise correlations between explanatory variables that exceed 0.8 are indicative of serious collinearity.

The independent (vegetation parameters) variables were tested for the presence of multicollinearity using the criterion of Hauser. Partial correlations between pairs of variables were computed and the resulting correlation matrix examined for the presence of correlation coefficients that exceed 0.80. Table 6.1 shows the partial correlation coefficients between the vegetation independent variables. It can be seen that some of the correlations coefficients are well over 0.8. The correlation between the tree height and number of tree species is 0.99. The correlation between aboveground biomass and tree basal area on the one hand and tree diameter and aboveground biomass on the other hand are 0.97 and 0.96 respectively. On the whole, twenty two partial correlations exceed 0.80. This is a case of serious problem of multicollinearity using the criterion of Hauser.

To eliminate the problem of multicollinearity from the independent variables (vegetation parameters), wherever the correlation coefficients between or among sets of variables exceed 0.8, one of the variables was picked and entered into the regression while the others are discarded. Looking at Table 6.1, it can be observed that the correlation coefficients between above-ground biomass and tree density, tree height, tree diameter, tree cover and basal area exceed 0.80. As such, aboveground biomass was used as one of the independent variables for the regression and tree height, tree basal area, tree diameter, tree density and tree cover were not used for the regression since they are actually measures of vegetation biomass and their inclusion in the regression will introduce the problem of multicollinearity. Of the remaining four vegetation parameters, the correlation coefficients between species diversity and total number of plants species on the one hand and between species diversity and number of tree species on the other hand exceed 0.80 (0.87 and 0.92 respectively) and since species diversity is a measure of floristic composition of vegetation, coupled with the fact that in the computation of species diversity both the total number of plant species and the total number of individual species of plant were used, the total number of pant species and total number of tree species were discarded and the data on species diversity were used as one of the independent variables for the regression. The third parameter (litterfall) used as independent variable for the

Table 6.1: Correlations Matrix of Vegetation Variables

	Vegetation properties	1	2	3	4	5	6	7	8	9	10
1	Tree height	1.00	0.81	0.77	0.95	0.95	0.83	0.87	0.99	0.48	0.78
2	Tree density		1.00	0.48	0.79	0.92	0.96	0.76	0.79	0.53	0.83
3	Basal area			1.00	0.86	0.70	0.97	0.67	0.76	0.38	0.47
4	TDA				1.00	0.87	0.96	0.82	0.87	0.41	0.69
5	Tree cover					1.00	0.87	0.84	0.90	0.87	0.71
6	AGB						1.00	0.73	0.76	0.78	0.58
7	TNPS							1.00	0.42	0.30	0.87
8	TNTS								1.00	0.47	0.92
9	Litterfall									1.00	0.51
10	Species diversity										1.00

Note: correlations above 0.8 have problem of collinearity

TDA = Tree diameter, AGB = Above-ground biomass, TNTS =Total number of tree species, TNPS = Total number of plant species regression analysis is not having problem of collinearity with any of the independent variable (vegetation parameters).

For the regression of soil physicochemical properties on the vegetation parameters, each of the soil physical (bulk density, total porosity and water holding capacity) and chemical (total nitrogen, available phosphorus, exchangeable cation, effective cations exchange capacity, soil organic matter and soil pH) properties was treated as a dependent variable and regression of the explanatory variables (above-ground biomass, species diversity and litterfall) was carried out on each of them.

6.5 Relationships between soil properties and vegetation parameters – simple bivariate correlation

The simple bivariate correlations between pairs of vegetation and soil properties were computed for two reasons –

1 To identify vegetation parameters that are strongly affected by soil properties and vice versa and

2 To amplify the nature and strength of the reciprocal relationship between the parameters of soil and those of vegetation.

In the discussion of the results of correlation attention is devoted principally to those strong relationships with a minimum correlation of 0.32 (correlation coefficients less than 0.32 are not significant at 0.05 significant level). In this study correlations that are below this value are regarded as trivial relationships which are best ignored (Tables 6.2 and 6.3).

The correlation between vegetation above-ground biomass and all the nutrient elements are all significantly positively correlated at $P<0.05$ (Table 6.2).

The highest correlation between species diversity and soil nutrients is that between species diversity and soil organic matter (0.78), while the least correlation coefficients between soil nutrients and species diversity is 0.46 which is the correlation coefficient between soil species diversity and soil available phosphorus. The correlations between species diversity and all the elements (nutrients) in the soil are positively significant at $P<0.05$.

Table 6.2: Correlation coefficients between vegetation parameters and soil nutrients status characteristics

Vegetation variables	Soil variables								
	Som	N	P	Mg	Na	Ca	K	Ecec	pH
Above-ground biomass	0.84	0.94	0.68	0.62	0.82	0.89	0.90	0.70	-0.37
Species diversity	0.78	0.53	0.46	0.57	0.70	0.50	0.50	0.56	-0.43
Litterfall	0.57	0.44	0.19	0.23	0.83	0.31	0.32	0.05	-0.30

NB: Correlation coefficients that exceed 0.30 are significant at 0.05

The proportions of clay, silt and sand respectively are not significantly correlated with aboveground biomass, species diversity and litterfall. Above-ground biomass and species diversity are significantly positively correlated with soil water holding capacity and total porosity but negatively correlated with soil bulk density (Table 6.3). These results suggest that the greater the aboveground biomass of vegetation, the higher the nutrient content of the soil. The relationship is to be expected because secondary forest depends on soil nutrients for its development, while increase in soil nutrients contents, is dependent on the ability of the secondary forests to return nutrients to soil through the fall and mineralization of litter. Vegetation above-ground biomass is significantly positively correlated with soil organic matter and nutrients, because aboveground biomass enhances the capacity of secondary forests to regenerate soil fertility during the regeneration of secondary forests from abandoned degraded rubber plantations due to the increasing rate of return of nutrients to soil through litterfall with increasing amount of biomass.

The strong positive correlation between the above-ground biomass and soil water holding capacity and between above-ground biomass and total porosity and the strong negative correlation between above-ground biomass and soil bulk density, suggest a two-way relationship between soil and above-ground biomass. These are:

1 Increase in vegetation above-ground biomass encourages the build up of organic matter in the soil through rapid litter production. The build up of soil organic matter enhances soil water holding capacity and the aggregation of soil particles to increase porosity.

2 Increases in soil water holding capacity and total porosity enhance the growth of plants.

Table 6.3 correlation coefficients between soil physical properties and vegetation parameters

Vegetation variables	Soil variables					
	WHC	Bulk density	Total porosity	Clay	Silt	Sand
Aboveground biomass	0.92	-0.69	0.69	0.29	0.26	-0.09
Species diversity	0.79	-0.46	0.64	0.19	0.17	0.22
Litterfall	0.48	-0.19	0.24	0.11	0.16	-0.13

NB: Correlation coefficients that exceed 0.30 are significant at 0.05

WHC = Soil Water Holding Capacity

Species diversity has strong positive correlations with soil nutrients and this indicates that secondary forests such as the mature forest and the older fallows which are floristically heterogeneous are likely to be more efficient than homogeneous ones in regenerating soil fertility. This suggests that the build up of soil nutrients status during the course of secondary forest regeneration from degraded abandoned plantation makes it possible for an ecosystem to support more species most importantly 'tree' species which make more demands on soil nutrients.

The bulk density of the soil is negatively correlated with above-ground biomass and species diversity, indicating that the higher the above-ground biomass and species diversity the lower the bulk density, as to be expected. There are three likely reasons for this:

i. Increase in soil organic matter content as a result of increase in biomass and species diversity may help to loosen the soil thereby reducing soil bulk densities and increasing total porosity.
ii. The roots of the large trees may help to loosen the soil thereby reducing bulk density of the soil and increase total porosity.
iii. The crown cover provided by the larger biomass could help to reduce rainfall impact on the soil thereby reducing the bulk density of the older fallows and the mature forest, while the direct impact of rainfall on the soil of the younger fallow could make the soil to be compact and high in bulk density.

The above analysis indicates that soil physical and chemical properties are significantly correlated with vegetation biomass and the diversity of species. Therefore the hypothesis which states that soil physical and chemical properties significantly affect vegetation biomass and species diversity is accepted.

The correlations between litterfall and the following soil properties are positively significant at 0.05 level of significance:

i. Litterfall and soil organic matter (0.54)
ii. Litterfall and sodium concentration (0.83)
iii. Litterfall and nitrogen (0.44)
iv. Litterfall and potassium (0.32)
v. Litterfall and soil water holding capacity (0.48)

These results suggest that the higher the quantity of litter produced, the higher the concentration of soil organic matter, total nitrogen, potassium the water holding capacity. It seems that the increase in litterfall increase the of return of these nutrients to the soil and the rate of soil organic matter build up which enhances the capacity of the soil to hold water.

6:6 THE STEPWISE MULTIPLE REGRESSION MODEL

Attention is devoted mainly to the influence of the three vegetation properties (above-ground biomass, species diversity and litterfall) on soil properties in this section (recall that the vegetation parameters had been reduced to three due to multicollinearity among them). Emphasis is placed chiefly on the fundamental relationships between the independent variables (vegetation parameters) and the individual soil variables. The independent variables (vegetation parameters), were entered into the stepwise regression based on the strength of their individual relationships with each of the soil physico-chemical properties (see Tables 6.2 and 6.3), such that the vegetation parameter with the highest correlation with an individual soil parameter, is entered into the regression first. The regression models are shown below:

Soil Water Holding Capacity (Topsoil)

The results presented in Table 6.4 revealed that above-ground biomass and species diversity significantly explain the variation in soil water holding capacity. When above-ground biomass was entered into the model as the first explanatory variable based on the strength of its relationship with soil water holding capacity, a significant relationship was revealed ($R^2 = 0.517$; $P < 0.01$). This indicates that above-ground biomass alone explain 51.7% of the variation in soil water holding capacity. With species diversity entered into the model as the second explanatory variable, a significant relationship was also revealed ($R^2 = 0.857$; $P < 0.01$). This revealed that above-ground biomass and species diversity together explained 85.7% of the variation in soil water holding capacity. Species diversity accounted for 34% of the variation in soil water holding capacity. Litterfall accounted for 3.1% of the variation in soil water holding capacity.

Table 6.4: Stepwise multiple regression results of soil water holding capacity on the three explanatory vegetation parameters

Independent variables	B coefficients	Standard error	Partial R	R^2	Level of explanation	Multiple R^2	T-values	T values	Multiple R
LOGAGB	0.622422	0.092641	0.719	0.517	51.74%		6.7186**	6.718645**	0.719
SD	0.250909	0.059682	0.341	0.857	34.08%	0.8893	4.2041**	4.426846**	0.926
LOGLF	0.232126	0.122423	0.031	0.889	3.11%		1.8961	0.403208	0.943

Intercept = 0.635113, ** Significant at 0.01 confidence level

F = 101.7526.

