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EFFECTS OF RUBBER PLANTATIONS ON THE NUTRIENT STATUS OF SOILS ESTABLISHED UNDER DIFFERENT LAND-USES

BY

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EFFECTS OF RUBBER PLANTATIONS ON THE NUTRIENT STATUS OF SOILS ESTABLISHED UNDER DIFFERENT LAND-USES

by

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DEDICATION

This thesis is dedicated wholeheartedly to my uncle, Ebenezer Tawiah.

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STATEMENT OF ORIGINALITY

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any other degree or diploma of a University or other institution of higher learning, except where due acknowledgement is made"

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ABSTRACT

Natural rubber (NR) cultivation has been on the increase in the Ahanta West, Nzema East, Jomora and Wassa West Districts of the Western Region, since the inception of the Rubber Outgrower Plantation Project (ROPP) in 1995. As a result, many land-uses especially secondary forests have been converted to NR plantations, raising several environmental issues including nutrient removal from the soil, change in soil surface chemistry, and fear of disruption in soil fertility. The purpose of this study was to assess the effects of rubber plantations on the nutrient status of soils established from different land-uses. Forty-five soil samples were collected from NR plantations at Ghana Rubber Estates Limited (GREL) for laboratory analysis. Samples covered depths 0-20 cm, 20-40 cm, and 40-60 cm, and represented three land-use types (secondary forest, old rubber plantation and abandoned farmland). Total nitrogen, Total phosphorus, available potassium, calcium, magnesium and pH analyses were determined using the atomic absorption spectrophotometer (AAS). The results generally indicated no significant differences ($P > 0.05$) in the soil properties among the three land-use types. Similarly, soil depth did not have any strong effect on the soil nutrient status. However, total nitrogen (35.3 – 69 %), total phosphorus (65.5 – 137 %) and available potassium (44.3 - 76.5 %) increased with age of the NR stand whilst calcium (10.2 - 51.1 %) and magnesium (5.1 - 11.3 %) decreased with increasing age of the NR stand. These results suggest that NR establishment had no deleterious effects on soil quality parameters, consistent with the notion that most soil nutrients are returned into soils through accumulation and subsequent turnover of leaf litter.

Table of Contents

Content Page

Dedication ………………………………………………………………………………… iii

Acknowledgements……………………………………………………………………... iv

Statement of Originality………………………………………………………………… v

Abstract ………………………………………………………………………………. vi

Table of Contents ………………………………………………………………………. vii

List of Appendices ……………………………………………………………………... x

List of Tables …………………………………………………………………………… xi

List of Figures …………………………………………………………………………... xii

List of Plates ……………………………………………………………………………. xiii

List of Acronym ………………………………………………………………………... xiv

Chapter One 1

Introduction 1

1.1 Background ....
1

1.2 Problem Statement 2

1.3 Justification ....
3

1.4 Objectives 3

1.4.1 Specific Objectives 4

Chapter Two.. 5

Literature Review 5

2.1 Botany and distribution of *Hevea brasiliensis* 5

2.3 Environmental factors that influence the growth and development of natural rubber 8

2.3.1 Effect of climate on the rubber tree 8

2.3.2 Soil requirements of the rubber tree 10
2.4 Soil fertility 10
2.5 Nutrients requirement 11
2.6 Fertilizers 12
2.6.1 Types of Fertilizers 12
2.6.2 Organic Fertilizers 12
2.6.3 Inorganic Fertilizers 13
2.7 Soil fertility management for rubber plantation 14
2.7.1 Role of cover crops 15
Chapter Three 19
Materials And Methods 19
3.1 Study Area 19
3.2 Study Design 22
3.2.1 Soil Sampling and Processing 23
3.3 Procedures for Laboratory Analysis 27
3.3.1 Soil pH 27
3.3.2 Total nitrogen 27
3.3.3 Available phosphorus (Bray's No.1 phosphorus) 28
3.3.4 Determination of Calcium and Magnesium 29
3.3.5 Determination of exchangeable potassium 30
3.4 Data Analysis 30
Chapter Four 31
Results 31
4.1 Variations in Soil Fertility Indicators Among the Land-Use Types 31
Chapter Five 43
Discussion 43
5.1 Effect of NR Plantations on Soil Nutrients 43
Chapter Six 49
Conclusions And Recommendations 49

6.1 Conclusions 49
6.2 Recommendations 50
References 51
Appendices 61

APPENDICES

Appendix Page

A: Analysis of Variance (ANOVA) table for mean %TN among the ……………………….. 60
three (3) land-uses at various depths
B: Analysis of Variance (ANOVA) table for mean %TP among the ………………………… 60
three (3) land-uses at various depths
C: Analysis of Variance (ANOVA) table for mean K among the ……………………………. 60
three (3) land-uses at various depths
D: Analysis of Variance (ANOVA) table for mean Mg among the ………………………….. 60
three (3) land-uses at various depths
E: Analysis of Variance (ANOVA) table for mean Ca among the …………………………… 61
three (3) land-uses at various types
F: Analysis of Variance (ANOVA) table for mean pH among the …………………………… 61
three (3) land-uses at various depths types
G: Analysis of Variance (ANOVA) table for mean %TN among the ………………………… 61
three (3) land-uses
H: Analysis of Variance (ANOVA) table for mean %TP among the ………………………… 61
three (3) land-uses
I: Analysis of Variance (ANOVA) table for mean K among the ……………………………..… 62
three (3) land-uses
J: Analysis of Variance (ANOVA) table for mean Mg among the …………………………… 62
three (3) land-uses
K: Analysis of Variance (ANOVA) table for mean Ca among the …………………………… 62
three (3) land-uses
L: Analysis of Variance (ANOVA) table for mean pH among the …………………………… 62
three (3) land-uses

LIST OF TABLES

Table Page 1: Experimental blocks sampled... 21

LIST OF FIGURES

Figure Page

1: Worldwide distribution of rubber plantations (FAO, 2010) 6
2: Distribution of rubber in Africa interms of land area (FAO, 2010) 6
3: A rubber tree under tapping ……………………………………………………………………7
4: Location of study area in Ghana 19
5: Location of experimental blocks sampled 21
6: Comparison of TN levels among different land-use types and at different depths .... .31
7: Comparison of TP levels among different land-use types and at different depths 37
8: Comparison of mean K levels among different land-use types and at different depths 33
9: Comparison of Mg levels among different land-use types and at different depths 38
10: Comparison of Ca levels among different land-use types and at different depths 34
11: Comparison of pH levels among different land-use types and at different depths 39
12: Comparison of mean TN levels among the three land-uses over a 20-year period 36
13: Comparison of mean TP levels among the land-use types over a 20-year period 37
14: Comparison of mean K levels among the land-use types over a 20-year period 38
15: Comparison of mean Mg levels among the land-use types over a 20-year period 39
16: Comparison of mean Ca levels among the land-use types over a 20-year period ...………..40
17: Comparison of mean pH levels among the land-use types over a 20-year period..…………41

LIST OF PLATES

Plate Page
3.1: A soil screw auger for soil sampling.. 23
3.2: Buckets for collecting soil at varying depths.. 24
3.3: An experiment worker pushing the screw auger... 24
3.4: Removal of soil sample from the screw auger.. 25
3.5: Air-drying soil samples 25
3.6: Sieving soil samples to finer granules 26
3.7: Soil sample ready for soil analysis... 26

LIST OF ACRONYM

AF – Abandoned farmland
AFD – Agence Francaise de Development

CEC – Cation Exchange Capacity

FAO – Food and Agriculture Organisation

GDP – Gross Domestic Product

GREL – Ghana Rubber Estates Limited

ORP – Old Rubber Plantation

ROPP – Rubber Outgrower Plantation Project

SF – Secondary Forest

SOC – Soil Organic Carbon

CHAPTER ONE

INTRODUCTION

1.1 Background

Hevea brasiliensis (Willd. ex A. Juss.) Mull. Arg is a commercial tree grown in plantations around the world with the capacity to produce 60 million pounds of natural rubber by the year 2020 (Venkatachalam, Geetha, Sangeetha, & Thulaseedharaan, 2013). According to the FAO (2010), *H. brasiliensis* (natural rubber plant) has a long history of being cultivated for commercial uses, and is important in the socio-economic life of many tropical countries. Natural rubber (NR) is of strategic importance because it cannot be replaced by synthetic alternatives in many of its most significant applications owing to its unique properties such as resilience, elasticity, abrasion and impact resistance, efficient heat dispersion and malleability at low temperatures (van Beilen & Poirier, 2007). Africa produces 5 % of global NR, with Nigeria, Liberia and Cote d'Ivoire as the largest producers (WRM, 2008).

Natural rubber was first introduced into Ghana in the 1930s but it was until 1957 that the plant was established as a plantation at Dixcove in the Western Region (Gilard, 2012).

In the early 1990s, there was increasing demand for NR worldwide and the government of Ghana realizing the potential of NR cultivation to economically empower many small-scale farmers and alleviate poverty in rural communities, entered into an agreement with the Agence Francaise de Development (AFD) and IDA/World Bank to assist outgrowers in establishing NR plantations (Delarue, 2009). Under phase one of the project, which spanned the period from 1995 to 1999, 400 outgrowers were assisted to plant a little over 1,200 ha, whilst 3,500 ha of old rubber plantations of individuals and co-operatives were rehabilitated. This initiative provided bulk employment for the people of the Ahanta West, Nzema East, Jomoro and Wassa West districts all in the Western Region of Ghana (Sekondi-Takoradi Chamber of Commerce and Industry).

1.2 PROBLEM STATEMENT

Since the inception of the Rubber Outgrower Plantation Project (ROPP) in 1995, a total of 39,000 ha of land has been planted by outgrowers across the Western, Central and Eastern regions, mainly on secondary forestlands due to the notion that forestlands contain adequate nutrients for rubber growth. An increase in the demand for NR mainly from China led to a record increase in price and spurred rapid new plantings. The expanding plantings heightened concerns among environmentalists and scientists about potential environmental impacts of rubber plantations. Some researchers have argued that the conversion of forestlands to agricultural landuse might impact seriously on soil physical and chemical properties and other ecological processes depending on the land-use and the post conversion management practices (Sharma, Rai, Sharma, & Sharma, 2004); (Goma-Tchimbakala, Moutsambote, & Makosso, 2008). While NR is deemed to be green due to, its capacity to absorb carbon dioxide, large tracts of planting have been found to remove considerable amount of nutrient from the soil, changing the soil chemistry, and contributing to loss of habitats for birds and other wildlife in the region.

Land-use systems characterized by perennial crops, which provide litter and shading to the soil especially during the maturity phase, may improve stocks of nutrients and other soil fertility parameters to levels capable of sustaining crop productivity (Beer, Muschler, Kass & Somarriba, 1998). Thus, while some studies Beer *et al*., 1998; (Duguma, Gochowski, & Bakala, 2001); Wall & Hytönen, 2005) have reported improvements in soil organic carbon and fertility under various tree crops and forest plantations, others (e.g., Adejuwon & Ekanada, 1988; Ekanade, Adesina and Egbe (1991); Ogunkunle & Eghaghara, 1992; (Duah-Yentumi, Ronn, & Christensen,

1998) have reported declines in soil fertility following forest conversion to plantations. Other reports (e.g., Kotto-Same, Woomer, Appolinaire, & Louis, 1997; Kauffman, Cummings, & Ward, 1998) have also indicated that soil carbon pools remain approximately constant during most land conversion practices in the tropics. These conflicting results not only obliterate understanding of the effect of natural rubber plantations on soil but also indicate that broad generalizations can be misleading.

Stand age has also been found to influence the physicochemical properties of soils (Sharma *et al.*, 2009). Plantation soils accordingly show a rise in soil nutrients from time of establishment up to a point where it stabilizes and then diminishes.

1.3 JUSTIFICATION

In Ghana, no studies have been conducted to assess changes in nutrient stocks with time under rubber plantations. As a consequence, the dynamics of soil physicochemical properties under perennial stands like rubber plantation are still not well understood. Studies are needed to understand the trends, magnitudes, nature and rates of soil quality changes especially for designing management options for sustainable agricultural productivity in rubber plantation establishment.

1.4 OBJECTIVES

The general objective of this study was to assess the responses of soil quality indicators to natural rubber established under different land-use systems.

1.4.1 SPECIFIC OBJECTIVES

The specific objectives of the study were:

1. To investigate the effects of rubber plantations established from different land uses on the soil physico-chemical properties.
2. To assess the effect of soil depth on the physico-chemical properties of soils under rubber plantation.
3. To determine the effect of age of rubber plantations on the physico-chemical properties of soils.

CHAPTER TWO

LITERATURE REVIEW

2.1 Botany and distribution of *Hevea brasiliensis*

H. brasiliensis (also known as the Para rubber plant) is a tropical, deciduous tree, which grows 25-30 m tall in its natural range. Most of the planted trees are small, because they have been bred for the production of latex without taking into account their wood production potential (Hong, 1999). The bole of the rubber tree is usually straight but quickly tapered, and heavy branching is common. The branching pattern is very variable, and the leading stem can be dominant or soon divided into several heavy branches. The tree is easily damaged by strong winds (Lemmens, Soerianegara, & Wong, 1995). Rubber tree matures at the age of seven to ten years, after which latex tapping can be started. When aiming at economic latex production, the life cycle of a rubber plantation is 30-35 years, after which replanting is necessary.

