CHARACTERIZATION AND EVALUATION OF SELECTED SOILS OF SOUTHERN NIGERIA FOR RUBBER (*Hevea brasiliensis,* Muell. Arg.) CULTIVATION

BY

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ABSTRACT

Successful land management for tree crop production requires good knowledge of the soil variation and suitability for specific tree crops. Most of the traditional rubber growing areas in Nigeria have not been evaluated for their suitability and production potential. Characterisation and evaluation of the land for rubber production was therefore conducted.

Soils of two rubber producing areas: Iyanomo, Edo State and Akwete, Abia State were characterised and evaluated using local, United States Department of Agriculture (USDA Soil Taxonomy) and FAO systems. Conventional parametric and non-parametric land suitability evaluation systems as well as Geographic Information System (GIS) methods were used to generate suitability ratings for rubber cultivation. Dry rubber yield from existing plantations on the two sites obtained in the 2005/2006 and 2006/2007 cropping seasons were used to validate the suitability ratings. Effects of soil and weather parameters on rubber yield were determined. Influence of the three stages of development of rubber plantations on soil properties were compared with forest and arable land use types. Data were analysed using descriptive statistics, correlation, concordance, path analysis and ANOVA at p = 0.05.

The soils studied were classified as Alagba, Orlu, Kulfo and Ahiara series at Iyanomo and Uyo, Calabar and Etinan Series at Akwete. The soils were in the Ultisol and Inceptisol soil orders of the Soil Taxonomy. The Ultisols covered 73.1 % and 70.9 % of the study area at Iyanomo and Akwete respectively; while Inceptisol covered 26.9 % and 29.1 % at Iyanomo and Akwete respectively. Soil maps produced by GIS and conventional method were not significantly different. Parametric and non-parametric land suitability evaluation rated 73.1 % and 26.9 % of studied area at Iyanomo as moderately suitable (S2) and marginally suitable (S3) respectively but

70.9 % and 29.1 % of Akwete site as S3 and not suitable (NS) respectively. The GIS method however rated 88.0 % of the Iyanomo site as highly suitable (S1) and 12.0 % as S2 and 52.8 % and 47.2 % of Akwete site as S1 and S2 respectively. Correlation between soil classes and actual rubber yield were not significant in 2005/2006 and 2006/2007 cropping seasons but soil classes significantly correlated with yield index in 2006/2007 season for both sites. Observed yield index ranged between 79.9 – 124.0 in 2005/2006 and 71.4 – 195.1 in 2006/2007 and were higher than the expected indices from conventional evaluation systems. Correlation coefficients of rainfall (r = 0.340*), humidity (r = - 0.245**), and path analyses revealed that relative humidity, K, bulk density and porosity were factors that significantly affect rubber yield.

Majority of the soils were Ultisols and Inceptisols and were suitable for rubber production. Suitability evaluation with Geographic Information System is better than conventional methods in predicting yield of rubber.

Keywords: Rubber production, Soil characterisation, Land suitability evaluation, Geographic Information System.

Word count: 463

CERTIFICATION

I certify that this project work was carried out by Julius Romiluyi Orimoloye in the Department of Agronomy, University of Ibadan under my supervision.

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DEDICATION

This work is dedicated to the loving memories of

Late Mrs. Janet Fayemi Orimoloye
My beloved mother

and

Late Mr. David Ayegbusi Orimoloye
My brother

Both of them toiled tirelessly and selflessly, endured many deprivations to give me a brighter outlook in life but died shortly before the completion of this work.

May their gentle souls rest in perfect peace.

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CHAPTER ONE

INTRODUCTION

Land is the most important natural resource of any region or country. The soil constitute the most vital component of the land because most of the complex biophysical and biochemical processes necessary for the sustenance of life and maintenance of the global ecosystem take place in the soil (Cârstea, 2010). Soil is the long-term capital on which nations build their resources (Wilding and Lin, 2006). Any serious attempt to use land judiciously for agriculture, engineering, urban development, pollution control, etc., must start with the knowledge of the nature, type and spatial distribution of soils existing in the regions as produced in land resource surveys (Ogunkunle, 1987; Brady, 2002; Thapinta and Hudak, 2003).

Soil survey delineates soil types on maps resulting in the recognition of soil classes or associations. While soil survey and soil maps provide information on the distribution and properties of soils in an area, they do not show whether soils can be successfully used for a particular management system, land use, etc. Therefore some form of interpretation is required. Land evaluation is the interpretation of soil survey data in order that every hectare of land should be used in accordance with its capability, suitability and limitations (FAO (2007). Land evaluation is primarily the analysis of data about the land (its soils, climate, vegetation, etc.) in terms of realistic alternatives for improving the use of that land. Ogunkunle (1998), observed that farmers are more interested in land evaluation reports that show the capability or suitability of their land areas for agricultural production in terms of probable yields per hectare, than the more technical soil classification and maps.

The suitability of soils for a particular crop or a specific land use is indicated by the kinds and extent of soil limitations that may impede the cultivation of the crop. Land evaluation using a scientific procedure is essential to assess the potential and constraints of a given land parcel for agricultural purposes (Rossiter, 1996). The knowledge of soil limitations arising from land evaluation reports therefore aims at providing practical approaches to ameliorating such limitations before, or during the cropping period (Lin *et al*., 2005).

Great demands are being placed on tropical soils to meet the need for food and fibre of a rapidly growing population. This requires either intensifying cultivation to increase crop yield per unit area or opening up new areas of land for cropping. To minimize damages to the environment, the land needs to be properly classified according to its suitability for the proposed kind of use. This requires a proper organization of land and soil data in such a way that could be interpreted and applied for agricultural development. Manual methods of soil data acquisition and handling for land evaluation are slow, laborious, expensive and are inefficient with large volumes of information (Nair *et al*., 1996, Collins *et al.*, 2001). Ameyan (1995), also observed that manual methods of land evaluation could only cope efficiently with one set of data for a given area at the same time.

A computer based technology that comes so handy is the Geographic Information System (GIS). GIS is a decision support system that deals with information related to spatial distribution of features on the earth surface. It is designed to efficiently capture, store, update, manipulate, analyze and display all forms geographically referenced information. Therefore, GIS is used as an effective tool for land evaluation and land suitability analysis (Collins *et al.*, 2001; Paradzayi and Ruther, 2002; Malczewski, 2004).

The use of GIS has been advocated for a comprehensive database on land and agricultural information in Nigeria (Ogunkunle, 1998; Usman, 2008; Ojanuga, 2008). Fagbami (1985), also suggested the use of GIS for assessing the agricultural potentials of land resources because of its ability to combine many simple physical data and overlay them to produce composite units that are more useful for planning purposes than any of the physical parameters. The ability of GIS to synthesize and manipulate both spatial and attribute data makes it an indispensable tool for land evaluation in this technology driven age (Alabi, 1998; Malczewski, 2004). This also applies to suitability evaluation of land for specific crops.

Rubber (*Hevea brasiliensis*, Wild ex de Juss, Muell. Arg) popularly referred to as *Para rubber* is a quick growing, erect tree crop with a straight trunk and bark which is usually grey and fairly smooth. It is a lowland crop that thrives mainly in the Southern rainfall belt of Nigeria. It is exploited for its latex, which is valued for its isoprene content. Other bye-products of rubber such as wood and seed have various industrial applications and good market values. The wood is used in construction and paper industries while the seed produces Rubber Seed Oil (RSO) and cake used in the manufacture of alkyd resin, putty, ink and animal feed supplements (Aigbekaen and Nwagbo, 1999). Rubber production in Nigeria has great potentials as a dependable source of raw materials for local industries. The crop is a major foreign exchange earner for the country before the advent of crude oil.