The regression of soil water holding capacity on the three vegetation parameters produced a regression model of the form:

WHC = 0.64+0.62LOGAGB + 0.25SD

Where

WHC = Soil water holding capacity

LOGAGB = Logarithm of aboveground biomass

SD = Species diversity

These results show the overwhelming importance of above-ground biomass and species diversity in influencing soil water holding capacity in secondary forests regenerating from abandoned plantation. These variables affect soil water holding capacity indirectly through their influence on soil organic matter.

In predominantly coarse-textured soils such as occur in the study area; organic matter is a major soil component that affects soil water holding capacity. It is not surprising therefore, that above-ground biomass, the variable that has the strongest influence on soil organic matter, exerts the greatest influence on soil water holding capacity (Table 6.4).

Soil Bulk Density (Topsoil)

Results presented in Table 6.5 revealed that above-ground biomass, species diversity and litterfall significantly explain the greater variation in soil bulk density ($P < 0.05$). When aboveground biomass was entered into the model as the first explanatory variable based on the strength of its relationship with bulk density, a significant relationship was revealed ($R^2 = 0.505$; $P < 0.01$). This indicates that above-ground biomass alone explain 50.51% of the variation in soil bulk density. When species diversity entered into the model as the second explanatory variable, a significant relationship was also revealed ($R^2 = 0.854$; $P < 0.01$). When litterfall was entered into the model as the third explanatory variable a significant relationship was also revealed ($R^2 = 0.91$; $P < 0.05$). This revealed that above-ground biomass, species diversity and litterfall together explained 91.43% of the variation in soil bulk density. Species diversity accounted for 34 .9% of the variation in soil bulk density while litterfall accounted for 6.02%.

6.5: Stepwise multiple regression results of soil bulk density on the three explanatory vegetation parameters

Independent variables	B coefficients	Standard error	Partial R	R^2	Level of explanation	Multiple R^2	T values
LOGAGB	-0.058621	0.009001	0.710	0.5051	50.51%		-6.5127**
SD	-0.436241	0.101442	0.591	0.349	34.90%	0.9143	-4.3004**
LOGLF	-0.211112	0.092213	0.245	0.060	6.02%		-2.2894**

Intercept = 4.220010, ** Significant at 0.01 confidence level

F = 118.6694

Regression of soil bulk density on the three vegetation variables produced a regression model of the form:

BD = 4.22– 0.06LOGAGB – 0.44SD – 0.21LOGLF

Where

BD = Bulk density
LOGAGB = Logarithm of above-ground biomass
SD= Species diversity
LOGLF = Logarithm of litterfall

Analysis of variance test for the significance of the regression coefficient yielded an F value of 118.67 which is significant at 0.05. The three vegetation parameters taken together explain 91.42 % of the variation in soil bulk density. It is pertinent to note that the regression coefficients have negative signs indicating a negative relationship between the vegetation parameters and soil bulk density. This indicates that as the above-ground biomass and species diversity of secondary forests increase the bulk density decreases.

This is probably due to the loosening of the soil by the large biomass thus making the soil to be less compact. Also, an increase in vegetation biomass results in an increase in soil organic matter which reduces bulk density.

Soil Total Porosity (Topsoil)

Regression analysis for soil total porosity and the three vegetation explanatory variables produced a regression model of the form.

TP = 6.03 + 0.51LOGAGB + 1.98LOGLF + 0.37SD

The test for significance of the regression coefficients with analysis of variance yielded an F ratio of 73.44 which is significant at 0.01 confidence level. Table 6.6 revealed that above-ground biomass, species diversity and litterfall significantly explain the variation in soil total porosity ($P < 0.01$). When aboveground biomass was entered into the model as the first explanatory variable based on the strength of its relationship with total porosity, a significant relationship was revealed ($R^2 = 0.35$; $P < 0.01$). This indicates that above-ground biomass alone explain 34.75 % of the variation in soil total porosity. With litterfall entered into the model as the second explanatory variable, a significant relationship was also revealed ($R^2 = 0.34$; $P < 0.01$). When species diversity was entered into the model as the third explanatory variable a significant relationship was also

Table 6.6: Stepwise multiple regression results of soil total porosity on the three explanatory vegetation parameters

Independent variables	B coefficients	Standard error	Partial R	R^2	Level of explanation	Multiple R^2	T values
LOGAGB	0.509237	0.120913	0.59	0.35	34.75%	0.8893	4.2116**
LOG LF	1.978582	0.481161	0.58	0.34	33.88%		4.1121**
SD	0.366923	0.122031	0.39	0.15	15.31%		3.0068**

Intercept = 6.034214, ** Significant at 0.01 confidence level

F = 73.43892

revealed ($R^2 = 0.15$; $P < 0.01$). This revealed that above-ground biomass, species diversity and litterfall together explained 88.93% of the variation in soil total porosity. Litterfall accounted for 33.88% of the variation in soil total porosity while litterfall accounted for 15.31%.

Soil total porosity is greatly influenced by these three vegetation variables because as the biomass and species diversity of secondary forest increase, the density of roots in the soil increases and consequently, the soil is loosened and opened up. In addition, the addition of soil organic matter to soil through increase in litterfall with increasing biomass, improves the aggregation of soil particles thus improving soil porosity by increasing the porosity.

Soil Organic Matter (Topsoil)

The regression for topsoil organic matter concentration and the three vegetation explanatory variables is of the form:

$SOM = -9.14 + 0.71SD + 0.99LOGAGB + 0.72LOGLF$

Where

SOM = soil organic matter

LOGAGB =Log of above-ground biomass

LOGLF = Log of litterfall

SD = Species diversity

The three vegetation parameters entered into the regression equation were significant in explaining the variation in topsoil organic matter concentration and jointly account for 91.30 % of the variation soil organic matter. Table 6.7 revealed that above-ground biomass, species diversity and litterfall significantly explain the variation in soil organic matter ($P < 0.05$). When species diversity was entered into the model as the first explanatory variable based on the strength of its relationship with soil organic matter, a significant relationship was observed ($R^2 = 0.45$; $P < 0.01$). This indicates that species diversity alone explain 44.89 % of the variation in soil organic matter. With above-ground biomass entered into the model as the second explanatory variable, a significant relationship was also revealed ($R^2 = 0.25$; $P < 0.01$). When litterfall was entered into the

Table 6.7: Stepwise multiple regression results of soil organic matter and the three explanatory vegetation variables

Independent variables	B coefficients	Standard error	Partial R	R^2	Level of explanation	Multiple R^2	T values
SD	0.705620	0.122031	0.67	0.4489	44.89%		5.7823**
LOGAGB	0.985947	0.281161	0.50	0.2528	25.28%	0.9130	3.5067**
LOGLF	0.719198	0.224161	0.47	0.2178	21.78%		3.2084**

F = 120.11, Intercept = -9.1422, ** Significant at 0.01 confidence level model as the third explanatory variable a significant relationship was also revealed ($R^2 = 0.22$; $P < 0.01$). This revealed that above-ground biomass, species diversity and litterfall together explained 91.95 % of the variation in soil organic matter. Litterfall accounted for 21.78 % of the variation in soil organic matter while above-ground biomass accounted for 25.28 %.

These results indicate the overriding importance of above-ground biomass, species diversity and litterfall in influencing soil organic matter accumulation in secondary forests during fallow period.

Total Nitrogen (Topsoil)

The regression equation for total nitrogen is of the form:

TN = -4.28 + 0.31LOGAGB + 0.25SD + 0.16LOGLF

Where

TN = Total nitrogen

LOGAGB = Logarithm of aboveground biomass

SD = Species diversity

Results in Table 6.8 revealed that above-ground biomass, species diversity and litterfall significantly explain the variation in soil total nitrogen ($P < 0.01$, $F = 138.67$). When above-ground biomass was entered into the model as the first explanatory variable based on the strength of its relationship with total nitrogen, a significant relationship was revealed ($R^2 = 0.48$; $P < 0.01$). This indicates that above-ground biomass alone explain 47.79 % of the variation in soil total nitrogen. With species diversity entered into the model as the second explanatory variable, a significant relationship was also observed ($R^2 = 0.39$; $P < 0.01$). When litterfall was entered into the model as the third explanatory variable a significant relationship was revealed ($R^2 = 0.06$; $P < 0.01$). This revealed that above-ground biomass, species diversity and litterfall together explained 93.42 % of the variation in soil total nitrogen. Litterfall accounted for 6.24% of the variation in soil total nitrogen while species diversity accounted for 39.4 %.

Table 6.8: Stepwise multiple regression results: Total nitrogen and the explanatory vegetation variables

Independent variables	B coefficients	Standard error	Multiple R^2	Partial R	R^2	Level of explanation	T values
LOGAGB	0.306847	0.049332	0.9342	0.69	0.48	47.79%	6.2213**
SD	0.250217	0.050311		0.63	0.39	39.40%	4.9734**
LOG LF	0.161336	0.068322		0.25	0.06	6.24%	2.3614*

F = 138.6736, Intercept = -4.2800, ** Significant at 0.01 confidence level

Soil Available Phosphorus (Topsoil)

The regression equation for available phosphorus is of the form:

$$P = - 4.16 + 0.54SD + 0.42LOGAGB + 0.41LOGLF$$

Where

P = Available phosphorus

LOGAGB =Logarithm of above-ground biomass

SD = Species diversity

LOGLF = Logarithm of litterfall

The results of the regression are summarized in table 6.9.

Table 6.9 revealed that species diversity, above-ground biomass and litterfall significantly explain the variation in soil available phosphorus ($P < 0.01$, $F = 138.67$). When species diversity was entered into the model as the first explanatory variable based on the strength of its relationship with available phosphorus, a significant relationship was observed ($R^2 = 0.37$; $P < 0.01$). This indicates that species diversity alone explained 37.21% of the variation in soil available phosphorus. With above-ground biomass entered into the model as the second explanatory variable, a significant relationship was also observed ($R^2 = 0.32$; $P < 0.01$). When litterfall was entered into the model as the third explanatory variable a significant relationship was observeded ($R^2 = 0.10$; $P < 0.01$). This revealed that above-ground biomass, species diversity and litterfall together explained 79.51 % of the variation in soil available phosphorus. Aboveground biomass accounted for 32.83 % of the variation in soil available phosphorus while litterfall accounted for 9.83 %.