The current worldwide distribution of rubber plantations is approximately 9.7 billion ha (Figure 1). Africa has a combined total of 680,000 ha of rubber plantations (i.e., about 7 % of the world's total), with Nigeria (50 %) having the most in Africa as shown in figure 2.

Rubber belongs to the family Euphorbiaceae, a large family with about 280 genera and 8,000 species (Verheye, 2010). The genus *Heve*a is native to South America, where it grows wild in the Amazon and Orinoco valleys.This genus, which exhibits much morphological variability, has about nine species, ranging from large forest trees to little more than shrubs (Verheye, 2010).

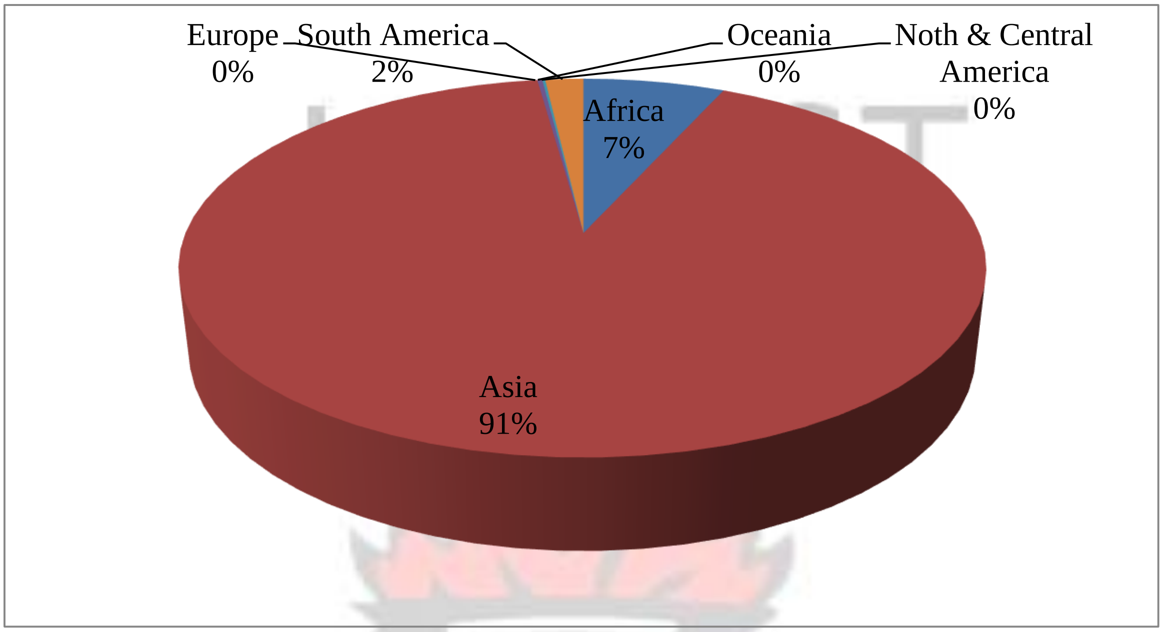

Figure 1: Worldwide distribution of rubber plantations (FAO, 2010)

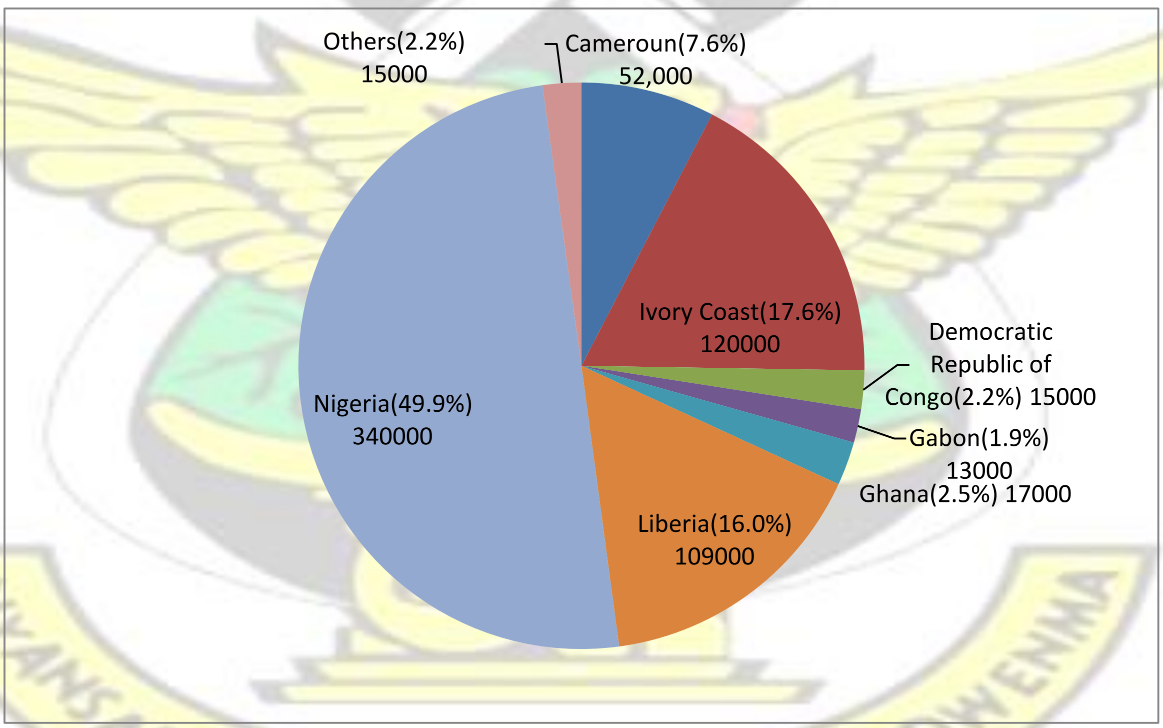

Figure 2: Distribution of rubber in Africa in terms of land area (FAO, 2010)

The trunk of the tree tapers from the base and is conical or cylindrical in shape and shows a periodicity of growth as shown in Figure 3. During the resting stage, whorls of scale leaves occur round the terminal bud. A fully grown leaf has a diameter of 15-20 cm. Young leaves are dark red in color, while old leaves are green on top and grayishgreen underneath (Verheye, 2010).

Figure 3: A rubber tree under tapping

2.2 Overview of Natural rubber production

Natural rubber is cultivated mostly in Asia with nearly 6.7 million ha or 70% of the world's total rubber area in Thailand, Indonesia and Malaysia (RRIT, 2005). The total area planted with rubber in the world was around 9.5 million ha in 2004 .Most of this area is in smallholdings of only a few hectares. The world rubber industry has grown steadily in the post-war period from 1960 to 2003, with a global production of natural rubber amounting to 8.01 million tonnes in 2003 (Jumpasut, 2004; RRIT, 2005).

World rubber consumption has grown at an average rate of 5.9% per year since 1900 (Jumpasut, 2004) to reach 19.31 million tonnes in 2003 (RRIT, 2005).

In Ghana, the main rubber producing company is GREL which produces annually 300,000 tonnes of natural rubber. There are also small holder farms which were established in 1995 that also adds up to the annual production.

2.3 Environmental factors that influence the growth and development of natural rubber

Several environmental factors affect the growth and development of NR plantations. NR plantations tend to do well when optimal environmental conditions are available. Some of these environmental factors and their influence on NR plantations are discussed below:

2.3.1 Effect of climate on the rubber tree

Rubber is mainly cultivated between latitudes 10 ^{o}N and 10 ^{o}S in the tropical rain forest zone. The performance in term of growth is most rapid at altitudes below 200 m with monthly mean temperature 27-28 ^{o}C. Optimal mean annual rainfall varies between 1500 and 4000 mm and well distributed through the year with no monthly mean being less than 100 mm. Both excessive amounts of rain and marked dry seasons reduce the yields (Landon, 1991).

In traditional rubber growing areas, the total rainfall ranges between 2000-4000 mm, distributed over 140-220 days, without more than one to four dry months (Rao & Vijayakumar, 1992). A general lower limit of annual rainfall for the economically viable cultivation of rubber cannot be easily given, since environmental factors other than climate also affect the survival of the tree (Compagnon, 1987). A well-distributed annual rainfall of 1500 mm has sometimes been considered as a lower limit for commercial production (Lemmens *et al*.,, 1995). However, the requirement depends on the distribution of rain throughout the year, length of dry season and soil water retention capacity. In favorable soils, rubber could tolerate a dry season of four to five months, during which less than 100 mm of rain is received or two to three months with rainfall less than 50 mm (Compagnon, 1987).

Plants encountering high temperature in the absence of rainfall are driven to higher rate of transpiration, which in turn leads to moisture stress. Effects of rainfall and temperature on the photosynthetic rate (Sangsing, 2004) and further the growth performance (Jiang, 1988) and the latex yield (Jiang, 1988; Rao, Rao, Rajagopal, Devakumar, Vijayakumar, & Sethuraj (1990); Rao, Saraswathyamma, & Sethuraj **(**1996); Raj, Chandra, & Patel (2005) of rubber trees have been well investigated. In general, moisture stress decreases latex yields as well as total production of dry matter. According to Grist, Menz, & Thomas (1998), the growth and latex yield of a tree are affected in different ways by soil moisture. Moisture stress has more dramatic effects on the latex yield than on tree growth, as turgor pressure in latex vessels inside the trunk of the tree is required to facilitate the latex flow.

Rubber trees shed their leaves annually, but the timing and intensity of leaf shedding depends on climatic condition and varies between clones (Lemmens *et al.*, 1995).

2.3.2 Soil requirements of the rubber tree

Soil chemistry determines the availability of nutrients required by the plants (Yusoff, 1988). There is a large variation in the chemistry and nutrient status of rubber plantation soils, which range from highly fertile to highly infertile. The soils in several rubber regions of different countries are very acidic with pH around 4.73 (Chivith, 1996), although it may be slightly alkaline in some cases. Both situations are favourable for upland rice production and rubber plantations (White *et al.*, 1997). In general, rubber will grow on soil of pH 3.6 to 8.0 but the most suitable soils are strongly to moderately acidic (i.e., pH 4.4 to 5.2). The cation exchange capacity (CEC) of the soil and organic matter level are moderate to high, which aids fertilizer management.

2.4 Soil fertility

Soil fertility is the capacity of soil to support the growth of plant, on a sustainable basis, under given conditions of climate and other relevant properties of land (Bunch, 2000). Rubber trees grow satisfactorily on the majority of tropical soil types when newly cleared from the forest (Webster & Baulkwill, 1989). At clearing, there is some loss of nutrient due to burning, erosion and leaching but the residual fertility is generally sufficient to promote early growth and subsequent development of a good root system, which will help to support the plant through maturity. However in areas being replanted, the loss of nutrients caused by extraction of old rubber wood added to those sustained during the previous planting period and in the clearing operations leaves most sites greatly impoverished (Webster & Baulkwill, 1989). According to Webster & Baulkwill, (1989), severe Mg and K deficiencies have commonly occurred at this stage and major fertilizer inputs are generally required to promote satisfactory growth and yield.

2.5 Nutrients requirement

Young rubber trees require the major nutrients N, P, K and Mg for optimum growth until tapping. Large responses are obtained from applications of these elements but in the case of N, excess should be avoided as this increases vegetative growth and tree height with a greater risk of trunk breakage. In mature rubber, there is often only a very limited and slow yield response to the added fertilizers but a balanced nutrient supply is essential for maintaining vigorous and healthy trees with a high production potential. An annual yield of 1500 kg per ha of latex contains approximately 40 kg N, 10 kg P_2O_5 and 25 kg K_2O (Landon, 1991).

In the immature phase, the fertilizer application is for rapid girthing and branching. In the mature phase, fertilizer application is for maintaining tree vigour and yield (Yusoff, 1988). The total quantities of fertilizer that should be applied per tree will depend on the type of clone, age of the tree and the soil in the locality (Peries & Fernando, 1983). Nutrients are taken up by plants in solution along with soil water. Therefore, fertilizer should not be applied in the height of the dry weather. Periods of prolonged and heavy rain may wash the fertilizer out of the soil before its nutrients can be absorbed by the plant (Peries & Fernando, 1983).

2.6 Fertilizers

Any substance added to the soil to incorporate one or more plant nutrients in order to maintain adequate growth yield is referred to as a fertilizer (Evans, 1992).

Fertilizers are applied to correct mineral element deficiencies, increase growth rate and maintain satisfactory vigor. Fertilization generally increases seedling size, which could be advantageous on planting sites where competition with other species occur. For example, the survival and height growth of Douglas-fir were increased by nursery fertilization, which also increased seedling size (Mary & Thomas, 1984). Similar results have also been reported for Sitka spruce fertilized in the nursery after bud set. These studies, among others, have led to the suggestion that seedlings with high internal nutrient concentration are likely to survive and grow more than seedlings with low nutrient concentrations.

2.6.1 Types of Fertilizers

Fertilizers can be organic such as compost or manure and inorganic.