The production of rubber has been on the decline since the 1970s. However, with a renewed interest in the development of agricultural sector (especially the tree crops) of the Nigerian economy, some old rubber plantation need to be replanted and new plantations established. There is a dearth of information on the evaluation and classification of soil in the rubber-growing belt of Nigeria with respect to their potentials for sustainable rubber production. The few attempts made so far are either localized suitability assessments based on adopted land quality requirements which were not validated with rubber yields, or interventionist approaches based on dry calculations of perceived soil fertility requirements. This had not helped much in the face of low output of rubber compared with established yield potentials of locally improved and exotic clones of rubber being experienced in many parts of the country. Also, the necessary stake holders' participatory involvement in evaluation and soil fertility management as advocated by FAO (2007) is largely lacking. Most soils of the conventional rubber growing area were reported to be loamy sand in surface texture, characterized by low pH, low nutrient status, low ECEC and low water holding capacity (Ojanuga *et al*., 1981; Essiet, 1991) but with great potentials for tree crop production (Ataga *et al*., 1981). Some plantations have been abandoned as a result of excessive loss of trees or discouraging growth and yield of latex and other bye products. There is the need to have a soil information database upon which subsequent planning and policy for rubber can be based.

The objectives of this study therefore are to:

- identify and classify the soils of the two rubber producing sites;
- determine the suitability or otherwise of the soils for rubber cultivation;
- explore the use of Geographic Information System (GIS) tools for the mapping and evaluation of the soils;
- assess some of the impacts of rubber cultivation on the soils of the study area and
- evaluate the traditional knowledge of rubber farmers on soil fertility evaluation and management.

CHAPTER TWO

LITERATURE REVIEW

2.1 Modern concepts of land and soil

Soil is the invaluable, diverse, and fragile natural resource at earth's terrestrial surface that provides life support. Soil is a biologically active, porous medium referred to as pedosphere and it mediates most of the bio-geophysical and chemical interactions among the land, surface and ground waters and the atmosphere. Soil was defined by Soil Survey Staff (2003), as the 'natural medium for the growth of plants whether or not it has discernible horizons'. It was defined in the 1998 World Reference Base for Soil Resources (FAO, 1998), as a continuous natural body which has three spatial and one temporal dimensions, formed by mineral and organic constituents with solid, liquid and gaseous phases; the constituents are organised in structures, specific for pedological medium and is in constant evolution thus having a time dimension. Its upper limit is air or shallow water. At its margins it grades to deep water or to barren areas of rock or ice. Soil includes the horizons near the surface that differ from the underlying rock material as a result of interactions, through time, of climate, living organisms, parent materials, and relief. The lower limit of soil therefore, is normally the lower limit of biologic activity, which generally coincides with the common rooting depth of native perennial plants (Soil Survey Staff, 1975). It is the foundation of physical structures, serves as construction material, and sustains biomass productivity, the reactor of organic/mineral weathering, the living filter for water supplies, remediator of waste products and functions as the medium that determines the sustainability of the ecosystem. Soil is the long-term capital on which nations build their resources (Wilding and Lin, 2006). Soil is as old as creation. Man was created out of dust (soil) and had depended on the soil for posterity and survival. However, a systematic study of soils as a natural resource on the earth surface including formation and classification is as recent as roughly 100 years ago (King, 2006). There is an enormous diversity of soils and soil properties across the earth surface and several factors account for these differences. The processes of additions, removals, transformations and translocations that give rise to various types and variants of soil are controlled by the classical theory of soil forming factors and have been reproduced in many scientific texts. According to Bridges (1997), two variants of soil along a catena can be distinguished. In one, topography is modelled by denudation and/ or other processes from a formation originally similar in lithological character, soil differences along the catena were then brought about by drainage conditions, differential transport of eroded materials, leaching, translocation, and re-deposition of mobile chemical constituents on the other hand, topography could be carved out of two or more superimposed formations which differ lithologically. Agbede (2009), however believes man can and has substantially altered the physical and biological environment and therefore should be considered as a separate soil forming factor. Recognizing the critical role of the soil and the implications its misuse have on the survival of the planet, the international community in recent times, initiated studies and investigations into the strong impact human activities on the soil have on the ecosystems and environmental interactions in relation to humans through several international programs such as IGBP. United Nations Convention on Climate Change admits that soil is the habitat for a number of species covered by the Biodiversity Convention and that the soil plays a considerable role in the carbon sequestration (IUSS, 2008).

At one time it was a common practice to equate land with soil. FAO (1976), regarded land as a basis for agriculture and other rural land use activities, to include also the climate, vegetation, slope conditions, and other natural resources. Hence, land was defined as an area of the earth's surface, the characteristics of which embrace all reasonably stable, or predictably cyclic, attributes of the biosphere vertically above and below this area, including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations, and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by humans.

This view of land and land resources takes into account the physico-biotic and socioeconomic resources of the physical entity. The UN definition places more explicit emphasis on environmental aspects. The UN defines land as a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, infrastructure, buildings, etc.) (Rossiter, 1996; FAO/UNEP, 1997).

According to Troeh *et al*. (1998), the above definition conforms to land system units, landscape-ecological units as building blocks of a catchment or a biome. This is distinct from the administrative unit of land which is intrinsically linked to an ownership or political unit, and may encompass a number of natural units or parts of them. The components of the natural land unit (e.g. physical, biotic, environmental, infrastructural, and socio-economic) are termed land resources. Included in the land resources are surface and near-surface freshwater resources for reasons of management. Major freshwater bodies, underground geological resources and deeper geo-hydrological resources are excluded and considered a separate resource.

For the past three decades, soil science has experienced major shifts to environmental and ecological focus (Wilding and Lin, 2006) in which case, soil is now considered an important part of a holistic resource. NCR (2001), postulated the concept of the *critical zone* described as the portion of the earth's surface that includes the atmosphere, biosphere, pedosphere and lithosphere interfaces. It is mainly the fragile envelope of soil, rock, air and water that includes its canopy of vegetation, rivers, lakes and shallow seas extending through the pedosphere, unsaturated and saturated ground water zones, otherwise referred to as the epiderm of the earth. This is a more encompassing view than the earlier similar concepts of Wilding (1994) and Sparks (2000). The *critical zone* is very similar but slightly more complex than what economists refer to as *Land* as a factor of production.

2.2 Land evaluation in perspective

The knowledge of kinds, properties and potentials of the soil is critical for the judicious and optimal employment of the land resources in humanity's struggle for survival and well being. Soil is among the most stable attributes of the land yet, flexible in its response to man and offering the prospect of improvement. There is an enormous diversity of soils and soil properties across the earth surface. Such complexities necessitate the grouping of soils into classes. A soil is placed in a class which accommodates a group of soils with properties within a defined range. This classification of soils provides the basis for the prediction of individual properties and behavior from knowledge of the soil characteristics. It is obvious that the organization of our knowledge by means of classification is an important step forward in our understanding of the soil. Dent and Young (1981), believes that the most suitable unit of soil survey is the Soil series which are a group of soils with the same sequence of horizons, developed on similar parent materials under similar external conditions. Soil Series are useful both for general purpose interpretation and as a basis for research on soil plant relationships.

Soil survey and soil map provides information on the distribution and properties of soils in an area, they do not show whether soils can be successfully used for a particular management system, land use, etc. therefore some form of interpretation is required. Land evaluation is the interpretation of soil survey data on the assumption that every hectare of land should be used in accordance with its capability, suitability and limitations. FAO (2007), submits that Land evaluation is a vital link in the chain leading to sustainable management of land resources.