Soil Sodium Concentration

Table 6.10 shows the summary of the results of the regression analysis for sodium concentration of soil and the three explanatory vegetation variables. The three vegetation parameters entered into the regression equation were significant in explaining the variation in topsoil sodium concentration and the three vegetation variables jointly account for 94.72 % of the variation in soil sodium concentration.

Table 6.9: Stepwise multiple regression results: available phosphorus and the vegetation variables

Independent variables	B coefficients	Standard error	Multiple R^2	Partial R	R^2	Level of explanation	T values
SD	0.537937	0.114623		0.6091	0.3721	37.21%	4.6931**
LOGAGB	0.416057	0.103204	0.7951	0.5730	0.3283	32.83%	4.0314**
LOGLF	0.410285	0.151101		0.3135	0.0983	9.83%	2.7153*

F = 71.3614, Intercept = -4.800, * = significant at 0.05, ** = significant at 0.01 confidence levels

Table 6.10: Stepwise multiple regression results: Soil sodium concentration and three explanatory vegetation variables

Independent variables	B coefficients	Standard error	Multiple R^2	Partial R	R^2	Level of explanation	T values
LOGAGB	0.641880	0.079814		0.8290	0.6874	68.74%	8.0422**
SD	0.301303	0.100421	0.9472	0.3833	0.1469	14.69%	3.0004**
LOGLF	0.336492	0.1201242		0.3357	0.1127	11.27%	2.8012*

Intercept = 6.5232, F = 246.3816, ** significant at 0.01, * significant at 0.05

The regression equation for topsoil sodium concentration and the three vegetation explanatory variables is of the form:

$Na = 6.78 + 0.64LOGAGB + 0.30SD + 0.34LOGLF$

Where

Na = Sodium concentration of topsoil

LOGAGB = Logarithm of aboveground biomass

LOGLF = Logarithm of litterfall

SD = species diversity

Analysis of variance for the regression yields an F ratio of 246.3816 which is significant at 0.01 confidence level. Table 6.10 shows that above-ground biomass alone explained 68.74 % of the variation in soil exchangeable sodium. Species diversity explained 14.69 % of the variation in soil exchangeable sodium while litterfall explained 11.27 % of the variation in soil exchangeable sodium.

Magnesium Concentration (Topsoil)

The regression equation of soil magnesium concentration on the three vegetation explanatory variables is of the form:

$LOGMG = 1.68 + 0.47SD + 0.045LOGAGB$

Where

LOGMG = Logarithm of soil magnesium concentration

SD = Species diversity

LOGAGB = Logarithm of above-ground biomass

Table 6.11: shows the summary of the results of the regression analysis for magnesium concentration of soil and the three vegetation explanatory variables. The three vegetation variables entered into the regression equation jointly account for 91.63% of the variation in soil magnesium concentration. Of the three vegetation explanatory variables entered into the regression, two are significant (above-ground biomass 44.99% and species diversity 43.74%) in explaining the variation in soil magnesium concentration at 0.01 level of significant while litterfall (2.99%) is not significant even at 0.05 level of significance in explaining variation in soil magnesium content (Table 6.11). Analysis of

Table 6.11: Stepwise multiple regression results: Soil magnesium concentration and the three vegetation explanatory variables

Independent variables	B coefficients	Standard error	Multiple R^2	Partial R	R^2	Level of explanation	T values
SD	0.473504	0.080342	0.9163	0.6707	0.4499	44.99%	5.8936**
LOGAGB	0.452082	0.079814		0.6614	0.4374	43.74%	5.6642**
LOGLF	0.328105	0.193618		0.1729	0.0299	2.99%	1.6946

Intercept = -1.681576, F = 102.6432, ** = Significant at 0.01 confidence level variance for the regression yielded an F ratio of 102.6432 and is significant at 0.01 confidence level.

Calcium Concentration (Topsoil)

The regression equation for calcium concentration of soil and the three explanatory vegetation variables is of the form:

$\text{LOGCa} = 7.56 + 0.32\text{LOGAGB} + 0.36\text{SD} + 0.51\text{LOGLF}$

Where

LOGCa = Logarithm of Soil calcium concentration

LOGAGB = Logarithm of above-ground biomass

SD = Species diversity

LOGLF = Logarithm of litterfall

Analysis of variance for the regression yielded F ratio of 59.36 which is significant at 0.01. The three vegetation explanatory variables explain 78.34 % of the variation in soil calcium concentration. Table 6.12 shows that above-ground biomass alone explained 40.33 % of the variation in soil exchangeable calcium. Species diversity explained 28.46 % of the variation in soil exchangeable calcium while litterfall explained 9.55 % of the variation in soil exchangeable calcium.

Potassium Concentration (Topsoil)

Table 6.13 revealed that species diversity, above-ground biomass and litterfall significantly explain the variation in soil exchangeable potassium ($P < 0.01$, $F = 11.54$). When above-ground biomass was entered into the model as the first explanatory variable based on the strength of its relationship with exchangeable potassium, a significant relationship was observed ($R^2 = 0.29$; $P < 0.01$). This indicates that species diversity alone explain 29.31 % of the variation in soil exchangeable potassium. With litterfall entered into the model as the second explanatory variable, a significant relationship was also observed ($R^2 = 0.17$; $P < 0.01$). When species diversity was entered into the model as the third explanatory variable a significant relationship was observed ($R^2 = 0.09$; $P < 0.01$). This revealed that above-ground biomass, litterfall and species diversity together explained 56.13 % of the variation in soil exchangeable potassium. Litterfall accounted

Table 6:12: Stepwise multiple regression results: Soil calcium and vegetation explanatory variables

Independent variables	B coefficients	Standard error	Multiple R^2	Partial R	R^2	Level of explanation	T values
LOGAGB	0.323740	0.063682		0.6351	0.4033	40.33%	5.0837**
SD	0.363842	0.093456	0.7834	0.5335	0.2846	28.46%	3.8932**
LOGLF	0.514074	0.192134		0.3090	0.0955	9.55%	2.6756*

Intercept = 7.5622, F = 59.3614, * Significant at 0.05, ** Significant at 0.01 confidence levels

for 17.25 % of the variation in soil available phosphorus while species diversity accounted for 9.25 %.

The regression equation for potassium concentration in soil and three vegetation variables is of the form:

$K = 10.18 + 0.54LOGAGB + 0.54LOGLF + 1.09SD$

Where

K = Soil potassium concentration

LOGAGB = Logarithm of Aboveground biomass

SD = Species diversity

Analysis of variance for the regression yielded an F value of 11.54 which is significant at $P<0.01$ (see table 6.13). The three vegetation explanatory variables explain 56.1 % of the variation in soil potassium concentration. The summary of the regression results is shown in table 6.13 below.

Effective Cation Exchange Capacity (Topsoil)

The regression equation for cation exchange capacity is of the form:

$ECEC = 12.14 + 0.08SD + 0.54LOGAGB + 0.65LOGLF$

Where

ECEC = Effective cation exchange capacity

LOGAGB = Logarithm of above-ground biomass

SD = Species diversity

Table 6.14 shows the summary of the results of the regression analysis for the effective cation exchange capacity of the soil and the three vegetation explanatory variables. The three vegetation explanatory variables jointly account for 54.22 % of the variation in soil effective cation exchange capacity. The three vegetation explanatory variables and soil effective cation exchange capacity regression analysis of variance yielded an F ratio of 11.15 which is significant at 0.01. When above-ground biomass was entered into the model as the first explanatory variable based on the strength of its relationship with effective cation exchange capacity , a significant relationship was revealed ($R^2 = 0.26$; $P < 0.01$). This indicates that aboveground biomass alone explain 26.13 % of the variation in soil effective cation exchange capacity. With species diversity entered into the model

Table 6.13: Stepwise multiple regression results of soil potassium concentration on the three vegetation explanatory variables

Independent variables	B coefficients	Standard error	Multiple R^2	Partial R	R^2	Level of explanation	T values
LOGAGB	0.540668	0.136422	0.561314	0.5414	0.2931	29.31	3.9632**
LOGLF	0.541222	0.173241		0.4153	0.1725	17.25%	3.1241**
SD	1.088133	0.410322		0.3041	0.0925	9.25%	2.6519*

Intercept = 10.180617, F = 11.5432, * Significant at 0.05, ** Significant at 0.01 confidence levels

Table 6:14: Stepwise multiple regression results of soil effective cation exchange capacity on the three vegetation explanatory variables

Independent variables	B coefficients	Standard error	Multiple R^2	Partial R	R^2	Level of explanation	T values
LOGAGB	0.079284	0.021122		0.5112	0.2613	26.13%	3.7536**
SD	0.535261	0.169322	0.5422	0.4260	0.1813	18.13%	3.1612**
LOGLF	0.655309	0.245214		0.3045	0.0927	9.27%	2.6724*

Intercept = 12.140313, F = 11.1544, * Significant at 0.05, ** Significant at 0.01 confidence levels

as the second explanatory variable, a significant relationship was also revealed ($R^2 = 0.18$; $P < 0.01$). When litterfall was entered into the model as the third explanatory variable a significant relationship was revealed ($R^2 = 0.09$; $P < 0.05$). This revealed that aboveground biomass, litterfall and species diversity together explained 54.22 % of the variation in soil effective cation exchange capacity. Species diversity accounted for 18.13% of the variation in soil effective cation exchange capacity while litterfall accounted for 9.27 %.

Soil pH

The regression equation for soil pH is of the form:

pH = 6.32 – 0.99SD -0.69LOGAGB-1.99LOGLF

Where

pH = Soil pH

SD = Species diversity

LOGAGB = Logarithm of above-ground biomass

LOGLF = Logarithm of litterfall

Analysis of variance for the regression yielded an F ratio of 7.86 which is significant at 0.01 levels of significance. The three explanatory variables jointly account for 52 % of the variation in soil pH. When species diversity was entered into the model as the first explanatory variable based on the strength of its relationship with soil pH, a significant relationship was observed ($R^2 = 0.33$; $P < 0.01$). This indicates that species diversity alone explain 33.13 % of the variation in soil pH. With aboveground biomass entered into the model as the second explanatory variable, a significant relationship was also observed ($R^2 = 0.11$; $P < 0.01$). When litterfall was entered into the model as the third explanatory variable a significant relationship was observed ($R^2 = 0.08$; $P < 0.05$). This revealed that aboveground biomass, litterfall and species diversity together explained 52.06 % of the variation in soil effective cation exchange capacity. Above-ground biomass accounted for 11.50 % of the variation in soil pH while litterfall accounted for 8.01 %.