2.6.2 Organic Fertilizers

Organic fertilizers are natural sources of nutrients. They include compost, manure and bone meal (Karl, 1994). Generally, the concentration of nutrient elements in organic fertilizers are usually low; for example, compost may contain 2 % to 4 % N and 0.2 % to 1.8 % P, and farmyard manure about 1.1 to 1.5 % N (Prasad & James, 1997). However, amelioration of soils with organic manure for raising nursery seedlings is considered a better choice than inorganic fertilizers in some tree species (Evans, 1992).

Organic fertilizers improve soil structure and increase beneficial fungal and bacterial activities in the soil. Organic fertilizers add organic matter to the soil which increases the water-holding capacity, aeration and CEC of the soil and this helps the soil to retain cationic nutrients. In addition, organic matter also buffers against changes in soil pH. Organic fertilizers are less likely to damage plants and are also less likely to add to water pollution because they are more stable in the soil and release nutrients at a slower rate (Karl, 1994).

2.6.3 Inorganic Fertilizers

Inorganic fertilizers are made up of nutrients obtained from non-living sources. They are manufactured to definite nutrient specifications, referred to as “the analysis” and may contain higher nutrient concentrations. For example, urea fertilizers contain 4546 % N and Ammonium phosphate contains 11 % N and 24 % P (Prasad and James, 1997).

The nutrients of inorganic fertilizers are readily available for plants use. They are easy to handle, apply, promote quick plant growth and increase yield (Karl, 1994). Chemical fertilizers also lead to better development of roots (Nambiar & Broen, 1992).

However, soil pH can be changed by the addition of inorganic fertilizers. For example: Ammonium and urea salts make the soil more acidic; ammonium sulfate is particularly effective in reducing soil pH. Nitrate fertilizers containing a base (KNO_3) or Ca $(NO_3)_2$ increase soil pH. Phosphate fertilizers either have no effect on soil pH or increase it, unless they contain ammonium, in which case they reduce it. Potassium sulphate and chloride have negligible effects on soil pH (California Fertilizer Association, 1980; Krause, 1965; Stumpe & Vlek, 1991). Chemical fertilizers are expensive and cannot improve the structure of the soil. They are highly soluble and are therefore likely to be washed into streams and water ways hence causing water pollution (Russell, 1988).

2.7 Soil fertility management for rubber plantation

Management of soil fertility is not only confined to fertilizer use. Agronomic practices such as the establishment of legume covers and other inter-row planting during the immature phase have been shown to sustain or even improve the nutrient status of soils.

The general management practices include:

(1) The establishment of a good creeping legume covers in the immature phase of rubber and the maintenance of a light cover during immaturity

(2) Mulching around the base of young rubber trees or allowing legume covers to creep to the base of the trees and spraying out periodically to ensure mulching effect

(3) Plugging of soil on steep slope along the contours

(4) Mechanical cultivation at the proper moisture content

(5) Terracing or digging of silt pits on steep slopes

(6) For serious physical limitations caused by shallow soils, trees with a light crown to be grown

(7) Split application of fertilizers on sandy soils and

(8) Proper drainage of water logged soils or soils with high water table (Ahmad, 1987).

2.7.1 Role of cover crops

Cover plants established in the inter-row areas had been shown to have beneficial effects on the growth and yield of rubber trees. These effects are attributed to the large quantities of plant litter, which on decomposition returns significant amount of nutrients, particularly nitrogen (Yusoff, 1988).According to Yusoff (1998), planting of a leguminous cover crop led to a greater nutrient return to the soil and increased the nutrient content of rubber leaves. This nutrient return, coupled with improved soil physical properties, led to an increased rate of growth of the rubber trees. Further, Broughton (1977) observed an average of 150 kg/ha per year nitrogen fixation under legumes grown in association with rubber over a 5 year period with maximum rates of about 200 kg/ha per year.

Among the cover crops, legume creepers have been found to be the best in improving soil physical properties. According to Watson (1957), there are large amounts of plant nutrients particularly nitrogen, which are returned to the soil by the creeping legumes during the immaturity period. The soil under legume creepers generally contains higher quantities of organic matter and nitrogen than any of the other covers. Legume covers tend to improve both soil physical and chemical conditions and generally give better growth of rubber tree, hasten maturity and also increase significantly the early yields of rubber (Yusoff, 1988).

Most of the creeping legume plants used as cover in rubber cultivation are able to fix atmospheric nitrogen. Indirect evidences of nitrogen fixation by *Centrosema pubescens* have been reported by Watson (1957). He estimated that a total of 235 kg of nitrogen per hectare could be fixed by *Centrosema pubescens* over five months in the absence of applied nitrogenous fertilizer. The amount was considerably reduced to 152 kg/ha where N fertilizer was applied (Ahmad, 1987).

Research has shown that the growth of legume cover crops can also inhibit the growth of weedy plants as revealed by Hermanawan & Bijlmer (1996). According to the authors, legume cover crops have several functions in the rehabilitation of weedy grassland and this helps in the improvement of the soil structure, organic matter, moisture retention and microclimate.

2.8 Land-use systems within the GREL concession area

The GREL operational area which covers mainly the Ahanta West district covers a total of 67,000 ha. Different land-uses occur within this concession area in the Ahanta West district with agriculture been the main land use and covering 38,900 ha, 20200 ha is under cultivation and 6,700 ha have been put under some sort of protection. There is a presence of dense vegetation which according to Iwara *et al*. (2011) reduces the loss in macro- and micro-nutrients which are essential for plants growth and energy fluxes. According to Thornley and Cannel (2000) and Elliot (2003), the continuous conversion of vegetal areas to non-vegetal surfaces reduces soil productivity as a result of increased soil erosion and changes in moisture content. Indeed, the concentration of nutrient in the soil is depleted when vegetation is destroyed through numerous anthropogenic activities such as deforestation and land preparation for agricultural production. The change in forest cover to other forms of land cover such as plantation and grassland results in the tremendous modification of canopy cover, thereby making the affected area more susceptible to soil erosion; this affects the stock of soil organic carbon (SOC). The conversion of forest ecosystem to other forms of land cover may decrease the stock of SOC due to changes in soil moisture and temperature regimes, and succession of plant species with differences in quantity and quality of biomass returned to the soil (Offiong and Iwara, 2012). Indeed, changes in land use cover have significant effect on the amount and diversity of biomass returned to the soil, which also disrupt the richness of nutrient restored to the soil. It is a known fact that soil erosion intensity and amount of nutrient element loss varies depending on the vegetation type at a particular place and time (Iwara, 2011). The author further emphasized that the rate of nutrient loss in both dissolved and sediment bound forms depends on the ability of vegetation canopy to effectively intercept the direct impact of raindrops that strike the soil surface. If the canopy is not dense enough or well developed, low quantity of nutrients will be returned to the soil as well as large quantities of nutrient will be removed from the soil surface during periods of heavy rainstorm when the soil is saturated.

Lal (1996) and (Shepherd, Bureh, & Gregory, 2000) noted that land use change in tropical ecosystems could cause significant modifications in soil properties. In stressing the effect of this phenomenon on the ecosystem, Schipper & Sparling (2000) posited that land use change modifications are biologically and chemically more rapid than physically. Forest soils are one of the major sinks of carbon on earth due to their high organic matter status (Dixon, Brown, Houghton, Solomon, Trexler, & Wisniewski, 1994), as such any land development effort or landscaping activities must mimic the characteristics of forest.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study was carried out in the over 20,000 ha of Ghana Rubber Estates Limited (GREL) plantations located close to Agona (4˚55´N and 2˚02´W) in the Western Region of Ghana (Figure 4). GREL was established from 1957 at Dixcove also in the Western Region (Gilard, 2012), along the shore in the vegetation zone of the wet evergreen (WE) forest characterized by a sub-equatorial climate. Tree species dominant in the area include *Cynometra ananta*, *Tarietia utilis,* and *Tieghemella heckelii*.

The rainfall regime is bimodal with two rainy seasons: a major in April–July and a minor in October–November, and two dry seasons: a major in December–March and a minor in August–September. Annual rainfall ranges from 1200 to 1800 mm. Average relative air humidity is between 95 and 100 %. Average temperature ranges between 24 and 27 ˚C. Absolute extreme temperatures are 15 and 40 ˚C. The landscape is undulating with slopes varying from 1 to 30 %. The soils developed from the weathering of granite (Atsivor, Dowuona, & Adiku, 2001). Acrisols are located on the eroding slopes of low hills while ferralsols are present on nearby stable sediments or uplands (Driessen, Manting, & van der Does, 2001). Fine earth (< 2 mm particle size) is dominated by sand (76 %) and clay (22 %) while gravel is found at a depth of 10-60 cm. The soils are acidic and well drained. Actual rubber stands are from a second generation of rubber trees with the company fast establishing new stands. In this region, most of the land is covered by secondary forest, light bush and oil palm crops.