Land evaluation is primarily the analysis of data about the land –its soils, climate, vegetation, etc. – in terms of realistic alternatives for improving the use of that land. It is true that uses which are socially or economically unrealistic, for example large-scale mechanized agriculture in areas already densely settled, are excluded at an early stage, and left out of the analysis. Nevertheless, land evaluation is focused upon the land itself, its properties, functions and potentials (FAO 2007). Brink man and Smith (1973), defined land evaluation as the process of collating and interpreting basic inventories of soil, vegetation, climate and other attributes of land in order to compare promising land use alternative in social and economic terms. FAO (2007), defined land evaluation as the process of assessment of land performance when used for specified purposes while Van Diepen *et al.* (1991), describes it as all methods to explain or predict the use potential of land. From the foregoing, Rossiter (1996), deduced that land evaluation is a tool for strategic land-use planning to predict land performance, both in terms of the expected benefits from it and constraints to productive land use as well as the expected environmental degradation due to these uses.

Land evaluation is aimed at classifying land according to the most suitable sustained use that can be made of it while providing for adequate protection from deterioration (Brady, 2002). This according to Dent and Young (1981), is by a systematical comparison of the requirement of land use with the resources offered by it. Land use itself is the human employment of a land cover type (Malczewski, 2004), which includes both the manner in which the biophysical and biochemical attributes of the land are manipulated, and the intent underlying that manipulation i.e. the purpose for which the land in used (Tunner *at al.*, 1995). Rossiter (1996), observed that land evaluation has largely been 'pedocentric' in that emphasis is laid more on the soil resource mainly because the FAO land evaluation methodology was developed by soil scientists whose experience has been in agricultural land suitability classification. Lin *et al.* (2005), attributes the success of soil based land evaluation over the years to the ability of soil survey interpretations to indicate the relative limitations for various land uses for any given soil type which has been used for broad land use planning and evaluation purposes over the years. However, Bouman and Hoosbeek (1996), pointed out that many specialties are necessary for a useful land evaluation which may necessitate a specialist in land evaluation methods working with a team of specialists in landuse, environmental and land resources analysts to develop a framework that should ease communication between the team members. Oluwatosin and Ogunkunle (1991), submitted that the solution to the farmers' problem of optimal productivity could only be obtained by carrying out land evaluation based on soil properties and environmental variables relevant to the crop or landuse type under consideration. Grossman *et al.* (2001), also suggested the combination of dynamic or use dependent properties (such as soil organic matter and aggregate stability) and inherent or use invariant (such as mineralogy and particle size distribution) to form a composite record for soil interpretation in survey databases and evaluation for landuse and land management options.

2.3 Land Evaluation Systems

Many systems of land evaluation have been developed in many countries and regions as a result of the enormous efforts in soil mapping between 1950 and 1980. Such mapping activities were usually accompanied with some kind of land evaluation to show the usefulness of the soil map and justify the cost and contributions of the mapping programmes. Van Diepen *et al*. (1991), submitted that most of the evaluation systems were derived from the USDA Land Capability Classification (Klingebiel and Montgomery, 1961); Irrigation capability Classification (USBR, 1978) and Storie Index (Edwards, 1970). These were however, supplemented with local expert knowledge and adapted for various land utilization types. Various terminologies for land evaluation have also evolved in the course of time including land classification, landuse capability classification, soil survey interpretation, survey application, soil/irrigation suitability classification, survey application, land assessment, ecological site classification, land judging, interpretative soil classification, site quality evaluation and land resource evaluation (Van Diepen *et al.*,1991). Some of the currently widely accepted systems include the land capacity classification (LCC), land suitability evaluation (LSE), The fertility capability classification (FCC), the productivity indices variously derived from suitability index of the University of California otherwise called Storie Index, the Irrigation Capability Classification (ICC) developed for the purpose of groping lands according to their potential for irrigation and Agro-ecological Zoning (AEZ).

2.4.1 Land Capability Classification (LCC)

The most widely known land classification system is the USDA Land Capability Classification (LCC) (Klingebiel and Montgomery, 1961). It was originally developed for use in the United States of America for the purpose of farm planning but it has been adapted at various degrees all over the world. LCC involves the grouping of soils primarily in terms of their capability to support arable crops. The data used in the classification is usually derived from land resource survey. The underlying principles include:

i. Land physical properties made available by soil survey is the major criteria in assessing land units

ii. The seriousness of a limitation is a function of the severity with which crop growth is inhibited and

iii. Capability of a land unit for crop conservation.

Soil mapping units were classified in eight classes (classes' I-VIII) according to their ability to support general kinds of land use without degradation or significant off-site effects. The first four classes (I-VI) are arable land, in which the limitations on the use and need for conservation measures and careful management increase with class number (Helms, 1992). The remaining four classes (V-VII) are not suitable for cropland, but may have uses for pasture, woodland, grazing, wildlife, recreation and other purposes. Within the broad classes, Land capability subclasses e, w, s and c signify special limitations which are erosion, excess wetness, problems in the rooting zone, and climatic limitations respectively. Within the subclasses, capability units give some indication of degree of limitation and management needs. Although indicative for local soil use and management, LCC only considers relatively permanent, static land characteristics and does not take into account socio-economic factors. This method has been employed in the classification of several plots in Nigeria but Ogunkunle (1987), and Oluwatosin and Ogunkunle (1991), pointed out that separation of subclasses into units is below normal management of farm/plot sizes and as such may not reflect real situations in the farmers' field.

2.3.2. Land Suitability Classification (LSE)

LSE is based on the Framework for land evaluation (FAO, 1976). The interpretation went beyond that of soil surveys to include climate, vegetation and other aspects of land in terms of the requirements of alternative forms of land use. The Framework formulated six principles of land evaluation and set out concepts, methods and procedures for a systematic biophysical and socio-economic assessment of the potentials for specific land uses likely to be relevant to the area. It provided detail on which factors or land qualities should be considered in the evaluation for different kinds of land uses and how to evaluate these qualities. The six principles are:

i. Land suitability is assessed and classified with respect to specified kinds of use**.**

ii. Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land

iii. The evaluation process requires a multi-disciplinary approach

iv. Evaluations should be in terms of the biophysical, economic, social and political context of the area concerned.

v. Suitability refers to use on a sustained basis

vi. Evaluation involves comparison of more than a single kind of use.

In the recent review of the Framework, (FAO, 2007), some socio- economic factors which formed part of the initial framework but were hardly utilized in practice were expanded to include institutions (such as legal structures, customary rules, property rights, etc), land tenure systems, markets, labour, transport, population, political and policy factors etc.

2.3.3. Fertility Capability Classification (FCC)

The FCC is a technical soil classification system that focuses quantitatively on the physical and chemical properties of the soil that are important to fertility management (Sanchez *et al.*, 1982). Information required by the system is obtained from soil profile descriptions and associated field data, laboratory analysis data, and soil classification (Soil Taxonomy). The system does not rank soil, but rather it states the soil properties important to management decisions, which will differ by crop type and management system. The system provides management statements for the classified soil and lists the general adaptability of various crops. Recently, the use of FCC for soil quality assessment in tropical regions has been advocated (Sanchez *et al.*, 2003). While the FCC could be very useful as a complement of soil testing in fertilizer recommendations because it could relate fertility limitations to crop yield responses in a wide variety of soil and crop combinations, Ogunkunle and Babalola (1986), pointed out that the system's capability unit designations are difficult to point out at a glance.