Table 6:15: Stepwise multiple regression results of soil pH and the three explanatory vegetation variables

Independent variables	B coefficients	Standard error	Multiple R^2	Partial R	R^2	Level of explanation	T values
SD	-0.994753	0.242836	0.5206	0.5756	0.3313	33.13%	-4.0964**
LOGAGB	-0.689722	0.243168		0.3391	0.1150	11.50%	-2.8364**
LOGLF	-1.985564	0.763297		0.2830	0.0801	8.01%	-2.6013*

Intercept = 6.320346, F = 7.8634, * = Significant at 0.05, ** = Significant at 0.01 confidence levels

6.7 Regression of Vegetation Variables on the Soil Variables

Having ascertained the relationship between soil properties and vegetation parameters by carrying out a regression of the soil variables on the vegetation variables, attempt is further made here to ascertain the relationship between the vegetation parameters and the soil parameters by carrying out a regression of the vegetation variables on the soil parameters. In this case, the soil parameters become the independent variables while the vegetation variables become the dependent variables.

6.8 Resolving miulticollinearity among soil physico-chemical properties

The independent variables (soil parameters) were tested for multicollinearity using the criteria of Hauser (1974).

Table 6.16 shows the partial correlation coefficient between the soil variables. The correlation coefficients between total porosity and bulk density was more than 0.8, there is therefore, problem of collinearity between them. To resolve the problem of collinearity between them their individual correlation coefficients with above-ground biomass, species diversity and litterfall (vegetation parameters) were observed, to see which has higher relationships with the vegetation parameters based on their correlation coefficients (Table 6.3). Based on the strength of their individual relationships with the vegetation parameters, total porosity was picked for the stepwise regression and bulk density dropped. Available phosphorus, water holding capacity and soil pH are not having problem of collinearity with any soil variable (Table 6.16), however, their individual relationship with each of the vegetation parameters are significant (Table 6.2 and 6.3) hence available phosphorus, water holding capacity and soil pH were entered into the stepwise regression analyses. Soil organic matter and total nitrogen are highly collinear (Table 6.16), however soil organic matter was entered into the regression analysis and total nitrogen dropped based on the strength of the relationships between soil organic matter and each of the three vegetation explanatory variables (Table 6.2).

Table 6.16 Correlation Matrix for Soil Physicochemical Properties

S/N	Soil properties	1	2	3	4	5	6	7	8	9	10	11	12
1	Bulk density	1.00	-0.99	0.62	-0.53	0.26	-0.52	-0.46	-0.51	-0.38	-0.61	-0.53	-0.37
2	TP		1.00	0.74	0.78	-0.18	0.58	0.38	0.41	0.44	0.39	0.34	0.31
3	WHC			1.00	0.78	-0.55	0.79	0.47	0.53	0.62	0.46	0.42	0.83
4	SOM				1.00	-0.47	0.84	0.45	0.48	0.44	0.42	0.47	0.46
5	Soil P^H					1.00	-0.29	0.19	0.21	0.16	0.24	0.22	0.20
6	TN						1.00	0.46	0.52	0.48	0.47	0.48	0.49
7	P							1.00	0.73	0.76	0.71	0.74	0.73
8	Na								1.00	0.89	0.86	0.84	0.93
9	K									1.00	0.88	0.92	0.95
10	Mg										1.00	0.89	0.89
11	Ca											1.00	0.91
12	ECEC												1.00

Note correlations above 0.8 are having problem of collinearity

WHC = Water Holding Capacity, TN = Total Nitrogen, TP = Total Porosity

Exchangeable sodium, magnesium, potassium and calcium are having problem of multicollinearity among themselves and with ECEC (Table 6.16). Based on the strength of the bivariate correlation between sodium and the three vegetation explanatory variables (above-ground biomass, litterfall and species diversity), which is higher than those of ECEC, potassium, magnesium and calcium (Table 6.2), sodium was entered into the regression analysis and ECEC, potassium, calcium and magnesium dropped. These soil variables (total porosity, soil organic matter, exchangeable sodium, water holding capacity, available phosphorus and soil pH) were regressed on species diversity and estimated above-ground biomass.

Species Diversity

Regression of species diversity on the six soil variables produced a regression model of the form:

$SPD = -2.65 + 0.14Na + 0.85SOM + 0.48WHC + 0.11TP$

Analysis of the data on table 6.17 showed that the six soil parameters taken together explained 89.11% of the variation in species diversity. As shown in the table no ‘B’ (independent variable) coefficient is zero, thus all the six soil parameters affected species diversity and their joint effects on species diversity is significant at 0.01 significant level of the ‘F’ statistics, considering the fact that their ‘F’ value is 36.81. However, ‘t’ test for the significance of the individual soil variables towards the explanation of variation in species diversity shows that four of the six soil variables are significantly correlated with species diversity.

When exchangeable sodium was entered into the model as the first explanatory variable based on the strength of its relationship with species diversity, a significant relationship was observed ($R^2 = 0.23$; $p < 0.01$). This indicates that exchangeable sodium alone explained 23.63 % of the variation in species diversity. Soil organic matter, water holding capacity and total porosity explained 22.49 %, 18.77 % and 18.74% respectively of the variation in species diversity (Table 6.17). Available phosphorus and soil pH did not significantly explain the variation in species diversity (3.03% and 2.45 %).

Table 6.17: Stepwise regression of species diversity on the soil explanatory variables

Independent variables	B coefficient	Std error	Multiple R^2	Partial R	R^2	Level of explanation	T values
Na	0.1440	0.0478		0.4866	0.2363	23.63	3.01 **
SOM	0.8565	0.2861	0.8911	0.4774	0.2249	22.49	2.99 **
WHC	0.4811	0.1926		0.4332	0.1877	18.77	2.50 **
TP	0.1107	0.0497		0.4330	0.1874	18.74	2.23 **
P	0.1254	0.1340		0.1741	0.030	3.03	0.94NS
pH	-0.0240	0.1246		0.1565	0.0245	2.45	-0.2NS

Intercept = -2.6504, F = 36.812, ** = Significant at 0.01, NS = Not significant

The combined effects of these soil characteristics serve to improve soil fertility, affect plant growth, regeneration and establishment of plants, thereby resulting in increasing species diversity as these soil properties increase over time. Cousins and Erikson (2002); Bochet and Garcia-Fayos (2004); De Bello, Leps and Sebastia (2006)and Cristofoli, Monty and Mahy (2010) reported that the combined effects of soil organic matter, water holding capacity, exchangeable sodium and total porosity helped to improve soil fertility thereby resulting in increasing species diversity as these soil properties increased over time. Soil pH and available phosphorus, had no significant effects on species diversity. Reitatua *et al*., (2009) and Bakhtiar and Ali (2011) observed that soil pH

Above-ground Biomass

Regression of aboveground biomass on the six soil parameters produced a regression model of the form:

$$LOGAGB = -17.53 + 0.53WHC + 0.76TP + 0.68SOM + 0.41Na - 0.79P^{H} – 0.38P$$

Where

AGB = Above-ground biomass

All the other variables in the equation are as defined in the species diversity equation. As with the previous the regressions of the soil variables on the vegetation variables, soil pH has negative sign, while the other soil variables have positive signs. All the soil explanatory variables jointly account for 81.62 % of the variation in vegetation aboveground biomass. Analysis of variance for the regression equation yielded an ‘F’ value of 61.23 which is statistically significant at the 0.01 confidence level. Soil exchangeable sodium, water holding capacity, total porosity, soil organic matter and pH explained 26.42 %, 18.46 %, 16.48 %, 11.72 % and 5.97 % respectively of the variation in aboveground biomass of vegetation. However, the influence of available phosphorus (2.58 %) in explaining variation in aboveground biomass is not statistically significant at 0.05 level of significant.

Table 6.18: Stepwise regression of above-ground biomass on the six soil explanatory variables

Independent variables	B coefficient	Std error	Multiple R^2	Partial R	R^2	Level of explanation	T values
WHC	0.5334	0.0932		0.5140	0.2642	26.42	5.72**
TP	0.7652	0.1914	0.8162	0.4296	0.1846	18.46	5.99 **
SOM	0.6846	0.1918		0.4059	0.1648	16.48	3.57 **
Na	0.4122	0.1624		0.3423	0.1172	11.72	2.54 **
pH	-0.7946	0.6141		0.2444	0.0597	5.97	-1.29**
P	0.3817	0.6836		0.1606	0.0258	2.58	0.56NS

Intercept = -19.8216, F = 61.28, ** = Significant at 0.01, NS = Not significant

Moving away from the individual regression models, we now turn to the goodness of the models in general. From the results presented in tables 6.3-6.18, and going by the diagnostic statistics of the models namely R-squared, and ‘F’ statistics, it can be inferred that the models constructed adequately explained the relationships between soil physicochemical properties and vegetation biomass parameters and species diversity.

The results obtained showed that soil organic matter, water holding capacity, total porosity exchangeable sodium and soil pH are significantly related to the vegetation estimated above-ground biomass. While the soil available phosphorus is not statistically significantly related to the vegetation above-ground biomass. Similarly, the soil water holding capacity, total porosity, soil organic matter and exchangeable cation are significantly related to species diversity while soil pH and available phosphorus are not.
Therefore, the hypothesis that soil physical and chemical properties significantly affect vegetation biomass and the diversity of species in secondary forest is accepted.

6.9 DISCUSSION

The results of the Pearson products moment correlation and stepwise regression analysis presented in this chapter emphasized the following facts:

1 Two of the three vegetation parameters aboveground biomass and species diversity exert the most influences on the nutrient status of soil and soil physical properties. This presupposes that secondary forest with adequate aboveground biomass and high diversity of species is more efficient in restoring soil nutrient status during the course of secondary succession than one with inadequate aboveground biomass (which is a measure of ground cover, tree density, numbers of tree, tree diameter and tree height) and low diversity of species. This finding agrees with the assertion of Bakhtiar and Ali (2011) and Erikson and Cousins (2002) that secondary forest with abundant aboveground biomass and species diversity encourage the build up of nutrients during the course of secondary forests regeneration.

2 Above-ground biomass, species diversity and litterfall exert strong influences on soil organic matter concentration, sodium concentration of soil and total porosity. As aboveground biomass increases litter production and root density increases and as litter production increases the activities soil fauna such as earthworms which help in loosening the soil increases also. This increases the porosity of the soil and the ability of the soil to hold water. This had earlier been reported in previous studies by Nye and Greenland (1960) in Ghana, Toky and Ramakrishnan (1983) in India and Bakhtiar and Ali (2011) in Iran.