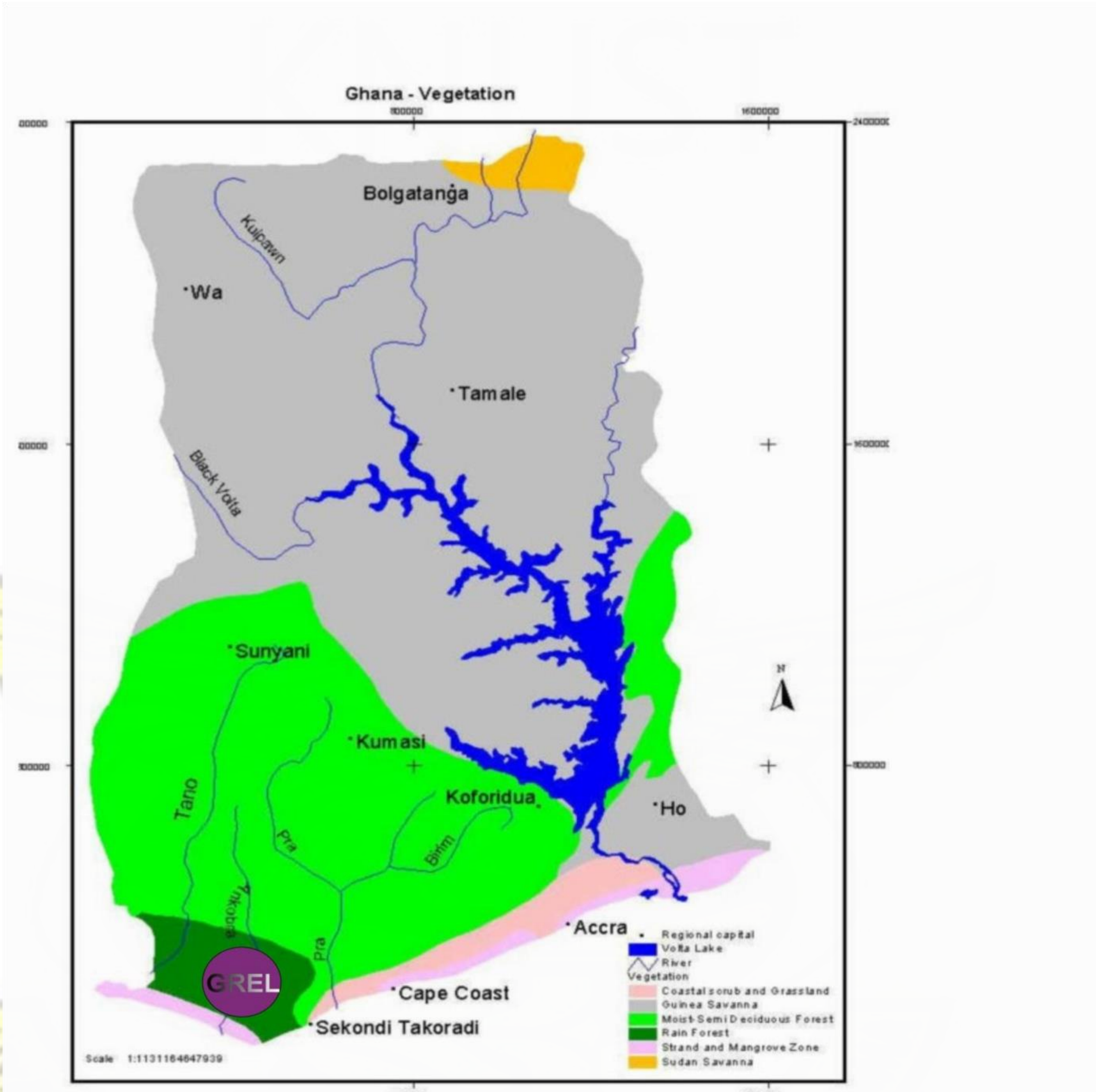

Figure 4: Location of the study area (GREL) in Ghana

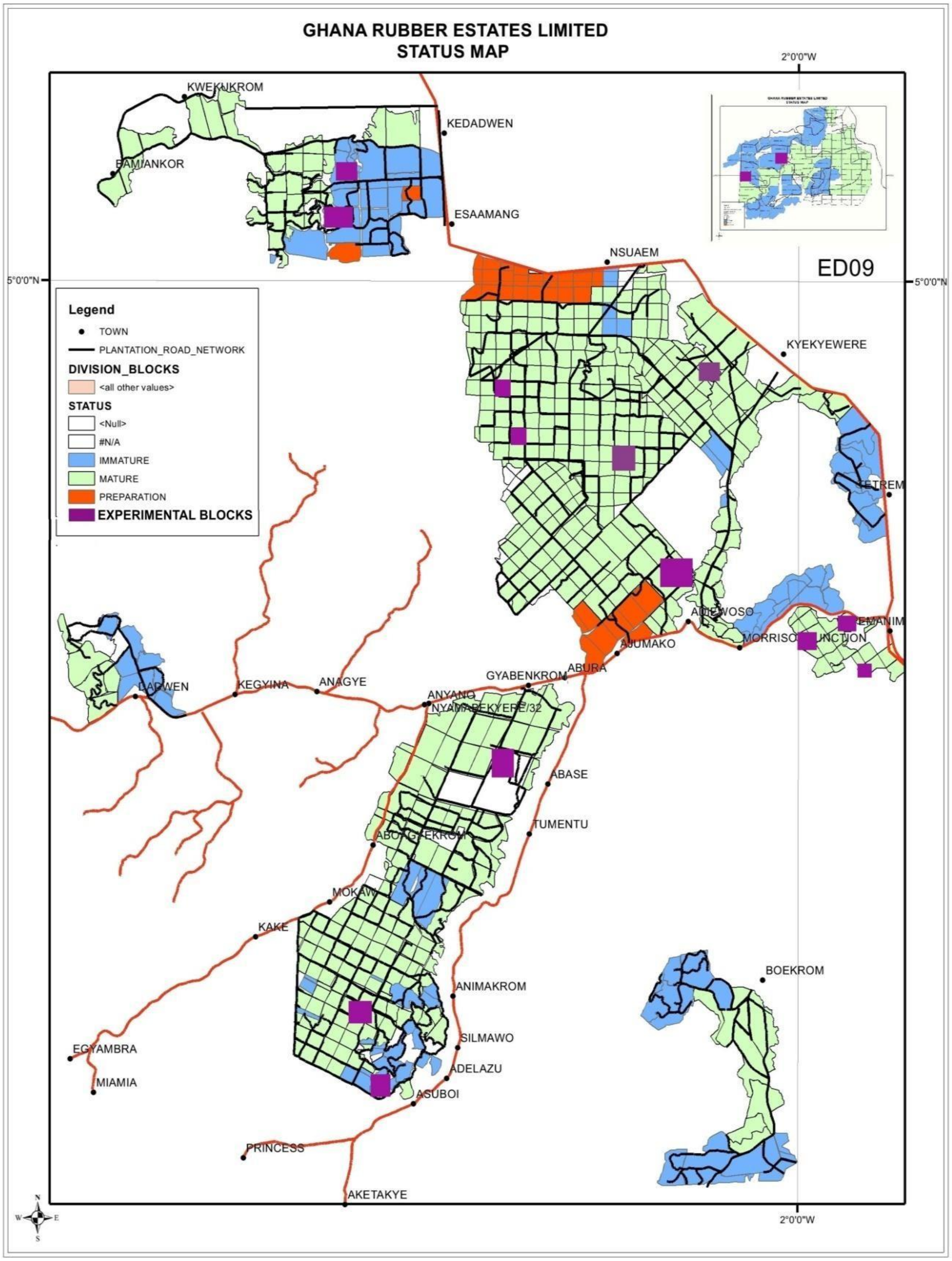

Figure 5: Location of experimental blocks sampled

3.2 Study Design

Twelve (12) blocks of NR plantations, each measuring 10 – 20 ha were selected for this study (Figure 5). The selected blocks were established on three (3) different landuses types with four (4) replicates each: (i) secondary forest (SF), - which had experienced human disturbance in the past; (ii) an old rubber plantation (ORP), which was previously occupied with NR for over forty (40) years; and (iii) an abandoned farmland (AF), which was previously used for farming through shifting cultivation. Thus, the secondary forest used as a reference site for the study. The four (4) replicates represented four distinct phases or chronosequence, i.e., Year 5 planting (2008), Year 10 planting (2003), Year 15 planting (1998) and Year 20 planting (1993).

These blocks were identified using codes derived from the block name, the division where it is located and the year of establishment, e.g., U1 (ED1) 2003 depicts block U1, estate division 1 and planted in 2013 (Table 1).

Table 1: List of the 15 experimental blocks sampled from the three sites within the GREL concession area

Old Rubber Plantation (ORP)	After Secondary Forest (SF)	Abandoned Farmland (AF)
T3-2(ED1) 2008	F5-1(ED7)2008	G11-1(ED9) 2008
B7(ED2) 2003	U1(ED1) 2003	B3-1(ED7) 2003
D1(ED6) 1998	F4(ED6) 1998	F3-2(ED7) 1998
F2(ED5) 1993	I4(ED5) 1993	M6(ED5) 1993

3.2.1 Soil Sampling and Processing

In each block of plantation, three (3) sampling points were randomly selected along an Sshaped transect starting from one of the corners. At each sampling point, three soil cores were taken at depths 0-20 cm, 20-40 cm and 40-60 cm with the help of a soil screw auger (Plates 3.1 to 3.4). Cores were combined for each block based on the depths and the composite sample weighed approximately 600 g. This sampling design thus gave a total composite sample of thirty-six (36), which were collected before the onset of the major raining season in March 2014. Soils sampled were air-dried before sieving with a 2 mm sieve to get finer granules (Plate 3.5 to 3.7) for the analysis at the Ecological Laboratory at the University of Ghana, Accra-Ghana.

Plate 3.1: A soil screw auger for soil sampling

Plate 3.2: Buckets for collecting soils at varying depths

Plate 3.3: An experiment worker pushing the screw auger into soil

Plate 3.4: Removal of soil sample from the screw auger

Plate 3.5: Air-drying soil samples

Plate 3.6: Sieving of soil samples to finer granules

Plate 3.7: Prepared soil samples ready for chemical analysis

3.3 Procedures for Laboratory Analysis

3.3.1 Soil pH

Soil pH was determined using a H1 9017 Microprocessor pH meter in a 1:2.5 suspension of soil and water. A 20 g soil sample was weighed into plastic pH tube to which 50 ml water was added from a measuring cylinder. The suspension was stirred frequently for 30 minutes. After calibrating the pH meter with buffer solutions at pH 4.0 and 7.0. The pH was read by immersing the electrode into the upper part of the suspension.

3.3.2 Total nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soils Laboratory Staff (1984). A 0.5 g soil sample was weighed into a Kjeldahl digestion flask. To this 5 ml distilled water was added. After 30 minutes, concentrated sulphuric acid (5 ml) and selenium were added and mixed carefully. The sample was then digested for 3 hours until a clear digest was obtained. The digest was diluted with 50 ml distilled water and mixed well until no more sediment dissolved and allowed to cool. The volume of the solution was made to 100 ml with distilled water and mixed thoroughly. A 25 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of 40 % NaOH solution added followed by distillation. The distillate was collected in 2.0 % boric acid and was titrated with 0.02 N HCl using mixed indicator as indicator. A blank distillation and titration was also carried out to take care of the traces of nitrogen in the reagents as well as the water used.

Calculation:

The % N in the sample was expressed as:

$$\%N = \frac{N \text{ x } (a-b) \text{x } 1.4 \text{ x mcf}}{w}$$

Where

N = concentration of HCl used in titration a = ml HCl used in sample titration   b = ml HCl used in blank titration w = weight of air-dry soil sample mcf = moisture correcting factor (100 % + % moisture) /100)

1.1 = 14 × 0.001 × 100 % (14 = atomic weight of N)

3.3.3 Available phosphorus (Bray's No.1 phosphorus)

The available phosphorus was extracted with Bray's No.1 extracting solution (0.03 M NH4F and 0.025 M HCl) as described by Bray and Kurtz (1945). Phosphorus in the extract was determined by the blue ammonium molybdate method with ascorbic acid as the reducing agent using a spectrophotometer.

A 5 g soil sample was weighed into a shaking bottle (50 ml) and 35 ml of extracting solution of Bray's No.1 added. The mixture was shaken for 10 minutes on a reciprocating shaker and filtered through a Whatman No. 42 filter paper. An aliquot of 5 ml of the blank, the extract, and 10 ml of the colouring reagent (ammonium molybdate and tartarate solution) were pipetted into a test tube and uniformly mixed. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21D spectrophotometer at a wavelength of 660 nm at medium sensitivity.

A standard series of 0, 1, 2, 3, 4 and 5 mgP/L was prepared from 20 mg/L phosphorus stock solution.

Calculation:

$$\text{P (mg/kg soil)} = \frac{(a-b)*35 \text{ x mcf}}{w*15}$$

Where a = mg/L P in sample

extract b = mg/L P in blank

mcf = moisture correcting factor

35 = ml extracting solution

15 = ml of aliquot taken w

= sample weight in gram

3.3.4 Determination of Calcium and Magnesium

Ten grammes (10g) of soil was weighed into an extraction bottle containing 100ml of 1N NH4 OAc solution. The extraction bottle was then put in a shaking machine and shaked for one hour. At the end of the shaking, the bottles were placed in a centrifuge and centrifuged for about 20 minutes. The supernatant solution was then filtered through No.24 Whatman filter paper. Aliquots of the extract were then put through the AAS machine to determine the reading for calcium and magnesium.

Calculation;

Calcium/Magnesium (cmol/kg) $= \frac{\text{AAS reading}}{\text{Molar mass of Calcium}} * \text{Valency}$

3.3.5 Determination of exchangeable potassium

A standard series of potassium was prepared by diluting 1000 mg/l K. In doing this, 25 ml portion of the solution was taken into 250 ml volumetric flask and made up to the volume with distilled water. Portions of 0, 5, 10, 15, 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks. One hundred millilitres (100 ml) of 1.0

M NH_4OAc solution was added to the flask and made to the volume with distilled water. This resulted in standard series of 0, 2.5, 5.0, 7.5; 10 mg/l for K. Potassium was measured directly in the leachate by flame photometry at wavelength of 766.5 nm.

Calculation:

Exchangeable K (cmol/kg soil) $= \frac{(a-b) * 250 * mcf}{10 * 39.1 * w}$

where; a = mg/l K in the diluted sample

percolate b = mg/l K in the diluted blank

percolate w = weight (g) of air- dried

sample mcf = moisture correcting factor

3.4 Data Analysis

The data were entered into microsoft excel and screened for errors and then to find out whether the means of the different land-uses were similar or not. The differences in the levels of the different soil parameters among the three land-use types and chronosequences were evaluated using analysis of variance (ANOVA) at 5% significance test (Bailey, 2008). Before the ANOVA, normality test was done for the data set.

CHAPTER FOUR

RESULTS

4.1 Variations in Soil Fertility Indicators Among the Land-Use Types

Soil nutrient status or fertility response to natural rubber plantations and secondary forests was assessed through analysis of key soil quality indicators or parameters including nitrogen, phosphorus, potassium, magnesium, calcium and pH.

Results of the analysis indicated that the soil properties did not differ statistically ($p > 0.05$) among the three land-use types. However, the secondary forest (SF) generally recorded slightly higher values of N, P, K, Ca and pH compared to the old rubber plantation (ORP) and the abandoned farmlands (AF) for all soil parameters analysed (Figures 6-8, 10-11), except Mg. The amount of Mg recorded was relatively higher for the ORP (6.27 cmol/kg at depth 0-20 cm, 6.18 cmol/kg at depth 20-40 cm and 5.89 cmol/kg at depth 40-60 cm) compared to SF (5.11 cmol/kg at depth 0-20 cm, 4.77 cmol/kg at depth 20-40 cm and 4.58 cmol/kg at depth 40-60 cm) and AF (4.73 cmol/kg at depth 0-20 cm, 4.50 cmol/kg at depth 20-40 cm and 4.29 cmol/kg at depth 40-60 cm) (Figure 8).

In general, the soil parameters analyzed exhibited a decreasing trend with increase in soil depth (Figures 6-11). Soil samples taken at depth 0-20 cm recorded the highest values for all the soil parameters analyzed. Soil samples taken at depth 0-20 cm recorded the highest TN for all the land-uses types studied. TN content in SF ranged from 0.960.86 % whilst those of ORP and AF ranged from 0.90–0.85 % and 0.76–0.66 %, respectively at depth 0-20 cm, and decreased by 6.21 % at depth 20-40 cm and 9.83 % at depth 40-60 among the three land-uses (Figure 6). The ANOVA revealed no significant differences in TN content among the various depths and land-use types (Appendix A). Similar to TN, total phosphorus decreased with increasing soil depth for all the land-uses (Figure 7). Soil samples taken at depth 20-40 cm and 40-60 cm showed a decline in TP from 3.3 % to 4.2 % and 6.6 % to 8.7 % respectively when compared to samples taken at depth 0-20 cm for all the land-use types. However, these differences were not statistically significant ($p > 0.05$; Appendix B).