2.3.4 Productivity indices

These are mostly multiplicative indices tied to soil properties and are used as a relative ranking of soils with respect to yield. Soil properties important to favourable rooting depth and available water capacity are the prime choice. The index of suitability of the University of California otherwise called Storie Index (Edwards, 1970), is the precursor of this system. Some productivity indices rely on a few critical soil properties such as pH and bulk density to rate soils (Pierce *et al.*, 1983). Sys *et al.*, (1991), expressed the effects of unfavourable land characteristics on the land production potential using a soil index. The soil index is calculated by multiplying numerical rating values attributed to each characteristic, after matching the collected or measured data with the requirements for the cultivation of a specific crop (Laya *et al.*, 1998). Soil potential ratings are classes that indicate the relative quality of a soil for a particular use compared with other soils of a given area (Beatty *et al.*, 1979). The following are considered in assigning ratings: (1) yield or performance level, (2) the relative cost of applying modern technology to minimize the effects of any soil limitations, and (3) the adverse affects of any continuing limitations on social, economic, or environmental values.

2.331.5 Irrigation Capability Classification (ICC)

Surveys for irrigation development take an engineering approach to plan the location of major and minor irrigation and drainage works. The enormous costs involved justify a comprehensive appraisal of land suitability, which usually includes biophysical and economic aspects, ICC is a special purpose land classification system designed to assess the technical and economic feasibility of a proposed irrigation scheme which serves as a guide to engineering designs and project construction plans. The United States Bureau of Reclamation USBR land classification for irrigation (USBR, 1951), is the most widely used among ICC systems. The system does not use a rigid or fixed methodology. Instead general principles are applied to fit land classification to the economic, social, physical and legal conditions existing in a project area. The classification is quantitative, with an emphasis on economic appraisal. The system uses six classes. Four classes are suitable for surface irrigation, one is potentially suitable and one class is unsuitable. According to FAO (2007), the USBR system heavily influenced the FAO Framework, especially the idea that only economic considerations can truly classify land for development projects.

2.3.6 Agro-Ecological Zoning

Agro-ecological Zoning (AEZ) is a quantitative assessment of plant adaptability to a certain region. It is an expanded and quantified methodology based on Framework concepts. A land resource mapping unit, defined in terms of climate, land form and soils, and/or land cover, and having a specific range of potentials and constraints for land use (FAO, 1996). Continental-scale efforts were intended to obtain a first approximation of the production potential of the world's land resources; national-scale AEZ maps and reports provide the physical data base necessary for planning future agricultural development and zoning for rural development policies. The first country-scale study of its kind was done for Kenya (Kassam *et al*., 1991) while Ojanuga (2006), compiled the Agro ecological zones of Nigeria. A key concept is the length of growing period, which is based on rainfall and evapotranspiration regimes. The growing period forms the basis for a quantitative climatic classification for each chosen crop under rain-fed agriculture.

2.3.7 Choice of Land evaluation methods

The choice of land evaluation method for planning purposes depends on several factors which basically includes purpose, scale and cost. If a general purpose evaluation is desired, the LCC and it's variants may be adopted but when specific land use types are the focus, the LSE is usually employed. Studies in Nigeria however have shown that suitability classes derived from generally accepted land evaluation system could be at variance with real situations in the farmers field (Oluwatosin, 1991). This is because the ratings of land characteristics in these systems sometimes may not agree with its impact on the actual performance of crops. This necessitates the selection and computation of land characteristic that are relevant to the crop being considered in the farm plot, the ecological zone and the region/country at Large (Oluwatosin and Ogunkunle, 1993 and Okusami, 1997),

2.4.0 Geographic Information Systems and Land Evaluation

Geographical information system (GIS) is a set of tools for capturing, storing, retrieving, analyzing and displaying spatial data from real world for a particular set of applications (Burrough, 1986). GIS) is often described as the integration of data, hardware and software designed for management processing, analysis and visualization of geo-referenced data. It is a powerful tool for environmental and land management as they are capable of recording, storing and processing data with geographical, temporal and thematic contents (Paradzayi and Ruther, 2002).

One of the most useful applications of GIS for planning and management is the land use suitability mapping and analysis (Brails and Klosterman, 2001; Collins *et al*., 2001). The GIS based approaches to land use evaluation and analysis have their roots in the application of hand-drawn overlay techniques used by American landscape architects in the late nineteenth century and early 20th century (Steinitz *et al.*, 1976; Collins *et al.*, 2001). This advanced into a procedure that involved mapping data on the natural and human-made attributes of the environment in an area, and then presenting this information on individual shaded transparent maps. The individual transparent maps are super imposed over each other to construct the overall suitability maps for each land use (McHarg, 1996). GIS based land use suitability techniques have increasingly become integral components of urban, regional and environmental planning activities (Collins *et al.*, 2001, Malczewski, 2004). Over the past decade, GIS have evolved from highly specialized niche to a technology that affects nearly every aspect of the human life; from finding road directions to managing natural disasters. A few years ago, the use of GIS was restricted to a group of researchers, planners and government workers, but now, everybody can create customized maps using data overly techniques. On the other hand, many complex problems related to urban and regional planning, environmental protection or business management require sophisticated tools and special expertise. Therefore, the current GIS technology spans a wide range of applications from viewing maps and images from the internet to spatial analysis, tracking, modeling and simulations. GIS can be implemented as a comprehensive and multipurpose system (e.g. ArcGIS, GRASS) or a specialized application tool or as a subsystem of a larger software package supporting the handling of geospatial data needed in its applications (e.g. Geospatial analysis software, modeling system, etc.). The multipurpose systems are usually built from smaller components and modules that can be used independently in applications oriented systems. Geostatistical techniques are useful in providing estimates of sampled attributes at unsampled locations from sparse information (Burrough, 2001). These methods are based on knowledge of the spatial structure of the phenomenon, which is obtained through spatial autocorrelation or auto-covariance functions, such as semi-variograms. Geostatistical techniques have been useful for characterizing the spatial distribution and mapping of soil properties (Booker, 2001; Emadi, *et al.*, 2008; Zuo *et al.*, 2008). Remotely sensed (RS) data coupled with soil survey information can be integrated in the GIS to assess crop suitability for various soil and biophysical conditions. The potential of the integrated approach in using GIS and RS data for quantitative land evaluation has been demonstrated earlier by several researchers (Beek *et al.*, 1997; Martin and Saha, 2009). In most soil studies, the common interpolation method adopted is krigging and trend surface analysis (Emadi *et al.*, 2008, Weindorf and Zhu, 2010) which has been optimized by with the introduction of geostatistics considering the spatial dependency of soil properties (Brus *et al.*, 2007, Blumfield *et al.*, 2007) which allows for correction for choice of semi-variogramme model that best suits the known variability pattern in an area.

Some classical examples include measuring suitability of potential sites for agricultural and forestry (greenway) development (Miller *et al.*, 1998); determining the sensitivity of a site to power transmission line (Towers, 1997); watershed development (Malczewski *et al.*, 2003); conflict management (Ligtenberg *et al.*, 2001) and monitoring groundwater pollution by pesticides (Thapinta and Hudak, 2003). The use of GIS technology and other computer-based databases for land evaluation has been employed in Kenya (Mantel and Engelen, 1999), Ethiopia (Yizengaw and Verheye, 1995) and in several other parts of Africa (Paradzayi and Ruther, 2002). In recent times, open source GIS which does not require proprietary rights play important roles in the adaptation of GIS technology by stimulating new experimental approaches and by providing access to GIS for users who cannot afford or do not want to use proprietary products. Several workers have suggested the adoption of GIS and remote sensing to improve our information capture and dissemination for land use planning purposes in Nigeria (Fagbami, 1985; Ogunkunle, 1997, 2009; Akamigbo, 1999 and Ojanuga, 2008).