3 The results of the Pearson product moment correlation and stepwise regression analysis show that vegetation aboveground biomass and species diversity are significantly related to soil exchangeable cations, soil organic matter, available phosphorus, total nitrogen, bulk density of soil, total porosity and water holding capacity with the former exerting the greater influence on water holding capacity and total porosity than the latter. The signs of the regression analysis suggest that the aboveground biomass and species diversity are negatively related to soil pH and soil bulk density. This is not strange because an increase in aboveground biomass and species diversity results in increased litterfall and increased root density in the soil resulting in increase microbial activities and the loosening of the soil thereby leading to decrease in soil pH and bulk density. The overriding influence of species diversity and aboveground biomass on soil physico-chemical properties was previously reported by Proctor *et al.* (1983), Toky and Ramakrishnan (1983) and Manlay *et al*., (2000).

However, it must be emphasized that this relationship does not imply that the soil nutrient status can be predicted from the vegetation aboveground biomass and the species diversity all the time. Though the 10-year old secondary forest has aboveground biomass that is more than twice the value of the 5-year old secondary forest, the 5-year secondary forest has more nutrients in the soil than the 10-year fallow. It will therefore be too simplistic to assume that higher aboveground biomass parameters such as higher tree diameter, tree density, tree height, tree cover and tree basal area in secondary forest in the tropical area are sure indications of higher soil nutrient content in the soil.

CHAPTER SEVEN

SUMMARY, CONCLUSION AND POLICY IMPLICATION

7.1: Introduction

This study demonstrates that the soil in rubber plantation plots which are degraded and abandoned for secondary forest to colonize, are capable of rejuvenating their fertility levels to the equilibrium level which is obtained in the mature forest if the regrowths forests are left long enough to fallow. Thus the main conclusions and findings emanating from this research can be summarized below.

7.2: Changes in Soil Physico-chemical Properties

Secondary forest development in areas used for rubber plantation and later abandoned was associated with changes in soil properties. These changes are:

1. Natural increase of soil organic matter as the age of secondary forest increases. In the study area the build-up of soil organic matter under secondary forest through time is significantly different among all the fallow categories and between the mature forest and the oldest secondary forest studied (10-year old secondary forest). The progressive accumulation of soil organic matter during the fallow period indicated that the accumulation of carbon in fallow vegetation is attained without any decrease in the level of soil carbon. This is because green plants are capable of synthesizing carbon compounds and do not depend directly on soil carbon (Post and Kwon, 2000; Feldpausch *et al*. 2004).

2. There is progressive build up of total nitrogen in both the topsoil and the subsoil, though the former has higher concentration of total soil nitrogen than the latter. The difference between the nitrogen content of soil in the different categories of fallow are significant. There is high nitrogen concentration in both the topsoil and the subsoil of the secondary forests studied. This may be due to addition through atmospheric deposition and nitrogen fixation.
3. The concentrations of exchangeable cations in the topsoil are higher than their concentration in the subsoil and also change significantly with increasing age of

fallow. The higher concentration of exchangeable cations in the topsoil than the subsoil is due to higher microbial activities at the topsoil and addition of nutrient cations to the topsoil through litterfall, atmospheric deposition and addition through stemflow and throughfall.

4. There is a progressive build-up of exchangeable cations in the soil till about the fifth year of soil regeneration after which there is a decline by the tenth year due to higher tree density at this time and rapid immobilization of the exchangeable cations by these trees which have become fully established by this time.

5. The mean levels of exchangeable calcium, magnesium and sodium concentrations are lower in the subsoil of the 10-year old secondary forest than they are in the 1-year old fallow. While for the topsoil the mean levels of exchangeable calcium and sodium are higher in the 10-year old secondary forest than they are in the 1-year old secondary forest. This is probably due to rapid rate of leaching of nutrients from the topsoil to the subsoil in the young fallows than the older secondary forest. In addition, it also suggests that the roots of the woody vegetation of the older secondary forests are more efficient than those of the *Chromolena odorata* (forb fallow) which characterize the 1-year old fallow in transferring nutrients from the subsoil to the topsoil. This was also the opinion of Aweto (1978).

6. The concentration of available phosphorus in the soil increased in the first five year of secondary forest regeneration after the abandonment of the degraded plantation after which it decreased by the tenth year below the level of available phosphorus in the soil of the 1-year old secondary forest. The implication of this is that, should this trend continue, phosphorus may become limiting to tree growth the older the forest becomes, unless other factors such as reduced phosphorus uptake by plants, increase deep soil phosphorus mining from subsoil by plants or increase in the rate at which unavailable forms of soil phosphorus shift to plant available phosphorus forms to replenish immobilized plant available soil phosphorus.

7. There are significant changes in soil bulk density, total porosity and water holding capacity between the first and tenth year of secondary forest regeneration from degraded abandoned plantation. While bulk density decreases significantly with increasing age of the secondary forest total porosity and water holding capacity increase significantly with increasing age of secondary forest. This suggests that natural secondary forest vegetation improves soil physical status (total porosity, water holding capacity and soil bulk density) over time.

8. There are no significant differences in the proportion of sand, clay and sand among the soil of the secondary forest studied in this work. All the soils are texturally similar. The textural homogeneity of soils under the secondary forests thus validates the use of the inferential method in this work. Thus the higher soil organic matter content, CEC and exchangeable cations recorded in the mature forest as compared to those of young fallows can be related to an increase in tree biomass and larger litter inputs (Nye and Greenland, 1960). The control of soil organic matter over CEC and some cations such as calcium and magnesium has already been widely reported for this class of soil (Asadu *et al*., 1997).

7.3: Changes in Vegetation Aboveground Biomass and Species Diversity

Major changes in aboveground biomass and species diversity take place in the plant community during the course of secondary forest regeneration from degraded abandoned rubber plantation. Both the foliage biomass and the wood (bole) biomass increase significantly with increasing age of fallow. While species diversity increases significantly with increasing age of fallow, dominance of species decreases with increasing age of secondary forest. In the early stage of secondary forest regeneration herbaceous plants and forbs dominates the spatial structure but are eventually replaced by woody species as the secondary forest becomes older.

Aboveground biomass increases with increasing age of fallow while the quality of biomass (measured by the nutrient concentration of aboveground biomass) decreases with increasing age of the secondary forest. The nutrient concentration of aboveground biomass is higher in the young secondary forest than the old and mature secondary forest.

The management implication of this is that, in the preparation of compost manure with plant biomass, the use of the leaves of plants from the younger secondary forests should be encouraged rather than using the leaves from plants in the older secondary forest and the mature forest. Similarly, mulching as practised in the study area should emphasize the use of the leaves of plants of the young secondary forest since they have higher concentration of nutrients.

The nutrient content of aboveground biomass increases significantly with increasing age of secondary forest due to linear increase in aboveground biomass with age. Except nitrogen, the quantities of the other nutrients elements are higher in the aboveground biomass than the top 30cm of the soil. This suggests that the slash and burn system of agriculture as practised in the study area is more beneficial the longer the duration of fallows. This is more so considering the fact that though the five year old fallow has higher soil nutrient content, than the 10-year old secondary forest, the amount of all the nutrient elements in the aboveground biomass of the 5-year old secondary forest is lower than that of the 10-year old secondary forest. The implication of this is that continuous logging and fuel wood exploitation would constitute a huge drain on the soil nutrients of secondary forests regenerating from abandoned rubber plantation as such, these activities should be discouraged in the study area. To ensure sustainable management of the soil of secondary forest regenerating from degraded abandoned rubber plantation, in the event of clear felling for agriculture either the felled trees and plants should be allowed to decay in situ or burnt to return the nutrients immobilized by the plants to the soil prior to cultivation.

7.4: Changes in Litterfall

The changes in litterfall during the course of secondary forest regeneration from abandoned rubber plantations are;

a. Litterfall increased significantly with the age of the secondary forest up to 11.2 tons per hectare in a 10-year old secondary forest.

b. There is seasonality of litterfall in all the secondary forest categories and the mature forest, with maximum litterfall occurring during the dry season in all the fallow categories and the mature forest. However, there is varied seasonal pattern of some species with some shedding their leaves during the wet season.

c. Litter nutrient concentrations decrease with increasing age of secondary forest. Despite the decrease in nutrients concentration of litter with increasing age of secondary forest, the gross increase in litterfall with increasing age of secondary forest, results in increasing rate of return of nutrient through litterfall with increasing age of secondary forest.

d. Litter nutrient concentrations reached their minima during the period of peak litterfall in all the fallow categories (which is during the dry season) and their maximum during the period of least litterfall (which is the rain season). Despite a reduction in nutrient concentration in the dry season, the gross increase in litterfall during the dry season results in higher nutrients input to soil through litterfall in the dry season than the rain season. This evidence suggests that the trees reabsorbed essential nutrients prior to massive litterfall in the dry season.

7.5: Nutrient Held in the Total Ecosystem

The nutrient content of the soil, aboveground biomass and litterfall (i.e. the total ecosystem) significantly increase with increasing age of the secondary forest. This indicates that the older the secondary forest, the more the nutrients that are retained in the total ecosystem.

Total nitrogen pool for the top 30cm of the soil is more than that of the vegetation in all the fallow categories, and that of mature secondary forest is about evenly divided between the soil and the vegetation. With the exception of available phosphorus and potassium, the pool of exchangeable calcium, magnesium and sodium are higher in top 30cm of the soil than the vegetation in the 1-year old secondary forest. The pool of nutrients in the vegetation is more than that of the top 30cm of the soil for the mature forest and the older fallows (5-year and 10-year old secondary forest).

7.6: Conclusion

The dynamics of soil physico-chemical properties and vegetation floristic and structural properties in relation to the age of secondary forests are essential given that the soil nutrients and vegetation structural and floristic attributes of secondary forests do not remain constant as secondary forests increase in age. This was reported in secondary forests in different parts of the world (Brown and Lugo 1990; Chandreshekera and Ramakrishnan, 1994; Aweto 1981; Toky and Ramakrishnan 1981b; Aide *et al*. 1995; Bautista-Cruz and del Castillo 2005). As noted earlier, the investigation was based on an inferential approach which involved comparison of both the physical and chemical attributes of soils under secondary forest of different ages in a monolithologic zone of sandstone parent materials. The different plots have similar history of cultivation, thereby eliminating the distortion of estimates of the rate of change in soil and vegetation properties that may have arisen from different histories of cultivation and variation in land use intensity.