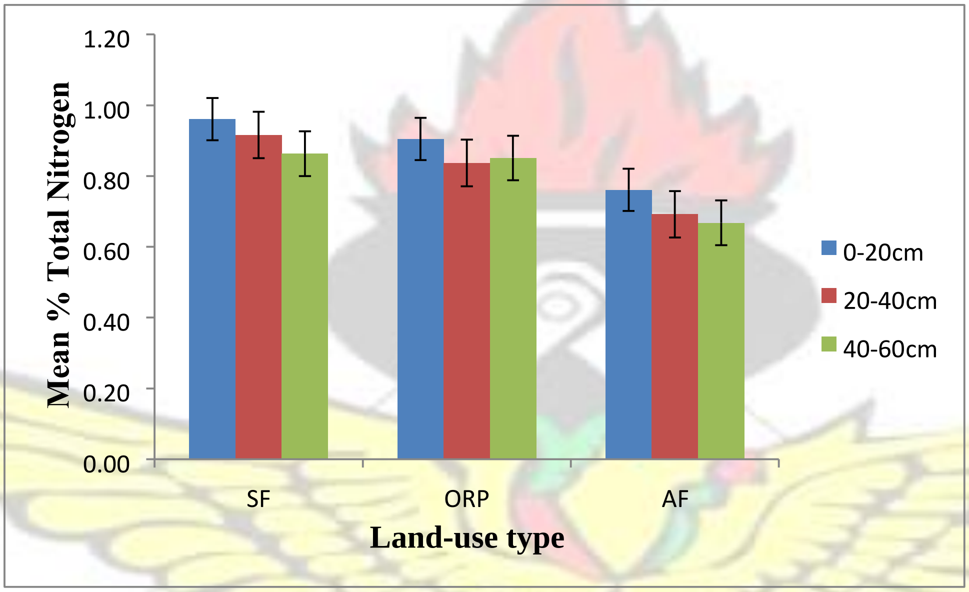

Figure 6: Comparison of TN levels among different land-use types and at different depths.

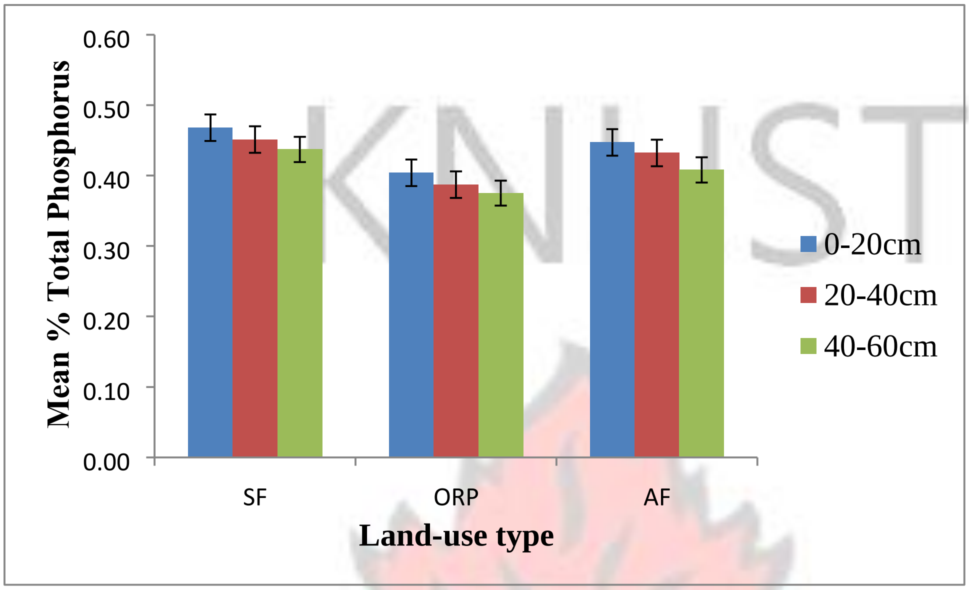

Figure 7: Comparison of TP levels among different land-use types and at different depths.

There were no significant differences in available K among the various land-use types at various depths (Figure 8; Appendix C). Nonetheless, K levels showed a decreasing trend with increasing depth across all land-use types. There was a marginal decrease in the value of K within the SF from 7.38-7.06 cmol/kg among the various depths. ORP declined from 3.3 % to 7.5 % at depths 20-40 cm and 40-60 cm respectively when compared to depth 0-20 cm. The AF generaly showed lower available K values among the land-use types, ranging from 6.34-6.67 cmol/kg.

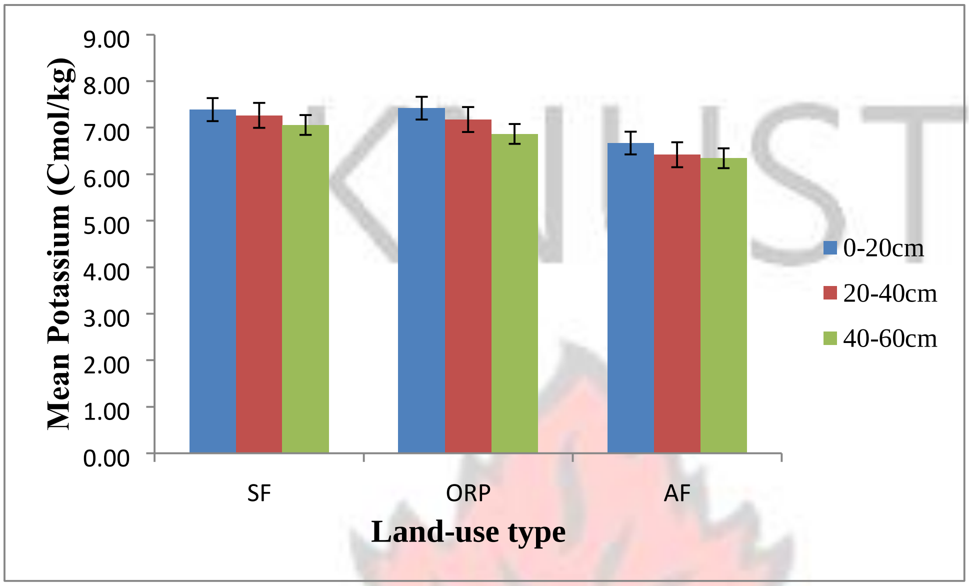

Figure 8: Comparison of mean K levels among different land-use types and at different depths.

The concentration of Mg did not differ statistically ($p > 0.05$) among the three land-use types (Figure 9; Appendix D). Like most of the other parameters, Mg decreased with increase in soil depth for all land-use types. The ORP had higher Mg values (6.285.89 cmol/kg) for all soil depths compared to SF and AF land-use types which ranged from 5.11-4.58 and 4.73-4.39 cmol/kg, respectively.

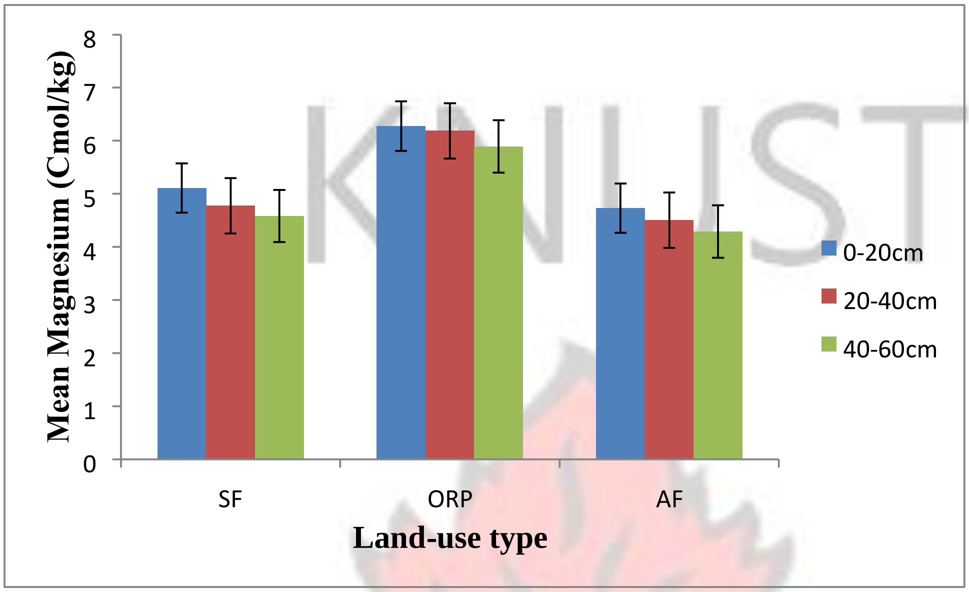

Figure 9: Comparison of Mg levels among different land-use types and at different depths.

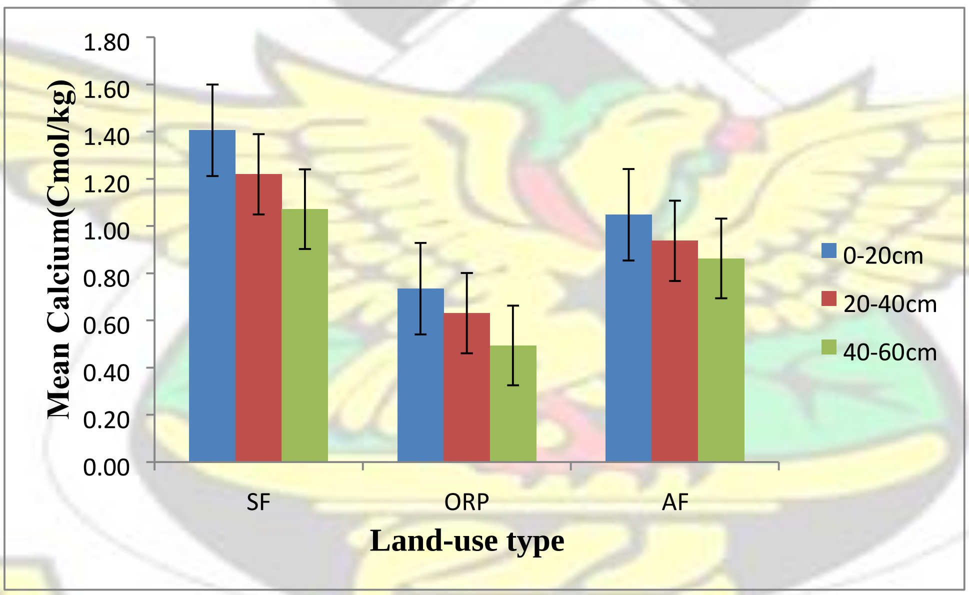

Figure 10: Comparison of Ca levels among different land-use types and at different depths.

The exchangeable Ca ranged from 1.41 to 1.07 for SF, 0.74 to 0.49 for ORP and

1.05 to 0.86 for AF land-use types (Figure 10). In addition, Ca also appeared to have decreased with increasing depth of the soil. However, no significant differences were observed among the land-use types and the soil depths as can be seen in Appendix E.

Soil pH showed similar pattern as Ca and decreased with increasing soil depth (Figure 11). The SF showed highest pH for depths 0-20 cm and 20-40 cm whilst AF showed highest for depth 40–60 cm. However, there were no significant differences among the three land-use types at the various depths.

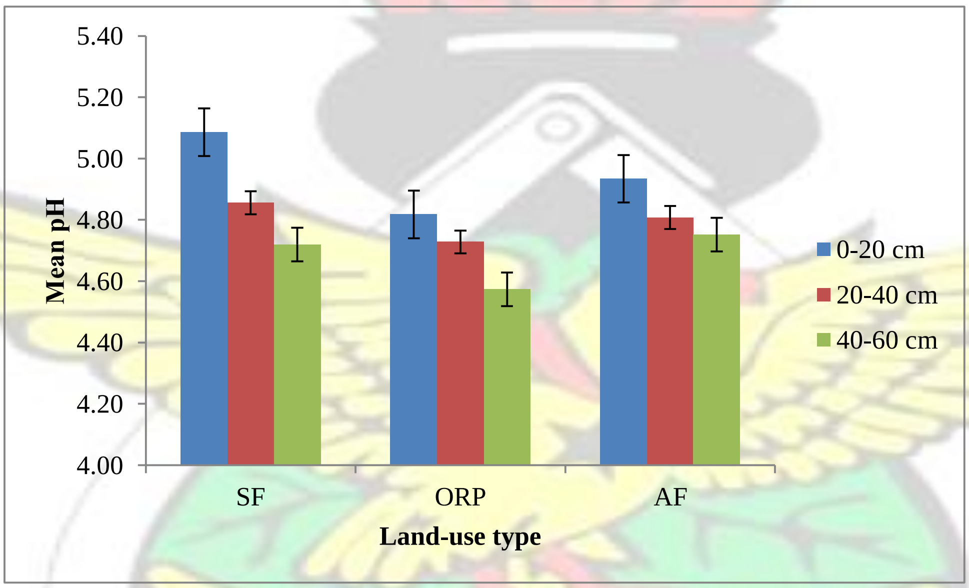

Figure 11: Comparison of pH levels among different land-use types and at different depths.

4.2 Changes in Soil Nutrient Status Over Time

Soil parameters studied exhibited three main patterns over time across all land-use types - an increase in TN, TP, and K (Figures 12-14), a decrease in the value of Mg and Ca (Figures 15 and 16), whilst pH remained largely unchanged (Figure 17). Mean values of TN for the SF ranged from 0.19 % (for Year 5) to 0.21 % (for Year 20) with a 10.5% increment, whereas that of the ORP ranged from 0.16 % to 0.22 % with a 37.5% increment over the same period. However, the TN for ORP dipped slightly after five years of cultivation. Overall, the AF land-use type appeared to show lower mean TN values across all the corresponding years. However, ANOVA (Appendix F) revealed no significant differences in TN among the land-use types.