2.4.1 Land / Environmental Information Systems

A land information system is a database system containing a wide range of soil and related land information (Heineke *et al.*, 1996). The exploitation of land and natural resources in an over populated world is on the increase. Paradzayi and Ruther (2002), stated that mankind's attempt to find the delicate balance between his feeding and developmental needs on the one hand and the complete preservation of the status quo or even a reversal of environmental damage on the other hand, necessitates the need to develop sound management strategies utilizing appropriate spatially referenced land information as input to achieve sustainable development. Such information as relating to topography, soil, geology, minerals, vegetation, land cover, land use etc. must be spatially referenced through soil survey records and remote sensing. (Paradzayi and Ruther, 2002). Ojanuga (2008), observed that a digitized geo-referenced land information system like soil information system can help to organize spatial data on a national scale from which other databases required for specific development projects or land development on individual farms can easily be derived. Ogunkunle (1998), suggested the adoption of Agricultural Information Systems (AGRIS), which include soil data from a large number of soil profiles, coded in a standardized system. This data handling system is highly efficient to store, retrieve and manipulate data to obtain information on land in terms of soil properties, land quality, expected yield of crops to eventually result in the optimum utilization of every parcel of land. Ogunkunle (1998) and Malczewski (2004), believe that facilities such as computers that can effect data linkage and integration of soil and other biophysical variables are prerequisites for sound land use planning for agricultural and non agricultural land development. Computers based information systems have been applied to soil survey and evaluation at different levels of detail.

Rossiter, (1996), reported that the first implementation of the FAO framework was the LECS system in Indonesia which was incorporated into the FAO's Agricultural Planning Toolkit (APT). A map unit based expert systems approach is the ALES framework (Rossiter, 1990, Rossiter and Wanbeke, 1995). ALES was used to implement several provincial, country and regional land evaluations (Johnson and Cramb, 1991; Mantel, 1994). SOTER is a computerised information system on soil and terrain attributes that has many potential applications in database construction, land evaluation and land use planning (Oldeman and van Englen, 1993). MicroLEIS is another computer programme designed for the Mediterranean climates that addresses land evaluation at reconnaissance, semi-detailed and detailed scales in an inter-related manner (De la Rosa *et al.*, 1992). Magogo (1989), developed SISTAN; a soil information system for Tanzania which includes could store soil survey information in a stratified retrieval format and allows a printout of soil profile descriptions. A GIS designed for programme that could be used for land evaluation is the ILWIS system (Meijerink *et al.*, 1988) and has been widely applied for resource management and environmental hazard assessment in Asia. It is noteworthy here that no information system has been reported for Nigeria except the evaluation of the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model (Jansen *et al.*, 1990) which was tested for Maize in the Northern Guinea Savannah zone by Tabi (2004). The development of remote sensing observation platforms and instruments capable of recording features on the surface, near surface and fluxes of the *critical zone* of the earth has opened up more research opportunities on the soil and its other attributes (Wilding and Lin, 2006).

2.6 Land Evaluation in Nigeria

Soil survey and land evaluation in Nigeria started in the 1950's with the pioneering works of Vine (1951), which was concluded by Smyte and Montgomery (1962). They carried out a survey of the soils overlying the basement complex rocks of central Western Nigeria. They used physical differences, physiographic positions and chemical analysis to differentiate soils into Soil Series and used soil associations to represent soil mapping units. Montgomery and Nwokoye (1961), evaluated the capability of the soils of this same region for cocoa. Soils were grouped into such classes as good, fairly good, poor and not suitable.

Higgins (1959), interpreted available soil survey information for suitability for sugar cane cultivation in the Bacita *Fadama* soils in Northern Nigeria. Ashaye and Jayeola (1973), and Ashaye *et al.*, (1975), carried out some detailed investigation on the soils of Ogere, Owode and Iyansan areas of Ogun State. Land capability ratings and constraints for sugar cane production in these soils were identified and management options were proposed.

Fagbami and Fayemi (1975), evaluated the soils of Lower Ofiki River with the USDA capability classification system while Fagbami and Babalola (1980), with the same USDA system grouped the soils of Ngell near Jos into classes II, III, IV, V and VI. Ogunkunle and Babalola (1986), employed four evaluation systems to group the soils of the lower Benue River in classes for rainfed and irrigated arable crop production.

Oluwatosin (1991), building on an earlier work of Mudroch *et al.* (1976), evaluated some soils of the savannah areas of western Nigeria for rainfed maize production. He discovered that some rating criteria for land evaluation used in major internationally accepted land evaluation systems could be at variance with the reality on the farmer's field and therefore proposed a more realistic rating criteria for rainfed maize. Ogunkunle (1993), evaluated the soils of the Nigerian Institute for Oil Palm Research (NIFOR) for oil palm cultivation and observed that in spite of the near optimal climate in the area, soil textural properties and fertility status confined the soils to marginally suitable classes. Fasina (1997), evaluated some selected soils of Lagos State in relation to the land qualities for some agricultural and non agricultural land utilization types. He observed that many suitable lands for agriculture are being used for non-agricultural uses in spite of their agricultural potentials.

While most of the land evaluation efforts in Nigeria had been based on specific needs or State or regional agricultural programmes, there was a need to have a comprehensive soil map of Nigeria. The Soil Map of Nigeria (FDALR, 1995), which was a compilation and correlation of various soil studies in Nigeria grouped the soils into 58 broad mapping units. Also a recent effort is the Agro-ecological zoning of Nigeria (Ojanuga, 2006), which is basically pedogenic in outlook and identified the agricultural constraints, productivity potentials and management strategies of various agro-ecological zones in Nigeria.

2.6 Traditional Knowledge and Land Evaluation

The knowledge that people in a given community or environment have developed over time and continue to develop is often referred to as 'indigenous' or 'local' or 'traditional' or 'indigenous technical knowledge' (Cools *et al*., 2003). Traditional knowledge was defined by Johnson (1992), as a body of knowledge built up by a group of people through generations of living in close contact with nature. It includes a system of classification, a set of empirical observations about the local environment, and a set of self-management that govern resource-use. A specific aspect of traditional knowledge that deals with classification of soils is known as ethnopedology.

Ethnopedology as a field of study aims to document and understand local approaches to soil perception, classification, appraisal, use and management (WinklerPrins and Sandor, 2003; Barrera-Bassols *et al.*, 2006a & b). Local soil knowledge is important to investigate for several reasons. The first is that it offers a different set of temporal and spatial scales with regard to land use, which has important implications for sustainable agriculture (Sandor and Furbee, 1996). Local or indigenous cultures and people hold significant knowledge of soils and environments, attained by experience and testing through many generations of living close to the land. The environmental knowledge embedded in local cultures provides a long-term perspective on land use and management not otherwise available. The long-term nature of local people's land use strategies, commonly on the order of many centuries to millennia, contrasts with the rapid changes, on the order of a century or less, of land use characteristics of many areas of industrial and globalized agriculture (WinklerPrins and Sandor, 2003).