This work demonstrates the regenerative capacity of tropical secondary forests to rebuild the soil nutrient capital following the abandonment of degraded rubber plantation. Even though the secondary forests were close to each other, soil nutrients were significantly higher in the 5-year and 10-year old secondary forests than the 1-year old secondary forest due to improvement in soil nutrient as a result of soil fertility rejuvenation due to fallow. The management of the soil of regenerating secondary forests following the abandonment of degraded rubber plantation through fallowing as practiced in the study area would be a significant contribution towards the rejuvenation of the soil in secondary forests regenerating from degraded abandoned rubber plantation. Therefore, fallowing as practiced in the study area should be encouraged and sustained.

7.7: Implications for Future Research and Practice

The observations from this study revealed that the proportion of nutrient stored in plants biomass to that of nutrient stored in the soil increased with increasing age of fallow. The implication of this is that the older the secondary forests, the higher are the amount of nutrients stored in their plant biomass. Based on this, burning the secondary forests prior to cultivation is more beneficial in the older secondary forest. However further research is needed to spotlight the effects of slash and burn on the soil of secondary forest regenerating from degraded abandoned rubber farms to throw more light on usefulness of burning in managing the soil of this type of ecosystem.

The study also suggests that leaving secondary forests regenerating from degraded abandoned rubber farms to fallow for 5 to 10 years is capable of restoring the fertility of the soil for sustainable agriculture. The management implication of this is that secondary forests of this types that are to be put to agricultural use should be left for a maximum of 5 years before being put to cultivation. Further study on the changes in soil in secondary forests over time should be based on the use of the direct method which would involve monitoring the changes in the soil right from the beginning of fallow to when mature forest is established. This will help to eliminate the inherent problems associated with the inferential method used in this study.

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APPENDIX 4:1 SOIL TEXTURAL COMPOSITION

1-year fallow

Topsoil			Subsoil		
Sand (%)	**Clay (%)**	**Silt (%)**	**Sand**	**Clay**	**Silt**
81.26	16.38	2.36	79.94	17.57	2.49
82.74	16.30	0.96	82.13	17.50	0.37
82.01	15.03	2.96	81.07	16.43	2.50
81.90	16.74	1.36	80.03	18.05	1.92
81.92	16.71	1.37	80.21	18.02	1.77
83.14	16.50	0.36	81.01	17.92	1.07
82.06	16.08	1.86	80.08	18.95	4.01
81.90	16.64	1.46	79.04	18.01	2.95
80.97	15.68	3.35	77.04	18.95	4.01
82.19	15.40	2.41	79.53	16.59	3.88

5-year old fallow

Topsoil			Subsoil		
Sand (%)	**Clay (%)**	**Silt (%)**	**Sand**	**Clay**	**Silt**
84.21	15.07	0.72	80.94	18.03	1.03
85.06	14.014	0.93	83.21	15.91	0.88
83.19	16.22	0.59	79.99	18.14	1.87
84.32	14.17	1.51	81.01	18.57	0.42
82.99	16.24	0.77	80.54	17.38	2.08
86.34	12.19	1.47	81.22	18.12	0.66
84.27	14.11	1.62	82.00	17.54	0.46
81.95	17.04	1.01	81.10	18.02	0.88
84.28	14.73	0.99	80.13	17.29	1.58
84.11	14.38	1.51	80.21	17.90	1.89

10-year old fallow

Topsoil			Subsoil		
Sand (%)	Clay (%)	Silt (%)	Sand	Clay	Silt
83.01	14.39	2.6	79.04	19.12	1.84
83.31	15.02	1.67	81.26	17.31	1.43
8.11	14.06	1.83	80.17	17.46	2.37
82.14	15.13	2.73	79.53	19.27	1.20
85.36	13.89	0.75	81.11	17.24	1.65
83.24	15.18	1.58	81.38	17.52	1.10
83.16	15.39	1.45	81.45	18.13	0.33
83.23	15.91	0.86	81.06	18.04	09.0
81.97	16.24	1.79	81.96	17.09	0.95
80.98	17.14	1.85	80.93	18.07	1.00

Mature forest

Topsoil			Subsoil		
Sand (%)	Clay (%)	Silt (%)	Sand	Clay	Silt
81.21	18.03	0.76	79.24	18.52	2.24
80.93	15.91	3.16	79.13	18.88	1.99
81.14	17.38	1.48	79.11	18.13	2.76
79.56	18.12	2.32	78.96	19.28	1.76
81.01	17.24	1.95	79.17	18.16	2.67
82.02	17.04	0.94	79.24	20.11	0.65
79.13	17.12	3.75	79.34	20.01	0.65
80.57	18.02	1.41	79.18	19.83	0.99
80.22	18.14	1.64	79.24	19.57	1.19
81.11	18.16	0.73	79.16	19.66	1.18

Appendix 4:2 Summary of the results obtained by analysis of variance for soil physicochemical properties

D F	Soil parameters	Source of variation	Sum of squares	Variance estimate (MSE)	F values	F probability
3	Total porosity	Between samples	167.84	55.95	21.96	0.0001
36		Within samples	91.72	2.55		
3	Bulk density	Between samples	0.11019	0.0367	18.26	0.0001
36		Within samples	0.07241	0.0020		
3	Water holding capacity	Between samples	95.56	31.85	43.17	0.0000
36		Within samples	26.56	0.74		
3	pH	Between samples	4.05	1.35	12.27	0.0001
36		Within samples	4.04	0.00		
3	Soil organic Matter	Between Samples	58.72083	19.574	183.35	0.0000
36		Within samples	3.84317	0.107		
3	Magnesium	Between samples	80891.225	26963.74	77.78	0.0000
36		Within samples	13157.275	365.48		
3	Calcium	Between samples	618983.989	17193.99	75.29	0.0000
36		Within samples	8221.641	283.38		
3	Sodium	Between samples	9621.89	3240.83	1017.68	0.0000
36		Within samples	114.636	3.18		
3	Potassium	Between samples	8208.506	2736.17	211.91	0.0000
36		Within samples	464.834	12.91		
3	Available phosphorus	Between samples	377.64	125.88	8.492	0.0000
36		Within samples	5.63	0.16		
3	Total nitrogen	Between samples	0.72918	0.24306	132.94	0.0000
36		Within samples	0.06582	0.001833		
3	ECEC	Between samples	738.04718	246.02	2259.10	0.000
36		Within samples	38.65742	1.07		
3	Sand	Between samples	66.16	22.06	0.95	0.2351
36		Within samples	833.05	23.14		
3	Clay	Between samples	0.8234	0.27440	0.797	0.4533
36		Within samples	12.3876	0.3441		
3	Silt	Between samples	1.104	0..368		
36		Within samples	13.572	0.377	0.976	0.2240

Appendix 4.3: Post hoc multiple comparison of soil properties using the least significant differences (LSD)

Soil properties	Pairs of fallow categories	Mean difference	STD errors	Significant level
pH	1 and 5-year	0.33	0.1483	0.0412
	1 and 10-year	0.84	0.1483	0.0009
	1 and forest	0.14	0.1483	0.4822 *
	5 and 10-year	0.51	0.1483	0.0024
	5 and forest	0.19	0.1483	0.2511 *
	10-year and forest	0.70	0.1483	0.0013
Soil organic matter	1 and 5-year	0.97	0.1463	0.0001
	1 and 10-year	2.62	0.1463	0.0001
	1-year and forest	2.98	0.1463	0.0001
	5 and 10-year	1.65	0.1463	0.0001
	5-year and forest	2.01	0.1463	0.0001
	10-year and forest	0.36	0.1463	0.0020
Bulk density	1 and 5-year	0.02	0.020	0.2731*
	1 and 10-year	0.08	0.020	0.0008
	1-year and forest	0.15	0.020	0.0006
	5 and 10-year	0.06	0.020	0.0021
	5-year and forest	0.13	0.020	0.0005
	10-yar and forest	0.06	0.020	0.0009
Total porosity	1 and 5-year	0.87	0.7141	0.2141*
	1 and 10-year	3.07	0.7141	0.0011
	1-year and forest	5.78	0.7141	0.0007
	5 and 10-year	2.15	0.7141	0.0146
	5-year and forest	4.91	0.7141	0.0009
	10-year and forest	2.76	0.7141	0.0019
Water holding capacity	1 and 5-year	7.87	0.1480	0.0000
	1 and 10-year	10.98	0.1480	0.0000
	1-year and forest	19.06	0.1480	0.0000
	5 and 10-year	3.12	0.1480	0.0000
	5-year and forest	11.18	0.1480	0.0000
	10-year and forest	8.07	0.1480	0.0000
calcium	1-yer and 5-year	104.5	56.6760	0.0000
	1 and 10-year	6.9	56.6760	0.6322 *
	1-year and forest	308.1	56.6760	0.0000
	5-year and 10-year	97.6	56.6760	0.0000
	5-year and forest	203.6	56.6760	0.0000
	10-year and forest	301.2	56.6760	0.0000
Sodium	1 and 5-year	27.62	0.6360	0.0000
	1 and 10-year	20.32	0.6360	0.0002
	10-year and forest	43.82	0.6360	0.0000
	5 and 10-year	7.30	0.6360	0.0009
	5-year and forest	16.20	0.6360	0.0004

	10-year and forest	23.50	0.6360	0.0001
Magnesium	1 and 5-year	65.6	73.096	0.0000
	1 and 10-year	16.3	73.096	0.0923 *
	1 and forest	125.6	73.096	0.0000
	5 and 10-year	81.9	73.096	0.0000
	5-year and forest	60.0	73.096	0.0000
	10-year and forest	141.9	73.096	0.0000
Potassium	1 and 5-year	9.20	2.5820	0.0003
	1 and 10-year	2.98	2.5820	0.0923 *
	1-year and forest	36.20	2.5820	0.0000
	5 and 10-year	6.22	2.5820	0.0008
	5-year and forest	27.0	2.5820	0.0001
	10-year and forest	33.22	2.5820	0.0001
Total nitrogen	1 and 5-year	0.04	0.0004	0.0220
	1 and 10-year	0.16	0.0004	0.0001
	1-year and forest	0.35	0.0004	0.0001
	5 and 10-year	0.12	0.0004	0.0001
	5-year and forest	0.31	0.0004	0.0001
	10-year and forest	0.19	0.0004	0.0001
Available phosphorus	1 and 5-yer	3.9	0.0320	0.0001
	1 and 10-year	0.34	0.0320	0.0532 *
	1-year and forest	0.69	0.0320	0.0001
	5 and 10-year	4.24	0.0320	0.0001
	5-year and forest	2.79	0.0320	0.0001
	10-year and forest	7.03	0.0320	0.0001
ECEC	1 and 5-year	1.93	0.2140	0.001
	1 and 10-year	0.90	0.2140	0.0516 *
	1 and forest	3.04	0.2140	0.0001
	5 and 10-year	1.03	0.2140	0.0452
	5-year and forest	1.11	0.2140	0.0423
	10-year and forest	2.10	0.2140	0.0001

Note: * is not significant at 0.05 significant level.