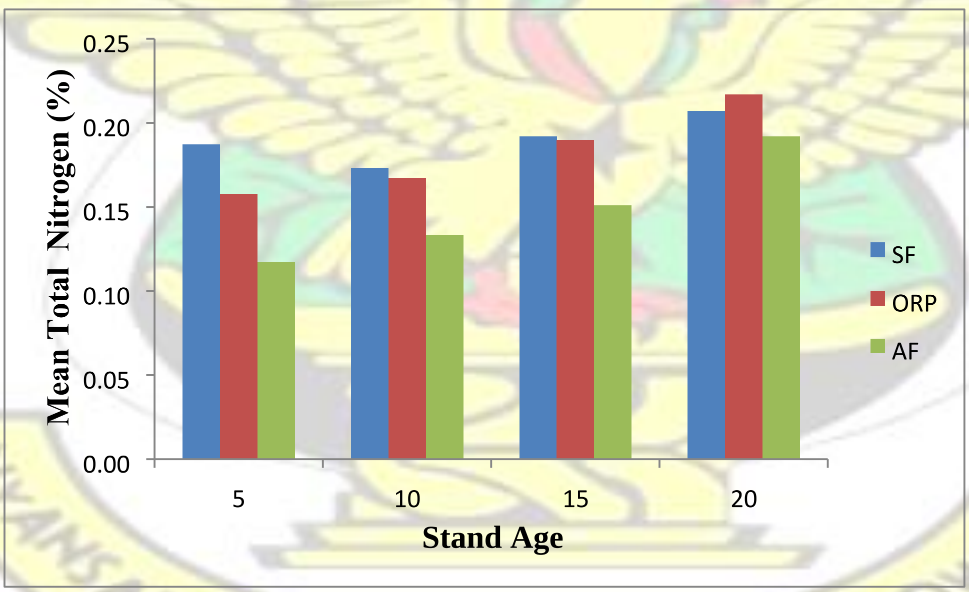

Figure 12: Comparison of mean TN levels among the three land-uses over a 15-year period

As with TN, TP increased with stand age of natural rubber plantations (Figure 13). There was a steady rise from Year 5 to Year 20. The AF in particular increased marginally (with a rate 0.45 %) from Year 5 to Year 20. On the contrary, the mean TP in the SF and ORP increased at 2.08 % and 3.33 % respectively between Year 5 and Year 20 after establishment of the rubber plantation. Though the SF appeared to show the highest mean TP values from Year 10 upwards, there were no significant differences ($p >$ 0.05) among the land-use types (Appendix G).

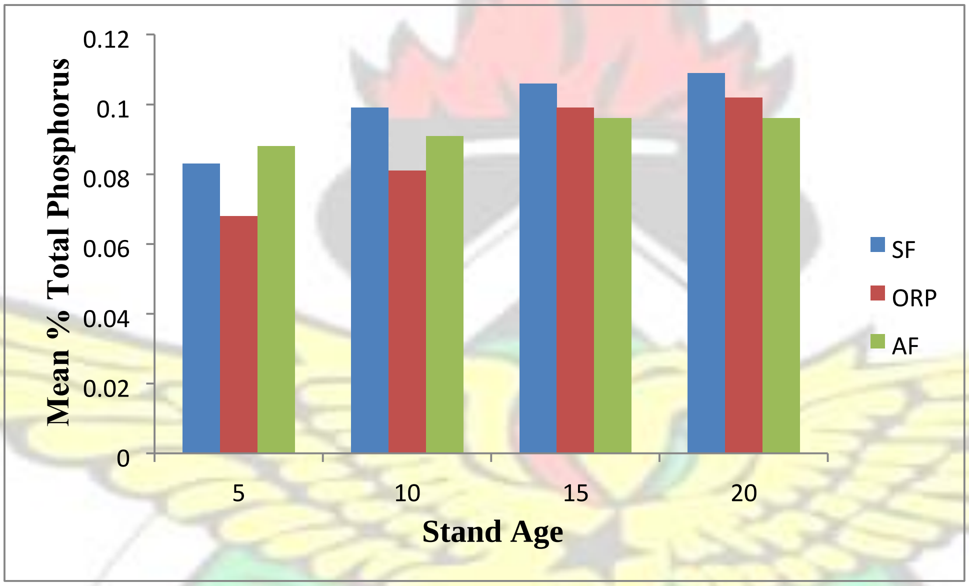

Figure 13: Comparison of mean TP levels among the land-use types over a 15-year period.

Analysis of the data revealed no significant differences ($p > 0.05$) in the amount of available K among the various land-use types (Appendix H). Available K barely changed between 5 and 10 years following plantation establishment, but increased marginally after this period. The SF had mean K values ranging between 1.44 and 1.73 cmol/kg from Year

5 to Year 20 (Figure 14). Over the same period, the ORP and AF recorded mean K values of 1.45-1.65 cmol/kg and 1.23–1.48 cmol/kg respectively.

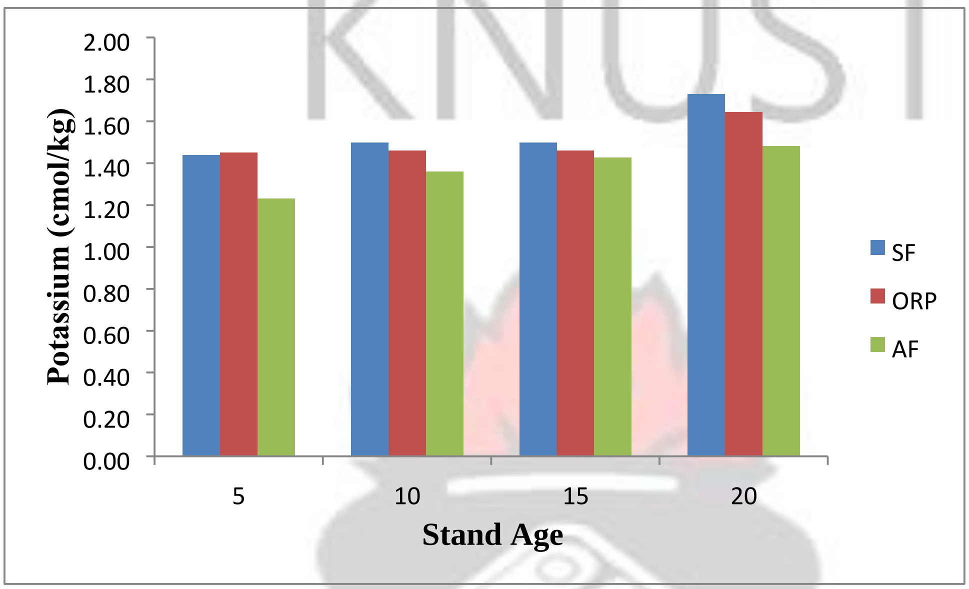

Figure 14: Comparison of mean K levels among the land-use types over a 15-year period

Contrary to the increasing trend observed with TN, TP and available K, the level of Mg decreased considerably over the years among all the three land-use types. The ORP, for example, had mean Mg decreased as much as 93.2 % from Year 5 to Year 20. The values for the AF and the ORP decreased similarly at 88.2 % and 81.7 % respectively from Year 5 to Year 20. However, ANOVA (Appendix I) revealed that there were no significant differences in TN among the land-use types.

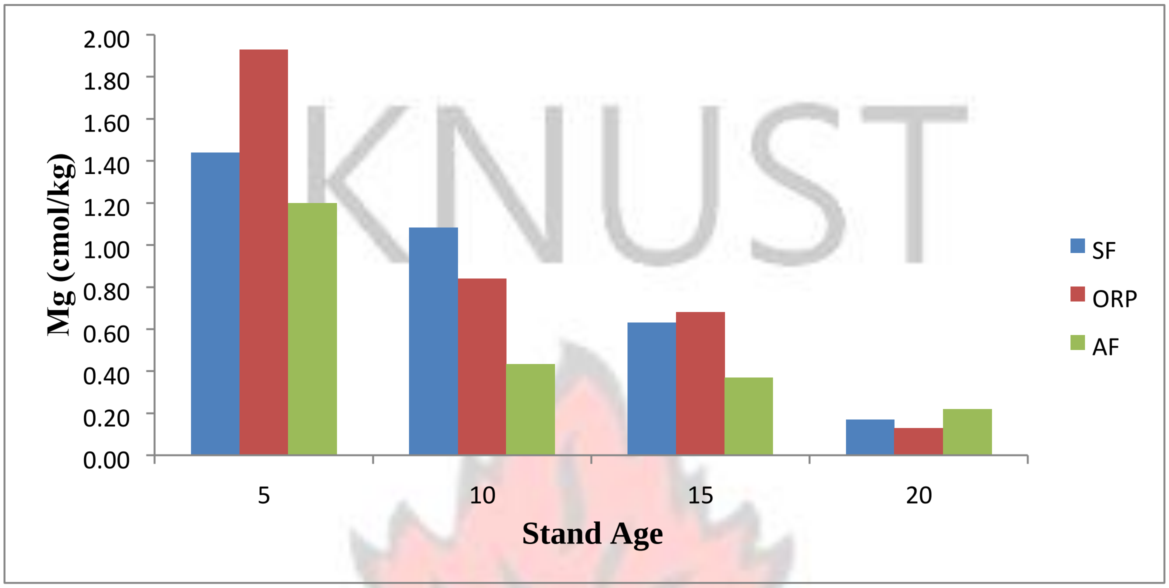

Figure 15: Comparison of mean Mg levels among the land-use types over a 15-year period

Soil exchangeable Ca also decreased with increase in age of rubber plantations (Figure 16). There was a sharp decline of the exchangeable Ca in the AF land-use from Year 5 to Year 10. It was observed that the value of exchangeable Ca for ORP which hitherto was the lowest from Year 5 to Year 10 suddenly had the highest exchangeable Ca from Year 15 to Year 20. Though SF appeared to show a moderate decline from Year 5 to Year 20, there were no significant differences ($p > 0.05$) among the land-use types (Appendix J).

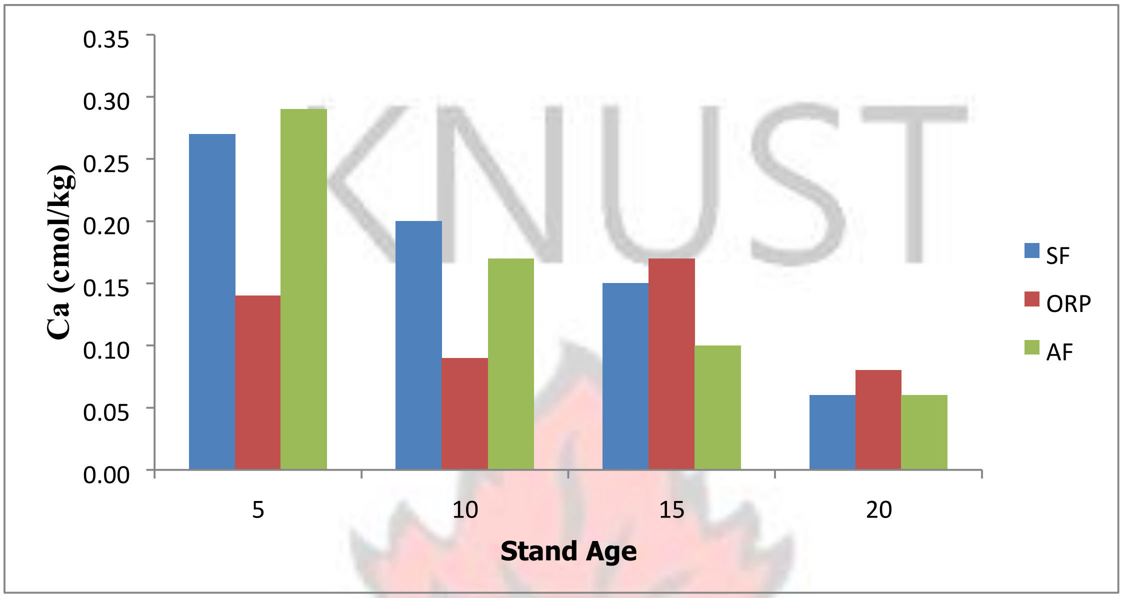

Figure 16: Comparison of mean Ca levels among the land-use types over a 15-year period

Despite a slight fluctuation, soil pH largely remained stable over time (Figure 17). The results indicated that the soils from all the three land-use types were acidic, ranging from 4.58 to 5.30 for SF, 4.58 to 5.03 for ORP and 4.64 to 5.33 for AF. However it was found out that there was no significant difference (p > 0.05) amongst them (Appendix F).