Farmers by experience, often dating back for generations, have developed informal systems of land quality appraisal based on empirical but accurate observations and experimentations that are sometimes sophisticated (Chambers *et al.*, 1989). Many studies from diverse geographic areas from the Arctic to the Amazon showed that indigenous people have their own systems of managing resources (WinklerPrins and Sandor, 2003). Natural scientists until now generally dismiss the knowledge gained by indigenous people during centuries as anecdotal and unsubstantial. However, their own specialized knowledge is based typically on studies carried out over much shorter periods of time under conditions that are so manipulated that they are sometimes far removed from the farmers field (Johannes, 1993). Although termed 'traditional knowledge', 'traditional' does not imply 'static'. The basic features of traditional knowledge are its firm roots in the past, with a specific origin in indigenous culture and the local environment. Tradition is often unwritten, based not only on what each generation learns from the elders, but also what that generation is able to add to the elders' knowledge (Baines, 1992). Each generation has to verify aspects of the previous generation's knowledge through its own experiences. If traditional knowledge systems did not have the ability to adapt, borrow and innovate, they could not serve a society's survival in ever-changing living conditions. Farmers as observed by Barker and Cross (1992), will adapt to use whatever method serves them best, be it traditional or modern, old or new; there is no nostalgic attachment to archaic practices. The spontaneous diffusion and adoption of rubber and cocoa cultivation by Nigerian farmers in the early 1920s is one example for their innovativeness concerning agricultural technologies (Ugwa and Umar, 2006 and Abolagba *et al.*, 2004). Up to now, very limited attempts have been made to use traditional knowledge in natural resource management. Scientists most concerned with folk knowledge systems were generally anthropologists and ethnographers, while natural scientists usually were less open towards folk ecological knowledge systems. Technical land evaluation uses sophisticated tools and is conducted by professionals while local evaluation results from the integration of 'mental documents' that each individual acquires through experience using relatively simple tools, observations, common sense and wisdom. Barrera-Bassols *et al*. (2006b), observed that ethnopedology is based noncomplex indigenous knowledge about the organization of the soil mantle and on universal soil recognition and classification criteria (Figure 2.1).

There is much need of fruitful dialogue between farmers, pedologists, extensionists and other specialists by applying multi-defined soil functions linking crop performance with soil properties and by using classifications that provide useful and practical information (Barrera-Bassols *et al*., 2006a). FAO (2007) observed that whereas stakeholder participation receives increasingly more attention in planning land resources management, recent developments in spatial analysis and landscape ecology have much to offer in understanding underlying linkages between land resources and local management, and in monitoring whether the management is sustainable. A methodology combining biophysical surveying and spatial modeling with participatory methods needs to be developed in order to incorporate local knowledge and environmental concerns into land evaluation and land resources models.

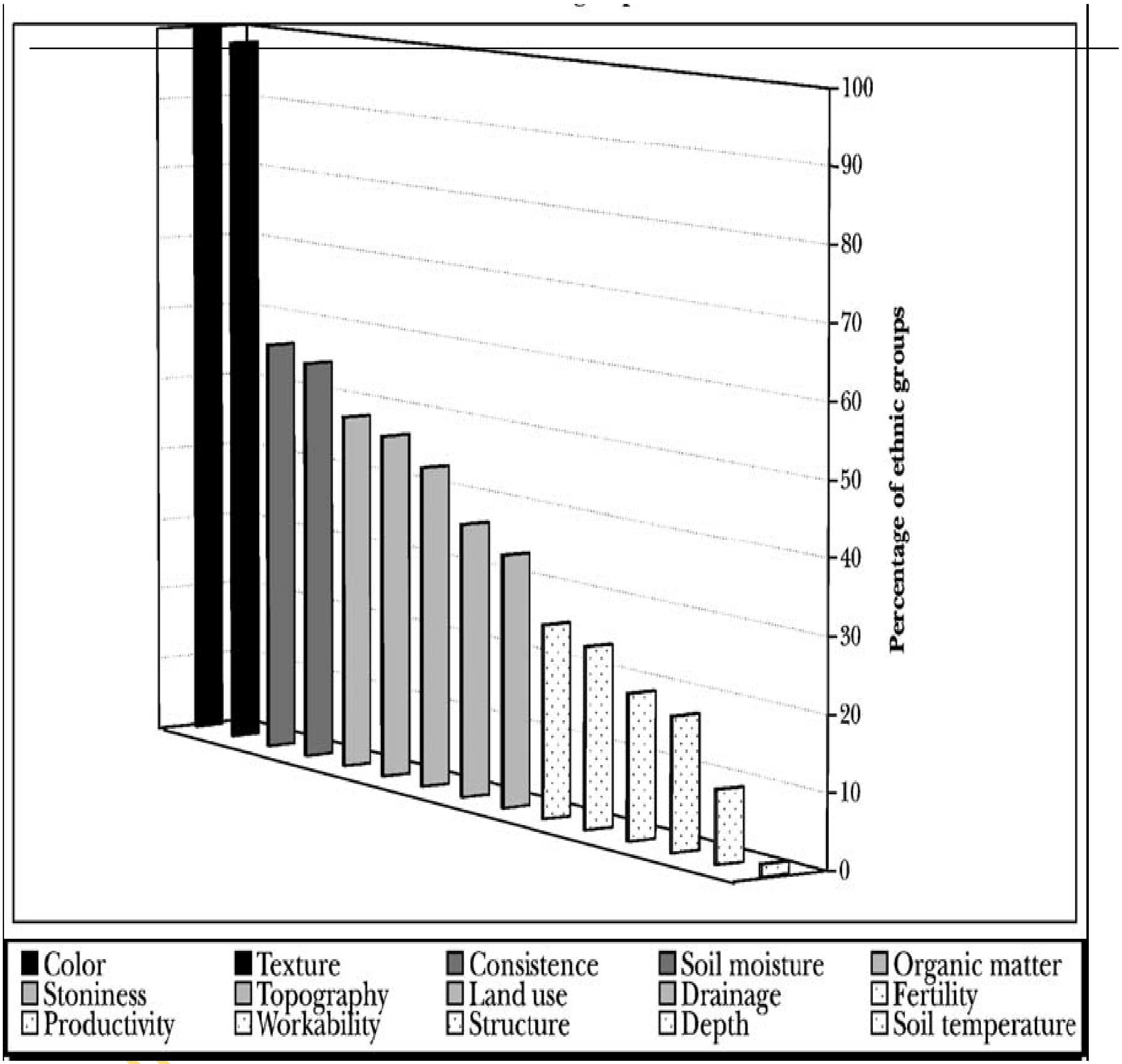


Fig. 2.1: Characteristics and qualities used by local peoples to classify soils. [Source: Barrera-Bassols and Zinck, (2003)].

2.7 Natural rubber

Rubber or Para rubber (*Hevea brasiliensis*) is a tall erect tree with a straight trunk and bark which is usually fairly smooth and grey in colour. The genus *Hevea* is a member of the Euphorbiaceae (spurge) family. One of the distinguishing characteristics of this family (Although not limited to the Euphorbiaceae), is latex production. There are 11 species of *Hevea* but *Hevea brasiliensis* is the only one that has been domesticated for commercial latex production resulting from its superior latex quality and bark regeneration ability. Rubber was first found in the Amazon basin but the successful domestication and commercialization was transferred to Southeast Asia (Smith *et al.*, 1992). The plant, growing up to over 40 meters (m) in the wild, characteristically does not exceed 25 m in height when it is under cultivation. Whereas by nature the rubber tree is a perennial (lasting for over 100 years) plant, it is usually replanted after 25-35 years in plantations, when latex yields tend to decrease to an uneconomic level.