APPENDIX 5.1 Density of predominant plant species (per hectare) and frequency in regenerating secondary forests up to 10 years old and a primary forest in Orogun n=50

Plant Species	1-year old secondary forest		5-year old secondary forest		10-year old secondary forest		Primary Forest	
	Frequency %	Density	Frequency %	Density	Frequency %	Density	Frequency %	Density
Chromolena odorata	100	159500	100	6000	-	-	-	-
Elusine indica	40	3000	30	600	-	-	-	-
Panicum maximum	40	4300	-	-	-	-	-	-
Ageratum conyzoides	40	1700	-		-	-	-	-
Maesobotrya barteri	5	42	40	200	30	100	90	301
Aspilia Africana	60	6	20	4	-	-	-	-
Cnetis feruginea	-	-	70	7.2	70	9.7	-	-
Paspalum	-	-	70	5.6	-	-	-	-
Pentaclethra macrophylum	-	-	30	1.2	20	1.6	80	8.0
Balphia nitida	-	-	60	8	80	19.7	70	111.2
Blighia sapida	-	-	10	1.2	50	14	80	80
Albizia adianthifolia	-	-	-	-	40	324	80	412
Antiaris toxicaria	-	-	40	320	60	506	100	486
Anthonatha macrophyla	-	-	60	1170	100	1440	40	492
Sarcabus vermiculatus	-	-	60	7.2	70	14.8	60	9.6
Purshia tridenta	-	-	60	5.2	70	11.2	60	112.4
Alstonia boonei	-	-	-	-	-	-	60	9.2
Lecaniodiscus cupaniodes	-	-	60	2.4	80	6.4	-	-
Microdesmis puberula	-	-	60	2.8	70	6.8	-	-
Ricinodendron heudelotti	-	-	-	-	-	-	70	7.2
Sterculia tragacantha	-	-	-	-	-	-	90	7.2
Centrosema pubescens	-	-	-	-	-	-	70	8.4
Elaeis guinensis	40	1.6	50	2	80	3.2	60	16
Celtis Africana	-	-	-	-	-	-	70	2.8
Cleistopholis patens	-	-	-	-	-	-	70	2.8

Berlinia grandifolia	-	-	-	-	50	3.2	80	32
Havea brasiliensis	10	0.4	40	1.6	20	0.8	-	-
Piptadeniastrum Africanum	-	-	-	-	-	-	70	2.8
Nauclea dederrichi	-	-	-	-	60	4.8	50	20
Triplochiton scleroxylon	10	0.4	40	1.6	30	2	70	2.8
Scottellia coriacca	-	-	-	-	10	0.4	60	2.4
Macaranga barteri	-	-	40	2	50	0.48	-	-
Ravolfia vomitoria	-	-	50	2	60	2.4	-	-
Funtumia elastica	-	-	-	-	60	3.2	90	3.6
Harungana madagascariensis	-	-	50	2	60	28	-	-

Appendix 5.2

Post hoc multiple comparisons of the means of vegetation floristic characteristics of the different forest categories using the least significant differences (LSD)

Floristic characteristics	**Pairs of fallow categories**	**Mean difference**	**STD errors**	**Significant level**
Species diversity	1-year and 5-year	32.17	1.8412	0.0001
	1-year and 10-year	34.59	1.8412	0.0001
	1-year and forest	34.68	1.8412	0.0001
	5-year and 10-year	2.42	1.8412	0.1952*
	5 and forest	2.51	1.8412	0.1732*
	10-year and forest	0.09	1.8412	0.7331*
Number of tree species	1-year and 5-year	12.4	1.0431	0.0001
	1-year and 10-year	14.0	1.0431	0.0001
	1-year and forest	22.2	1.0431	0.0001
	5-year and 10-year	1.6	1.0431	0.4612*
	5-year and forest	9.8	1.0431	0.0024
	10-year and forest	8.2	1.0431	0.0043
Number of plant species	1-year and 5-year	11.3	2.9240	0.0001
	1-year and 10-year	18.1	2.9240	0.0001
	1-year and forest	28.6	2.9240	0.0001
	5-year and 10-year	6.8	2.9240	0.0464
	5-year and forest	17.3	2.9240	0.0001
	10-year and forest	10.5	2.9240	0.0001

Values with the superscript * are not significant at 0.05 significance level

Appendix 5.3

Post hoc multiple comparisons of the means of vegetation aboveground biomass characteristics of the different forest categories using the least significant differences (LSD)

Biomass characteristics	Pairs of fallow categories	Mean difference	STD errors	Significant level
Tree diameter	1-year and 5-year	3.72	0.4980	0.0001
	1-year and 10-year	8.20	0.4980	0.0001
	1-year and forest	19.64	0.4980	0.0001
	5-year and 10-year	4.48	0.4980	0.0001
	5 and forest	15.92	0.4980	0.0001
	10-year and forest	11.39	0.4980	0.0001
Tree height	1-year and 5-year	2.44	0.0894	0.0001
	1-year and 10-year	4.70	0.0894	0.0001
	1-year and forest	6.97	0.0894	0.0001
	5-year and 10-year	2.26	0.0894	0.0001
	5-year and forest	4.53	0.0894	0.0001
	10-year and forest	2.27	0.0894	0.0001
Tree basal area	1-year and 5-year	2.60	2.9048	0.3212*
	1-year and 10-year	18.05	2.9048	0.0001
	1-year and forest	72.83	2.9048	0.0001
	5-year and 10-year	15.45	2.9048	0.0001
	5-year and forest	70.23	2.9048	0.0001
	10-year and forest	54.78	2.9048	0.0001
Tree density	1-year and 5-year	3.58	0.3193	0.0001
	1-year and 10-year	6.96	0.3193	0.0001
	1-year and forest	5.28	0.3193	0.0001
	5-year and 10-year	3.35	0.3193	0.0001
	5-year and forest	1.70	0.3193	0.0001
	10-year and forest	1.68	0.3193	0.0001

Values with the superscript * are not significant at 0.05 significance level

APPENDIX 5.4

Summary table of the results obtained by analysis of variance for vegetation parameters

Parameter	Source of variation	Sum of squares	MSE	Calculated F	Probability of F	DF	Decision
Above ground biomass	Between samples	757179.98	252393.33		0.0000	3	Significant
	Within samples	28064.66	779.57	323.76		36	
Litterfall	Between samples	60409.35	20136.45			3	
	Within samples	78892.39	1793.01	11.23	0.001	36	Significant
Species diversity	Between samples					3	
	Within samples					36	
Basal area	Between samples	34534.02	11211.34	272.85	0.0000	3	Significant
	Within samples	1518.98087	42.19			36	

Apendix 5.5

Multiple comparisons using the least significant differences post hoc test for litter nutrient concentration

Name of elements in litter fall calcium	Pairs of fallow categories	Mean difference	Std errors	Significant level	LSD	Remarks
Calcium	1-year and 5-year	1.20	0.1291	0.001	0.64	Significant
	1-year and 10-year	3.43	0.1291	0.001	0.64	Significant
	1-year and forest	3.97	0.1291	0.001	0.64	Significant
	5-year and 10-year	2.23	0.1291	0.001	0.64	Significant
	5-year and forest	2.57	0.1291	0.001	0.64	Significant
	10-year and forest	0.54	0.1291	0.001	0.49	Significant
Sodium	1-year and 5-year	0.23	0.05	0.001	0.08	Significant
	1-year and 10-year	0.29	0.05	0.001	0.08	Significant
	1-year and Forest	0.32	0.05	0.001	0.08	Significant
	5-year and 10-year	0.06	0.05	0.001	0.02	Significant
	5-year and forest	0.09	0.05	0.0101	0.060	Significant
	10-year and forest	0.03	0.05	0.1014	0.2154	Significant
Magnesium	1-year and 5-year	0.89	0.0408	0.0006	0.23	Significant
	1-year and 10-year	0.99	0.0408	0.0005	0.23	Significant
	1-year and forest	2.45	0.0408	0.0000	0.23	Significant
	5-year and 10-year	0.09	0.0408	0.0500	0.082	Significant
	5-year and forest	1.56	0.0408	0.0007	0.23	Significant
	10-year and forest	1.46	0.0408	0.0005	0.23	Significant
Potassium	1-year and 5-year	0.72	0.0408	0.0012	0.35	Significant
	1-year and 10-year	0.84	0.1000	0.0011	0.35	Significant
	1-year and forest	1.34	0.1000	0.001	0.35	Significant
	5-year and 10-year	0.12	0.1000	0.1002	0.115	Significant
	5-year and 10-year	1.34	0.1000	0.0010	0.35	Significant

	5-year and forest	0.62	0.1000	0.0013	0.35	Significant
	10-year and forest	0.50	0.1000	0.0010	0.35	Significant
Nitrogen	1-year and 5-year	2.51	0.3055	0.0019	1.08	Significant
	1-year and 10-year	4.68	0.3055	0.0010	1.08	Significant
	1-year and forest	4.80	0.3055	0.0010	1.08	Significant
	5-year and 10-year	2.17	0.3055	0.0020	1.08	Significant
	5-year and forest	2.28	0.3055	0.0019	1.08	Significant
	10-year and forest	0.12	0.3055	0.6840	0.111	Significant
Phosphorus	1-year and 5-year	0.49	0.0158	0.0010	0.055	Significant
	1-year and 10-year	0.58	0.0158	0.0010	0.055	Significant
	1-year and forest	0.61	0.0158	0.0010	0.055	Significant
	5-year and 10-year	0.09	0.0158	0.0010	0.055	Significant
	5-year and forest	0.12	0.0158	0.0010	0.055	Significant
	10-year and forest	0.03	0.0158	0.0500	0.032	Significant
pH	1-year and 5-year	0.60	0.1581	0.0500	0.319	Significant
	1-year and 10-year	0.40	0.1581	0.0500	0.319	Significant
	1-year and forest	0.10	0.1581	0.0500	0.106	Significant
	5-year and 10-year	0.40	0.1581	0.0500	0.319	Significant
	5-year and forest	0.10	0.1581	0.2531	0.106	Significant
	10-year and forest	0.40	0.1581	0.0500	0.319	Significant

Note: The difference between two fallow categories is significant if the value of the mean difference is greater than the value of the least significant difference (LSD).