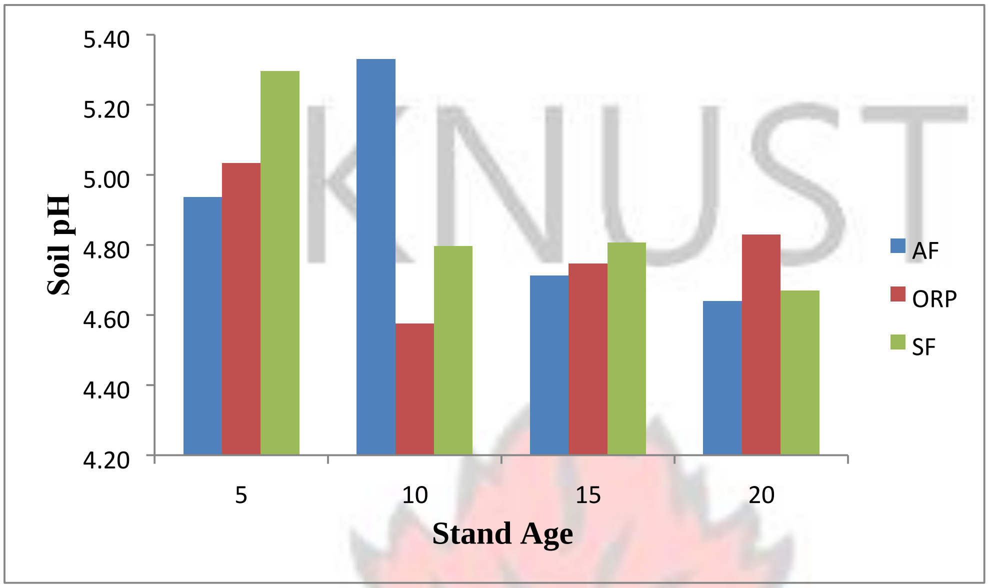

Figure 17: Comparison of mean pH among the land-use types over a 15-year period

CHAPTER FIVE

DISCUSSION

5.1 Effect of NR Plantations on Soil Nutrients

The purpose of this study was to assess the effects of rubber plantations established on different land-use systems on the soil physicochemical parameters such as nitrogen, phosphorus, potassium, magnesium, calcium and pH. The results generally showed that these parameters did not differ greatly among the studied land-use types and the soil depths. However three patterns emerged with respect to the changes in the soil nutrient parameters of time (i.e., with the age of plantation establishment)—nitrogen, phosphorus and K showed an increasing pattern, magnesium and Ca decreased, whilst pH remained stable. These results broadly suggest varying dynamics of the different soil nutrient properties in response to the plantation establishment under different land-use types.

Total nitrogen was observed to have improved with the establishment of rubber plantations on all the land-use types studied over the 15 - year period. This result is consistent with that observed in studies conducted by Yasin *et al*. (2010) on the changes of soil properties on various ages of rubber trees. The increase in total nitrogen with stand age could be attributed to the mature rubber trees with their large biomass, which not only afford adequate ground cover, but also act as a huge reservoir of nutrients, thereby preventing nutrients from being leached away from the soil beneath it.

Decomposition of these large rubber trees enriches the soil with nitrogen.

Available phosphorus of the soils studied under the land-use types increased with the establishment of rubber plantations. There was a gradual increase from 8.3 %, 23.8 % and 33.3 % of available phosphorus among AF, SF and ORP land-use types over the 15 year period. The rise of available phosphorus across the land-use types might be due to the application of phosphorus fertilizers. This finding corroborates that of Iwara *et al*. (2011) which suggested that application of phosphorus fertilizer leads to increase in litter inputs, and *in situ* decomposition, which favours increase in soil available phosphorus.

Similarly, the rapid rise in the amount of potassium at early establishment can be attributed to the use of potassium fertilizers. The steady increase in potassium over the years could also be explained by the application after NR establishment to the time of opening at year seven (7). However, available K showed no significant effect on the three land-use types corroborating the findings of Aweto and Dinkiya (2003).

Unlike nitrogen, phosphorus and potassium, the proportion of magnesium decreased with establishment of rubber plantations for all land-use types. Initial decrease in Mg can be attributed to land preparation activities that are undertaken before the establishment of the rubber plantation as this leaves the soil bare and hastens the leaching of base cations to the deeper soils, according to Yasin *et al*. (2010). Subsequent decrease in Mg at the production stage could be due to the uptake of magnesium by the rubber plant particularly during tapping. According to Shorrocks (1964), Mg forms a significant part of the latex from the rubber tree and this could explain why Mg decreases when rubber is established on soils.

Calcium exhibited a similar trend as magnesium as exposed land surfaces, irrespective of the land-use type, recorded higher values at initial establishment and reduced marginally with the formation of tree canopy. Yasin *et al.* (2010) affirms this and attributes it to the leaching of base cations. It has been observed that there is a buildup of calcium oxylate crystals at the bark of rubber trees and this explains why Ca in soils under rubber cultivation decreases with increase in stand age. Although Ca in the rubber tree is water soluble, it is relatively immobile and is not readily redistributed back into the soil (Shorrocks, 1964).

pH is one of the most important soil physicochemical factors, which influence the chemistry as well as fertility management of tropical soils. Any drastic change in pH value indicates drastic change in soil environment (Alexander *et al*., 1981). The study revealed that the soils from all three (3) land-use types were acidic with a pH range of 4.58 to 5.33. According to Chivith (1996) and White *et al.* (1997), this observed range falls within the critical range for rubber cultivation as desirable limits for the optimal growth and performance of rubber in tropical soils. However, the acidic nature of the soils may also be explained by the high rainfall in the study area which is sufficient to leach basic cations especially calcium from the surface horizons of the soils. This finding is consistent with the findings by Paudel and Sah (2003) that the acidic nature of soils studied under *Shorea robusta* and mixed *Shorea robusta* plantations were affected by environmental factors such as aspect, rainfall and vegetation composition.

5.2 Effect of Age of Natural Rubber on Nutrient Status

Results of this study clearly revealed a considerable effect of age of rubber on the soil nutrient status of the soil from all the three land-use types studied.

The average value of TN was highest in the 15-year stands for all the land-use types studied, as TN content increased considerably with stand age. This increasing trend may be attributed to the activity of the bacterial nitrogenase within the roots of rubber trees, which helps in fixing atmospheric nitrogen (Roper *et al*., 1994). According to these authors, application of nitrogenous fertilizers depresses nitrogenase activity and this might account for the low values of TN at the early stages of rubber establishment. The increasing trend in the total nitrogen of the studied plantation soils collaborated earlier, similar studies (Geetha and Balagopalan, 2009; Yasin *et al*., 2010) on soil fertility variations within teak plantations.

Phosphorus is another element that exhibited significant improvement with age of the rubber plantations. Among all the land-use types studied, phosphorus increased with age of the stand.. The overall increase in phosphorus with age affirms similar work by Aweto and Dinkiya (2003), which elaborated on the canopy formed as rubber grows and its subsequent reduction in raindrops from directly hitting the soils as well as reduction in infiltration.

The increase in the quantity of potassium with age of rubber plantations can be attributed to the high rate of biomass production and the subsequent decomposition of organic matter. Litter fall and decomposition are the main means of recycling nutrients back to the soil in tropical ecosystem; as nutrient cycling in a mature tree is "closed" so as the loss of nutrients from the soil is minimal over time. This confirms earlier studies undertaken by Polglase and Attiwill (1992) on Mountain Ash (*Eucalyptus regnans*) which revealed an increase in potassium content of soils with age due to organic matter decomposition and release of phosphorus from litter.

The decrease in magnesium with increasing age of the rubber stand for all landuse types conforms to earlier findings by Yasin *et al.* 2010 who attributed the high level of Mg to leaching of base cations to the deeper soils. At the early stages of rubber establishment, there is virtually no land cover and hence raindrops hit soil surface directly and enhances the leaching process of base cations compared to the stage where the rubber tree forms adequate canopy. According to Shorrocks (1964), Mg forms a significant part of the latex from the rubber tree and this could explain why Mg decreases as the rubber stand ages. Similarly, there is a buildup of calcium oxylate crystals at the bark of rubber trees as it ages and this best explains why there is a reduction in Ca levels with age of the stand.

Analysis of soil pH among the different land-uses studied showed that the pH becomes more or less stable when a rubber tree ages. However, the significant differences among the various land use types n pH observed from Year 5 to Year 10 may be due to lack of canopy at this stage to reduced incident rainfall from directly hitting onto the plantation floor. The pH range corresponds to that observed in studies conducted by Boateng *et al.* (2000) on the pH range of soils within the study area.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The results of this study have demonstrated that rubber establishment impacted somewhat positively on most of the soil quality parameters analyzed, consistent with the notion that most soil nutrients are returned into soils through accumulation and subsequent turnover of leaf litter.

N, P, and K in soils under rubber plantation increased with stand age.

The application of inorganic fertilizers should be done at the initial stages of rubber establishment when the existing nutrients might have been leached from the soils during the periods of land preparation.

NR plantation appeared to have led to an improvement in the soil qualities in the long term as the trees formed canopies, which protected the soils from the direct incidence of rainfall thereby reducing the leaching of soil nutrients.

Rubber plantations have no deleterious effect on soil fertility.

Statistically, all the soil quality parameters analyzed showed no significant difference between the three land-use types.

6.2 Recommendations

From the results of this study, it is recommended that companies and individuals involved in rubber cultivation should establish leguminous cover crops on lands earmarked for rubber plantation immediately they are cleared so as to minimize the loss of nutrients through leaching. Again, NR- producing companies and individuals should ensure that there is minimal turnover of the soils during land preparation so as to keep the soil structure intact.

REFERENCES

Adejuwon, J. O. & Ekanada, O. (1988). A comparison of soil properties under different land use types in a part of the Nigerian cocoa belt. Catena 15: 319-331.

Ahmad, H. A. B. B. (1987). RRIM training manual for plantation supervisors. Kuala Lumpur. pp 105, pp 92, pp 97

Alexander, T. G., Balagopalan, M., Thomas, T. P. & Mary, M. V. (1981). Properties of soils under teak. KFRI Research Report No.7. 13p.

Atsivor, L., Dowuona, G. N., & Adiku, S. G. K. (2001). Farming system-induced variability of some soil properties in a sub-humid zone of Ghana. Plant Soil 236, 83–90.

Aweto, A. O., & Dikinya, O. (2003). The beneficial effects of two tree species on soil properties in a semi-arid savanna rangeland in Botswana. Land Contamination & Reclamation, 11 (3): 339 – 344.

Bailey, R. A. (2008). *Design of Comparative Experiments*. Cambridge University Press. ISBN 978-0-521-68357-9.

Beer, J., Muschler, R., Kass, D., & Somarriba, E. (1998). Shade management in coffee and cocoa plantations. Agroforestry Systems 12: 229-249.

Boateng, E., Breuning-Madson, H., Jones, R. J. A., King, D., Montanarella, L., & Nachtergaele, F. (2000). A proposal for the compilation of a soil profile analytical database for West Africa. West Africa Journal of Applied Ecology, vol.

1

Bray, R. H. & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. Soil Science, 59: 39-45.

Broughton, W. J. (1977). Effect of various covers on soil fertility under *Hevea brasiliensis*. Kuala Lumpur, Malaysia. pp 66.

Bunch, R. (2000). More productivity with fewer external inputs. Environ. Develop. Sust. 1 (3–4), 219–233.

California Fertiliser Association (1980). Soil Improvement Committee, Fertiliser Handbook. The Interstate Printers and Publishers, Inc Danville, Illinois pp 269.

Chivith, B. (1996). Rubber establishment scheme for smallholding farmers. Rubber Research Institute of Cambodia, pp. 16

Compagnon, P. (1987). Le Caoutchouc Naturel- Biologie, Culture, Production. Techniques Agricoles et Productions Tropicales. G.-P. Maisonneuve and Larose, Paris. 595 p. ISBN 2-7068-0910-8

de Levie, Robert (2004). *Advanced Excel for scientific data analysis*. Oxford University Press. ISBN 0-19-515275-1.

Delarue, J. (2009). Developing Smallholder Rubber Production. Lessons from AFD's Experience. Evaluation and Capitalisation Series, No. 26.

Dixon, R. K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C., & Wisniewski, J. (1994). Carbon Pools and Fluxes of Global Forest Ecosystems. Science, 263, 185–190. http://dx.doi.org/10.1126/science.263.5144.185

Driessen, A.J., Manting, E.H., & van der Does, C. (2001). The structural basis of protein targeting and translocation in bacteria. Nat. Struct. Biol. 8, 492–498.

Duah-Yentumi, S., Ronn, R. & Christensen, S. (1998). Nutrients limiting microbial growth in a tropical forest soil of Ghana under different management. Applied Soil Ecology, 8: 19-24

Duguma, B., Gochowski, J., & Bakala, J. (2001). Smallholder cacao (Theobroma cacao Linn.) cultivation in agroforestry systems of West and Central Africa: Challenges and opportunities. Agroforestry Systems 51:177–188.

Ekanade, O., Adesina, F.A. & Egbe. N.E. (1991). Sustaining tree crop production under intensive land use: An investigation into soil quality differentiation under varying cropping patterns in western Nigeria.J. Ev. Manage. 32: 105-113.

Elliot, W. J. (2003). "Soil Erosion in Forest Ecosystems and Carbon Dynamics", in Kimble, J.M.; Heath, L.S.; Birdsey, R.A. and Lal, R. (Eds.), The Potential of US Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect. CRC Press, Boca Raton, FL, pp. 175–190.

Evans J. (1992). Plantation Forestry in the Tropics. 2nd Edition. Claredron Press, Oxford University, UK. pp 403.