The earliest and principal use of rubber tree products was for food. The seeds of the rubber tree and some of its close relatives can be consumed after prolonged soaking or boiling to remove the cyanic poison (Smith *et al.*, 1992). The usefulness of natural rubber from *Hevea brasiliensis* was first discovered by the native Indian populations of the Upper Amazon, who were manufacturing a variety of rubber products for domestic use and trade in the 18th and 19th century. Cultivation of *Hevea brasiliensis* in Brazil, its native habitat, was severely hindered by South American Leaf Blight (SALB) in the early 20th century, (Webster and Baulkwill, 1989). Accordingly, the production of natural rubber (NR) is concentrated in a few tropical countries.

The identified areas that are particularly well suited for *Hevea* rubber production are: the Amazon basin of Latin America; the Thai-Malay peninsula; Sabah and Sarawak in East Malaysia; Sumatra, Java and Kalimantan in Indonesia; Kerala in India and the South-Western part of Sri Lanka; West-Central Africa including Nigeria, Côte d'Ivoire and, Liberia. There are also some areas suitable for NR production in Southern China and Southern Vietnam. However at present, most of the world's natural rubber is produced in the three Southeast Asian countries Malaysia, Indonesia and Thailand. These three countries account for 73 % of the world production. Its reduced cost was an important factor in the emergence of a mass market of automobiles as two-thirds of natural rubber production worldwide is used for the manufacturing of tires. Apart from tires, footwear, belts and hoses, wire cables and other latex products used in the household and pharmaceutical industries are the most important uses for rubber.

2.7.1 Agro-climatic requirements of Rubber

Hevea is native to the rainforests of the Amazon basin in South America. The area lies between the equator and 15^o Latitude and is characterised by distinctly flat topography with altitudes not exceeding 200m. The area has a wet equatorial climate with over 2000 mm rainfall annually and a mean monthly temperature of 25-28^o C (Priyadarshan, 2003). The fundamental weather elements that primarily influence rubber cultivation are rainfall, temperature, sunshine, relative humidity and wind. However, rainfall and temperature are the predominant factors that determine the selection of areas for rubber cultivation. This is because rubber is traditionally grown under rainfed conditions except at the nursery stage where some essential irrigation may be supplied. The potential evapotranspiration rate of the tropical climate is around 4mm per day (Vijayakumar *et al*., 2000). Therefore a monthly rainfall that is sufficient to meet the water requirement of the plantation should be evenly distributed at about 125-130mm per month. Though, most of the rubber growing areas of the world are free from water deficits, some marginal areas where annual water deficits of 200-300mm have been brought under cultivation as a result of breeding activities that has conferred tolerance to water stress on some clones of rubber (Vijayakumar *et al.*, 1988). Where soil textures are heavy, the high rainfall predisposes the soil to problems associated with water-logging while problems of nutrient loss, runoff, leaching, runoff and erosion are challenges of light textured soils.

Temperature and relative humidity exerts their influence on rubber through the interplay of factors that results in evapo-transpiration and moisture balance moderated by rainfall and sunshine hours. Sunshine also exerts considerable influence on crop growth and productivity through its effect on photosynthesis and crop water requirements. In rubber, prolonged sunshine duration will have a negative effect on photosynthesis and growth. Conditions contributing to good supply of water to plant tissues or limiting loss of water by evapo-transpiration is favourable for prolonged flow of latex. Seasonal variations in the availability of water and sunlight coupled with changes in temperature and humidity as moderated by wind results in changes in the dry rubber content (DRC) of rubber latex. Increase in latex production with appreciable DRC content towards the end of the rainy season has been associated with optimum soil moisture with an increase in sunshine hours which produces the necessary gradient for latex flow. Apart from the effect of wind on air moisture, the speed and direction of wind is very important as high wind speeds tending towards gale can cause considerable damage to plantations by way of branch snap, trunk snap, tree uprooting etc., Clones of rubber however varies in their susceptibility to wind damage due to secondary characters such as canopy density, rooting depth and topography (Mokwunye *et al*,. 2007).

The ideal environmental attributes as postulated by earlier workers include 2000-4000 mm rainfall distributed over 100-150 raining days per annum (Watson 1989), Mean annual temperature of around ±28° C with diurnal variation of about 7° C (Barry and Chorley, 1976), sunshine hours of about 2000 hours per year at an average of 6 hr/day in all the months (Webster and Baulkwill 1989; Rao and Vijayakumar 1992 and, Vijayakumar *et al.*, 2000).

2.7.2 Soil requirements for rubber

Because the rubber plant is adapted to acid upland soils of low fertility, in the Amazon basin, rubber has oftentimes been described as a weed that will grow on any soil and thrive where other tree crops might fail (Watson, 1989). Rubber grows on a vast majority of acid soils of the humid tropics but its performance and economic viability can be restricted by deep acid peats, concretionary or rocky parent material, excessive or impede drainage, alkalinity (pH in excess of 6.5) as in young limestone or calcite derived soils. Watson (1989), also observed that nutrient deficiencies do not present a major limitation to rubber; any shortfall can generally be made up by application of appropriate fertilizers.

In the past, rubber plantations are raised mostly in newly cleared forests usually rich and balanced in plant nutrients. Over time, the increase in population with the resultant increase in the demand for land together with competing needs for other land utilization types such as urban development, mining and related activities made newly cleared forests unavailable. Therefore, rubber cultivation had to be taken up on less fertile croplands and denuded areas (George and Kuruvilla-Jacobs, 2000).

The important physical properties that affect plant growth are texture, structure, depth and drainage. Physical properties are of more paramount consideration in rubber cultivation than chemical properties because they less amenable to manipulations and corrections unlike chemical properties most of which could be corrected by fertilizer applications. Rubber grows on soils of varied textural properties but those with loamy surface texture seem best suited because of the average water hold and percolating capacities they have. Finer textures are desirable in the subsoils to prevent leaching of nutrients and retain moisture at a suitable depth especially during the dry seasons (Ugwa *et al.*, 2006). Granular or crumb structures are the most ideal for rubber growth. However in the tropics, maintaining a granular structure is rather difficult especially on the surface soil due to impacts of rain. Soil structure in rubber plantation can be improved by growing leguminous vegetative cover crops as well as addition of organic materials which increases microbial activities and soil aggregation. Rubber trees require an effective soil depth of a minimum of 100 cm without any intervening hardpan, impenetrable layer or permanent water table. The soil depth is essential as 100 cm of good soil aeration and root penetration helps the plant to anchor properly, tide over seasonal drought and utilize efficiently soil moisture stored at lower depths (Karthikakuttyamma *et al.*, 2000). Yield of rubber has been found to be very much reduced in shallow soils compared to soils with adequate depth. Also, water table and root depths below 60 cm could pre-dispose rubber tress to wind damage by uprooting (Watson, 1989).