Appendix 5.6 Summary table of analysis of variance for rate of return of nutrient to soil through litter fall

Name of element	Source of variation	Sum of squares	Degree of freedom	MSE	F	Significant	Remarks
Sodium	Between samples	7.57	3	2.52	5.43	0.01	Significant
	Within samples	1.27	44	0.06			
Potassium	Between samples	249.98	3	83.33	8.02	0.001	Significant
	Within samples	457.02	44	10.39			
Calcium	Between samples	135.37	3	45.12	7.78	0.001	Significant
	Within samples	256.11	44	5.80			
Nitrogen	Between samples	330.59	3	110.20	7.23	0.001	Significant
	Within samples	670.30	44	15.23			
Magnesium	Between samples	1521042.69	3	507014.23	12.27	0.001	Significant
	Within samples	1818568.16	44	41331.09			
Phosphorus	Between samples	5321.66	3	1773.89	6.16	0.01	Significant
	Within samples	12674.23	44	288.05			

Appendix 5.7 Summary table of ‘t’ test analysis showing the rate of return of nutrients through litterfall in the dry season and the rain season

Fallow categories	Nutrients name	Season	X	SD	DF	T critical	Significant level	Calculated t value	Decision
1-year	Sodium	Dry	0.06	0.005	18	2.10	0.05	0.52	Not significant
	Rain	Rain	0.03	0.0015					
1-year	Phosphorus	Dry	0.07	0.42	18	2.10	0.05	0.45	Not significant
		Rain	0.432	0.0761					
1-year	Potassium	Dry	1.095	0.606	18	2.10	0.05	2.00	Not significant
		Rain	1.498	0.563					
1-year	Nitrogen	Dry	1.498	0.563					
		Rain	0.964	0.206	18	2.10	0.05	1.93	Not significant
1-year	Calcium	Dry	1.004	0.579					
		Rain	0.593	0.133	18	2.10	0.05	1.54	Not significant
5-year	Sodium	Dry	0.18	0.0861	18	2.10	0.05	0.69	Not significant
		Rain	0.11	0.0516					
5-year	Phosphorus	Dry	0.219	0.089	18	2.10	0.05	1.03	Not significant
		Rain	0.120	0.0485					
5-year	Magnesium	Dry	3.84	1.985	18				
		Rain	2.26	0.958		2.10	0.05	2.83	Significant
5-year	Potassium	Dry	5.718	2.855					
		Rain	2.999	0.274	18	2.10	0.05	4.86	Significant
5-year	Nitrogen	Dry	1.498	0.563					
		Rain	0.964	0.206	18	2.10	0.05	3.34	Significant
5-year	Calcium	Dry	5.716	2.849					
		Rain	3.475	1.459	18	2.10	0.05	3.41	Significant
10-year	Sodium	Dry	0.202	0.0969					
		Rain	0.128	0.0317	18	2.10	0.05	0.80	Not Significant
10-year	Phosphorus	Dry	0.404	0.164					
		Rain	0.285	0.066	18	2.10	0.05	0.96	Not significant
10-year	Magnesium	Dry	5.797	3.592					
		Rain	3.592	3.162	18	2.10	0.05	3.48	Significant

10-year	Potassium	Dry	5.844	2.636					
		Rain	4.287	1.214	18	2.10	0.05	2.51	Significant
10-year	Nitrogen	Dry	9.539	4.776					
		Rain	6.113	1.3413	18	2.10	0.05	4.38	Significant
10-year	Calcium	Dry	6.087	3.004					
		Rain	3.991	0.9059	18	2.10	0.05	3.35	Not significant
Forest	Sodium	Dry	0.178	0.121					
		Rain	0.099	0.070	18	2.10	0.05	0.70	Not significant
Forest	Phosphorus	Dry	0.446	0.304					
		Rain	0.23	0.150	18	2.10	0.05	1.24	Not significant
Forest	Magnesium	Dry	3.349	2.728					
		Rain	2.219	1.609	18	2.10	0.05	1.72	Not significant
Forest	Potassium	Dry	5.91	4.079					
		Rain	3.279	2.104	18	2.10	0.05	3.35	Significant
Forest	Nitrogen	Dry	10.113	7.117					
		Rain	5.162	3.517	18	2.10	0.05	4.80	Significant
Forest	Calcium	Dry	5.915	4.082					
		Rain	3.365	2.085	18	2.10	0.05	3.25	Significant
1-Year	Magnesium	Dry	46	97	18	2.10	0.05	1.60	Not Significant
			0.432	0.0761					

Appendix 5.8 Summary table of the least significant difference (LSD) post hoc test of return of nutrient to soil through litterfall

Name of nutrient	Pairs of fallows	Standard error	Mean difference	Significant level	Remarks
Phosphorus	1-year and 5-year	6.929	19.60	0.01	
	1- year and 10- year	6.929	26.69	0.001	
	1-year and forest	9.929	24.47	0.001	
Phosphorus	5-year and 10-year	6.92	7.09	0.636	*
	5-year and forest	6.929	4.87	0.784	*
	10-year and forest	6.929	2.22	0.893	*
Sodium	1-year and 5-year	0.071	0.10	0.002	
	1-year and 10-year	0.071	0.12	0.001	
	1-year and forest	0.071	0.09	0.05	
	5-year and 10-year	0.071	0.04	0.18	*
	5-year and forest	0.071	0.01	0.86	*
	10-year and forest	0.071	0.03	0.28	*
Potassium	1-year and 5-year	1.3159	3.49	0.02	
	1-year and 10-year	1.3159	5.78	0.001	
	1-year and forest	1.3159	5.37	0.001	
	5-year and 10-year	1.3159	2.29	0.104	*
	5-year and forest	1.3159	1.88	0.216	*
	10-year and forest	1.3159	0.41	0.893	*
Calcium	1-year and 5-year	0.9832	3.70	0.001	
	1-year and 10-year	0.9832	4.16	0.001	
	1-year and forest	0.9832	5.30	0.001	
	5-year and 10-year	0.9832	0.47	0.836	*
	5-year and forest	0.9832	0.03	0.984	*
	10-year and forest	0.9832	0.43	0.858	*
Nitrogen	1-year and 5-year	1.5932	4.97	0.01	
	1-year and 10-year	1.5932	6.40	0.001	
	1-year and forest	1.5932	6.31	0.001	
	5-year and 10-year	1.5932	1.43	0.482	*
	5-year and forest	1.5932	1.34	0.632	*
	10-year and forest	1.5932	0.09	0.911	*
Magnesium	1-year and 5-year	82.997	244.99	0.01	
	1-year and 10-year	82.997	406.59	0.001	
	1-year and forest	82.997	276.34	0.01	
	5-year and 10-year	82.997	161.60	0.104	*
	5-year and forest	82.997	31.35	0.632	*
	10-year and forest	82.997	130.25	0.202	*

Note * represents no significant different

Appendix 5.9: Phosphorus concentration in litterfall

	1-year fallow	5-years fallow	10-years forest	Mature forest
May	0.98	0.49	0.39	0.39
June	0.99	0.50	0.41	0.38
July	1.00	0.51	0.43	0.38
Aug	1.00	0.50	0.41	0.39
Sept	1.01	0.51	0.42	0.40
Oct	1.01	0.51	0.43	0.40
Nov	0.99	0.50	0.42	0.40
Dec	0.98	0.49	0.39	0.38
Jan	0.90	0.44	0.37	0.36
Feb	.83	0.40	0.36	0.34
March	0.68	0.34	0.29	0.27
April	0.95	0.47	0.37	0.34

Appendix 5.10 Nitrogen concentration in litterfall

	1-year fallow	5-years fallow	10-years forest	Mature forest
May	12	10.3	8	7.9
June	13	10.5	8.2	8
July	14	10.5	8.4	8.2
Aug	14	10.6	8.4	8.3
Sept	14	10.6	8.6	8.4
Oct	15	10.7	8.9	8.5
Nov	14	10.6	8.6	8.4
Dec	13	10.5	8.5	8.3
Jan	12	10.4	8.3	8.2
Feb	11	10.1	8.1	8
March	10	10.0	7.6	7.4
April	11	10.1	7.8	7.2

Appendix 5.11 Potassium Concentration in Litterfall

Months	1-year fallow	5-year fallow	10-year forest	Mature forest
May	7.8	6.94	7.01	6.33
June	8.0	7.04	7.13	6.41
July	8.15	7.13	7.21	6.49
August	8.19	7.19	7.32	6.58
September	8.21	7.23	7.43	6.77
October	8.25	7.32	7.50	6.91
November	8.11	7.30	7.46	6.82
December	7.92	7.28	7.31	6.76
January	7.70	7.02	7.11	6.71
February	7.63	6.96	7.01	6.52
March	7.30	6.64	6.82	6.24
April	7.61	6.82	6.93	6.28

Appendix 5.12 Calcium Concentration in Litterfall

Months	1-year fallow	5-year fallow	10-year forest	Mature forest
May	8.8	7.66	5.31	4.89
June	9.0	7.75	5.44	5.03
July	9.1	7.77	5.62	5.08
August	9.1	7.78	5.68	5.11
September	9.2	7.78	5.74	5.18
October	9.3	8.01	5.86	5.23
November	9.4	7.78	5.63	5.01
December	8.9	7.71	5.51	4.93
January	8.7	7.68	5.36	4.86
February	8.6	7.63	5.30	4.66
March	8.3	7.08	4.80	4.28
April	8.6	7.59	5.26	4.74

Appendix 5.13 Magnesium Concentration in Litterfall

Months	1-year fallow	5-year fallow	10-year forest	Mature forest
May	6.01	5.03	4.91	3.53
June	6.03	5.07	4.98	3.59
July	6.01	5.11	5.02	3.59
August	6.06	5.16	5.08	3.42
September	6.09	5.22	5.12	3.48
October	6.11	5.28	5.17	3.63
November	6.01	5.25	5.14	3.60
December	6.00	5.18	5.11	3.58
January	5.94	5.02	4.98	3.55
February	5.88	4.96	4.89	3.51
March	5.83	4.91	4.82	3.46
April	5.91	5.10	4.87	3.51

Appendix 5.14 Sodium Concentration in Litterfall

Months	1-year fallow	5-year fallow	10-year forest	Mature forest
May	0.47	0.24	0.17	0.14
June	0.48	0.24	0.18	0.15
July	0.48	0.25	0.19	0.15
August	0.47	0.24	0.18	0.14
September	0.49	0.25	0.20	0.15
October	0.50	0.26	0.20	0.16
November	0.49	0.25	0.19	0.15
December	0.48	0.25	0.19	0.15
January	0.46	0.24	0.18	0.15
February	0.45	0.24	0.17	0.14
March	0.44	0.22	0.16	0.13
April	0.46	0.23	0.17	0.15