FAO (2010). Global Resources Assessment 2010. Country Report, Ghana, FRA 2010/077, Rome

Geetha, T. & Balagopalan, M. (2009). Soil fertility variations within a rotation period in teak plantations in Kerala. Advances in Plant Sciences, 22 (1): 317-319

Gilard, O. (2012). Smallholder rubber plantation Ghana. Workshop on contract farming, PhnomPehn[http://www.fao.org/fileadmin/user_upload/contract_farming/presentations/Olivier%20GILARD%20-%20AFD%20-%20Hevea_Ghana%20ENG[1].pdf], (accessed on 2013, July 29)

Goma-Tchimbakala, J., Moutsambote, J.M. & Makosso, S. (2008). Comparison of some soil chemical properties in four Terminalia superba Plantations and a Natural Tropical Forest in Mayombe, Congo. J. Appl. Sci., 8: 4152–4158

Grist, P., Menz, K. & Thomas. (1998). Modified BEAM Rubber Agroforestry Models: RRYIELD and RRECON. ACIAR Technical Reports Series 42. 43 p. ISBN 1-86320-225-0

Hong, L. T. (1999). Introduction. Pp. 1-15. In: Hong, L.T & Sim, H.C. (Editors) 1999. Rubberwood- Processing and Utilisation. Malayan Forest Records 39. Forest Research Institute Malaysia, Kuala Lumpur. 254 p. ISBN 983-9592-27-0

Iwara, A.I., Ewa, E. E., Ogundele, F.O., Adeyemi, J.A. & Otu, C.A. (2011). Ameliorating effects of palm oil mill effluent on the physical and chemical properties of soil in ugep, cross river state, south-southern Nigeria**.** International Journal of Applied Science and Technology, 1 (5): 106 – 112.

Jiang, A. (1988). Climate and natural production of rubber (Hevea brasiliensis) in Xishuangbanna, southern part of Yunnan province, China. International Journal of Biometeorology, Vol. 32(4): 280-282. ISSN 0020-7128

Jumpasut, P. (2004). Global NR and SR development in the next decade: focus on New Asia. In: Jewtragoon and Patthavut. Full Texts of the International Rubber Conference 200e. Thai Rubber Association. Chiangmai.

Karl, M. (1994). Sustaining Growth: Soil Fertility Management in Tropical Small Holdings. A Wiley Interscience Publication. New York. pp 102

Kauffman, J. B., Cummings, D. L. & Ward, D. E. (1998). Fire in the Brazilian Amazon. 2. Biomass, nutrient pools and losses in cattle pastures. Oecologia 113:415-427.

Kotto-Same, J., Woomer, P. L., Appolinaire, M., & Louis, Z. (1997). Carbon dynamics in slash-and-burn agriculture and land use alternatives of the humid forest zone in Cameroon. Agriculture, Ecosystems and Environment 65:245-256.

Krause, H. H. (1965). Effect of pH on leaching losses of potassium applied to Forest America Proc. Pp 29, 613,625, New York.

Lal, R. (1996). Deforestation and Landuse Effects on Soil Degradation and Rehabilitation in Western Nigeria. III. Runoff, soil erosion and nutrient loss. Land degradation & development, 7, 87-98.

Landon J. R. (1991). Booker tropical soil manual. England. pp 303

Lemmens R. H. M. J, Soerianegara I, & Wong W. C. (Eds.). (1995). Plant Resources of South East Asia (PROSEA). Timber trees: No. 5 (2).Minor commercial timbers. Backhuys Publisher, Leiden. 655 p. ISBN 90-73348-44-7

Mary, M.D. & Thomas, D.L. (1984). Forest Nursery Manual, Martinus Nijhoff/Dr W.Junk Publishers. The Hague/Boston/Lancaster, Oregon State UniversityCorvallis U.S.A. pp 63-72.

MOFA/SRID (2003). Agriculture in Ghana: Facts and Figures

Nambiar, E. K. S., & Broen, A. G. (1992). All India Coordinated Research Project on Long-Term Fertiliser Experiment, India Agriculture Research Institute, Amerind Publishers New Delhi.

Offiong, R. A., & Iwara, A. I. (2012). Quantifying the Stock of Soil Organic Carbon Using Multiple Regression Model in a Fallow Vegetation, Southern Nigeria. Ethiopian Journal of Environmental Studies and Management, 5(2), 166-172. http://dx.doi.org/10.4314/ejesm.v5i2.7

Ogunkunle A. O. & Eghaghara, O. O. (1992). Influence of land use on soil properties in a Forest region in Southern Nigeria. Soil Use and Manage. 8: 121-125.

Paudel, S. & Sah, J. P. (2003). Physico-chemical characteristics of soil in tropical Sal (Shorea robusta gaertn) forest in eastern Nepal. Himalayan J. Sci., 1 (2):107-110

Peries, O. S. & Fernando, D.M. (1983). A Handbook of Rubber Culture and Processing. Rubber Research Institute of Sri Lanka, pp. 89-90.

Peries, O. S. & A de S Liyanage (1984). A practical guides to rubber planting and processing. Rubber Research Institute Srilanka, pp 58, 79

Polglase, P. J. & Attiwill, P. M., (1992). Nitrogen and phosphorus cycling in relation to stand age of Eucalyptus regnans F. Muell. Plant Soil 142, 157±166.

Prasad, R. & James, F. P. (1997). Soil Fertility Management for Sustainable Agriculture, Lewis Publishers (1997) CRC New York. pp 6-9 and 63.

Raj, A., Chandra, R., & Patel, D. K, (2005). Physicochemical characterization of pulp and paper mill effluent and toxicity assessment by a Tubificid worm, Tubifex tubifex. Toxicology International, 12: 109–188.

Rao, P., Saraswathyamma, C.K., & Sethuraj, M.R. (1996). Studies on the relationship between yield and meteorological parameters of para rubber tree (*Hevea brasiliensis*). Agricultural and Forest Meteorology 90: 235-245.

Rao, G., Rao, P., Rajagopal, R., Devakumar, A.S., Vijayakumar, K.R. & Sethuraj, M. R. (1990). Influence of soil, plant and meteorological factors on water relations and yield in Hevea brasiliensis. International Journal of Biometeorology, Vol. 34(3): 175-180. ISSN 0020-7128.

Rao, P. & Vijayakumar, K. R. (1992). Climatic Requirements. Pp. 200-220. In: Sethuraj, M.R. & Mathew, N.M. 1992. Natural Rubber: Biology, Cultivation and Technology. Developments in Crop Science 23. Elsewier, Netherlands. 610 p. ISBN 0-444-88329-0

Roper, B. B., Scarnecchia, D. L., & La Marr, T. J. (1994). Summer distribution of and habitat use by chinook salmon and steelhead within a major basin of the South Umpqua River, Oregon. Transactions of the American Fisheries Society 123: 298308.

Rubber Research Institute of Thailand. (2005). Natural Rubber in Thailand. Presentation held inthe appraisal meeting on "Improving the Productivity of Rubber Smalholdings through Rubber Agroforestry Systems". September 5.-8.2005, Hat Yai.

Russell, F.W. (1988). Soil Condition and Plant Growth, McGraw-Hill Book Company. New York pp 426.

Sangsing, K. (2004). Carbon acquisition and plant water status in response to water stress of rubber (Hevea brasiliensis). Ph.D thesis. Kasetsart University. 130 p. ISBN 974-274-410-6

Schipper, L.A., & Sparling, G. P. (2000). Performance of Soil Condition Indicators Across Taxonomic Groups and Land Uses. Soil Science Society of America Journal, 64, 300-311. http://dx.doi.org/10.2136/sssaj2000.641300x

Sekondi–Takoradi Chamber of Commerce and Industry. Economic activities. [http://www.westernghanachamber.org/economic_activities.pdf], (accessed on 2013, July 15)

Sharma, P., Rai, S. C., Sharma, R. & Sharma, E. (2004). Effects of land-use change on soil microbial C, N and P in a Himalayan Watershed. Pedo biologia 48:83-92.

Shepherd G., Bureh R. J., & Gregory, P. J. (2000). Land Use Affects the Distribution of Soil Inorganic Nitrogen in Smallholder Production Systems in Kenya. Biology and Fertility of Soils, 31, 348 – 355. http://dx.doi.org/10.1007/s003740050667

Shorrocks, V.M. (1964). Mineral deficiencies in Hevea and associated cover plants. J.Rubber Res.Inst.Malays. 18:75.

Stumpe, J. M. & Vlek, P. L. G. (1991). Acidification Induced by Different Nitrogen Source in columns of selected Tropical Soil, Soil Science Association America Journal pp 55:5-151.

Thornley, J. H. M., & Cannell, M. G. R. (2000). Managing Forests for Wood Yield and Carbon Storage: A Theoretical Study. Tree Phys., 20, 477–484. http://dx.doi.org/10.1093/treephys/20.7.477 **van Beilen J. B, & Poirier Y. (2007).** Establishment of new crops for the production of natural rubber. Trends Biotechnol. 2007 Nov;25(11):522-9. Epub 2007 Oct 22. Review. PubMed PMID: 17936926.

Verheye, W. (2010). Growth and Production of Rubber. In: Verheye, W. (ed.), Land Use, Land Cover and Soil Sciences. Encyclopedia of Life Support Systems (EOLSS), UNESCO-EOLSS Publishers, Oxford, UK. http://www.eolss.net

Venkatachalam, P., Geetha, N., Sangeetha, P., & Thulaseedharaan, A. (2013). Natural rubber producing plants: An Overview. African Journal of Biotechnology Vol. 12(12), pp. 1297-1310, 20 March, 2013. ISSN 1684–5315 ©2013 Academic Journals

Wall, A., & Hytönen, J. (2005). Soil fertility of afforested arable land compared to continuously forested sites. Plant and Soil.275: 245-258.

Watson, G. A. (1957). Cover plants in rubber cultivation. J. Rubber Res. Inst., Malaya, 15:2-18

Webster, C. C. & Baulkwill, W. J. (1989). Rubber. The Rubber Research Institute of Malaysia, pp. 292-293

White, P. F., Oberthur, T. & Sovuthy, P. (1997). The soils used for rice production in Cambodia. Unpublished report. pp. 27

WRM Briefing (2008). Oil palm and rubber plantations in Western and Central Africa: An Overview. [*http://www.wrm.org.uy/publications/briefings/Western_Central_Africa.pdf.]*,

(accessed on 2013, August 4)

Yasin, S., Junaidi, A., Wahyudi, E., Herlena, S. & Darmawan (2010). Changes of soil properties on various ages of rubber trees in Dhamasraya, West Sumatra, Indonesia. J Trop Soils, 15 (3):221-227.

Yusoff, J. H. (1988). Training Manual on Soils, Management of Soils and Nutrition of Hevea. Rubber Research Institute of Malaysia, 211 p.

APPENDICES

Appendix A: Analysis of Variance (ANOVA) table for mean %TN among the three (3) land-uses at various depths

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.002789	2	0.001395	17.35492	0.003202	5.143253
Within Groups	0.000482	6	8.04E-05			
Total	0.003271	8				

Appendix B: Analysis of Variance (ANOVA) table for mean %TP among the three (3) land-uses at various depths

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*

Between Groups	0.000247	2	0.000123	11.00793	0.009823	5.143253
Within Groups	6.72E-05	6	1.12E-05			
Total	0.000314	8				

Appendix C: Analysis of Variance (ANOVA) table for mean K among the three (3) land-uses at various depths

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.041624	2	0.020812	11.68384	0.008528	5.143253
Within Groups	0.010687	6	0.001781			
Total	0.052311	8				

Appendix D: Analysis of Variance (ANOVA) table for mean Mg among the three (3) land-uses at various depths

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.174887	2	0.087444	41.00037	0.000317	5.143253
Within Groups	0.012797	6	0.002133			
Total	0.187684	8				

Appendix E: Analysis of Variance (ANOVA) table for mean Ca among the three (3) land-uses at various depths

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.02256	2	0.01128	16.42244	0.003685	5.143253
Within Groups	0.004121	6	0.000687			
Total	0.026682	8				

Appendix F: Analysis of Variance (ANOVA) table for mean pH among the three (3) land-uses at various depths

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.051318	2	0.025659	1.324	0.33397	5.143253
Within Groups	0.11628	6	0.01938			
Total	0.167598	8				

Appendix G: Analysis of Variance (ANOVA) table for mean %TN among the three (3) land-uses

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.004592	2	0.002296	2.773209	0.102319	3.885294
Within Groups	0.009935	12	0.000828			
Total	0.014528	14				

Appendix H: Analysis of Variance (ANOVA) table for mean %TP among the three (3) land-uses

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.000354	2	0.000177	0.39796	0.680234	3.885294
Within Groups	0.005333	12	0.000444			
Total	0.005687	14				

Appendix I: Analysis of Variance (ANOVA) table for mean K among the three (3) land-uses

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.061439	2	0.03072	0.614727	0.556975	3.885294
Within Groups	0.599673	12	0.049973			
Total	0.661112	14				

Appendix J: Analysis of Variance (ANOVA) table for mean Mg among the three (3) land-uses

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.293001	2	0.1465	0.217179	0.807881	3.885294
Within Groups	8.094746	12	0.674562			
Total	8.387747	14				

Appendix K: Analysis of Variance (ANOVA) table for mean Ca among the three (3) land-uses

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.037095	2	0.018547	1.074551	0.372147	3.885294
Within Groups	0.207127	12	0.017261			
Total	0.244222	14				

Appendix L: Analysis of Variance (ANOVA) table for mean pH among the three (3) land-uses

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.08553	2	0.042765	0.590483	0.569382	3.885294
Within Groups	0.869089	12	0.072424			
Total	0.954619	14				