The most important chemical properties affecting rubber growth are soil reaction (pH), organic matter content and fertility status. Soil organic matter (SOM) content and fertility status can be improved upon by proper soil management practices which include growing of leguminous cover crops, application of organic and chemical fertilizers and adoption of soil and water conservation measures. The optimal pH for rubber cultivation lies in the range of 4.0-6.5 but the crop can tolerate a pH range of 3.8-8.0 (Watson, 1989). Young seedlings are more sensitive to pH than mature trees and pH levels above 8.0 may cause growth retardation. SOM has a more or less stable form known as humus which is dark coloured, amorphous and colloidal in nature. Humus has physic-chemical properties similar to clay and carries negative electrical charges which attracts and holds cations. It is a cementing material which assists in the binding of soil particles to form crumbs. The colloidal nature of humus is of particular importance in rubber growing areas which are low activity clay soils. Soil nutrient needs of rubber are less than those of other tree crops like coffee, cocoa and oil palm (Karthikakuttyamma *et al.*, 2000). Rubber therefore can grow on soils poor in nutrient but of good physical properties. Majority of the traditional rubber growing soils are deficient in potassium (K) and phosphorus (P). Ugwa *et al.* (2006), Asawalam and Ugwa (1993) as well as Essiet (1991), all reported below optimum K and P status in most rubber growing Areas in Nigeria while Krishnakumar and Potty (1992), observed similar trend in Indian rubber soils. The available P is low due to high P-fixation in the soils as a result of the usually acidic soil reactions while low available K could be attributed to the inherent nature of the parent materials and leaching as rubber growing areas usually have high rainfall (Joseph *et al.*, 1990 and Ugwa *et al.*, 2005). However, at the acidic pH range of most rubber soils, micronutrients, Fe, Mn, Zn and Cu are easily released into the soil system and chances of deficiency is rare.

2.7.3 Impacts of rubber on the environment

The rubber tree is a renewable, sustainable, non-polluting and environmentally friendly source of industrial elastomer. Rubber cultivation has the functional components of an intensively managed agro-ecosystem in terms of energy fluxes, nutrients, matter and biological species (Matson *et al.*, 1997), rubber production systems (agroforests and plantations) have microflora and fauna characteristics that may indicate a forest habitat quality (Beukena and Noordwijk, 2004). The build up of biomass, microflora and understorey vegetations in rubber plantations is comparable to that of teak plantations (Krishnakumar, *et al.,* 1991). The biomass generation in rubber plantation is almost equal to that of humid tropical forests in about 30 years after planting (Jacobs, 2000) and is better than that of many forest ecosystems (Sivanadadyan and Moris, 1992). In the south Asian countries, rubber plantations have become an important source of timber of commercial value (Serkhar, 1992) contributing more than 10% of log production in Malaysia since 1993 (Najib and Ramley, 1996). In the face of an increasing global demand for carbon-emission free fuel production, plants of such high biomass yield as rubber promises to be an attraction in the nearest future.

Apart from the potentials of for fuel wood, biomass production potential of a plant species is directly related to its photosynthetic capacity per unit leaf area and the total leaf area of individual plants. In full sunlight, the photosynthetic rate of a mature rubber leaf is 10 – 15 µmol CO_2 per m^2 per second (Nataraja and Jacob, 1999) as compared to about 5-13 µmol CO_2 per m^2 per second in many other tree species (Sethuraj and Jacob, 1997). Therefore planting fast growing species like rubber is a potential means of ameliorating the ever-increasing concentration of atmospheric CO2 which is rising at an annual rate of 5 % (UNEP, 1992). The rubber plant is also known to aid soil and water conservation (Krishnakumar and Potty, 1992) and indirectly help in flood control (Sethuraj, 1996)

2.7.4 Impacts of rubber cultivation on the soil

One of the most important features of rubber plantations are their perennial nature, which excludes the need for frequent cultivation, the presence of a canopy of leaves, and their production of leaf litter. Leaf litter accumulates as a result of periodic litterfall, providing a form of surface cover over the soil. Reicosky and Forcella (1998), postulated that maintaining environmental quality implies sustainable agricultural systems that preserve and protect soil resources. The impacts of an intensive plantation management on soil quality and subsequent tree re-growth can be positive, neutral or negative. The direction and magnitude of the impact depends on the effects of specific management practices on soil physical, chemical and biological properties (Powers, 2000). In order to understand and predict the impact of an intensive landuse, the factors limiting productivity on each specific site must be understood. Soil organic matter (SOM) is a central contributor to soil processes. It mediates many of the physical, chemical and biological processes controlling the capacity of the soil to perform successfully (Quideau, *et al.*, 2000). It follows therefore that soil management practices that removes large quantities of organic matter from the surface soil, especially on sandy soils, can detrimentally impact on the soil environment. Generally speaking, soils under rubber are found to be rich in organic matter (Krishnakumar and Potty, 1992). In tropical tree-crop ecosystems such as rubber plantations, leaf litter plays an important role in nutrient recycling. Under mature rubber trees, the amount of litter fall is in the range 4620 to 5320 kg/ha/year (Moris, 1993). Leguminous cover crops that are usually established at the immature phase of rubber could add about six (6) tonnes of organic matter and 250 to 350 kg of fixed N per ha (Kothandaraman *et al.*, 1989). In mature rubber plantations, Shorrocks (1965), observed that a range of 2.9 to 7.7 tonnes of dry matter per ha is added to the soil annually through leaf fall which is comparable to 8.3 t obtained under forests (Sivanadayan and Moris, 1992). Karthikakuttyamma *et al.* (2000), attributed the ability of rubber plantations to maintain high organic matter status to the slow pace of oxidation inside the closed canopy of rubber. Also cultural operations under rubber are nearly zero tillage which favours stabilisation of organic matter (Krishnakumar and Potty, 1992). The minimum tillage inherent in most traditional rubber plantations encourages higher concentration of residues on the surface layer and less alteration of soil structure which could increase microbial metabolic activities (Piovaneli *et al.*, 1998). Karthikakuttyamma *et al.* (2000), reported that soils under the third cycle of replanting do not show much difference in structure, texture and morphological features from those in adjacent virgin forests except a marginal reduction organic matter. Asawalam *et al.* (1992), reported a decrease in soil PH, and exchangeable cations especially Ca, K and Mg with rubber cultivation. Also there are reported increases in total Fe, Al and sexquioxides (Watson, 1989).

Most agro-ecosystems result in net exportation of nutrients. The removal of nutrients through crop nutrition is less in rubber than most other crops but latex exploitation (quantity and composition) can affect and be affected by the soil nutrient status (Watson, 1989). Nutrient removal from under rubber plantations through latex tapping is estimated to be 755, 883, 1260 and 945 kg ha^{-1} of N, K, Ca and Mg respectively (Karthikakuttyamma, 1997). In comparison with the nutrient cycling ability, biomass and organic matter generation, rubber cultivation results in a net accumulation of soil nutrients.

2.9 The Rubber Belt of Nigeria

The Rubber belt of Nigeria lies in the southern rainforest Agro-ecological zone the country. The area consists of about 7.6 million hectares of land extending from Ogun to Cross River States (RRIN, 1998 and Aigbekaen and Nwagbo, 1999). The area overlies soils of sedimentary origin mainly of the Coastal plain sands and the southern fringes of the basement complex rocks (FDALR, 1995; Ojanuga, 2006). The physiography of the area ranges from flat to slightly undulating plains with predominantly coarse textured (sandy) topsoil. Vine (1970), described the soils as stoneless sandy latosols with more or less sandy topsoil merging into deep permeable saprolites derived from tertiary sediments and some places cretaceous sediments. A term ‘acid sands’ has been used to describe soils of the lowland regions of Nigeria where mean annual rainfall is 2000 mm and above. Ojanuga *et al.* (1981), further defined the soils as acidic soils occurring over sedimentary rocks in the humid region of Nigeria where a very high rainfall (1500 mm per annum) promotes a marked leaching state in the soils. They occupy a narrow strip in the southern part of Nigeria which is bounded in the North by the basement complex regions and in the south by the coastal fresh water and mangrove swamps. Geologically, the area is underlain by a variety of Cretaceous and Tertiary sediments (sandstones and Shales) with sandstones being the dominant rocks. The major areas are the cretaceous Abeokuta and Ilaro formations (mainly sandstones), akimbo and Oshosun formations (Shale) and the more recent Coastal Plain Sands

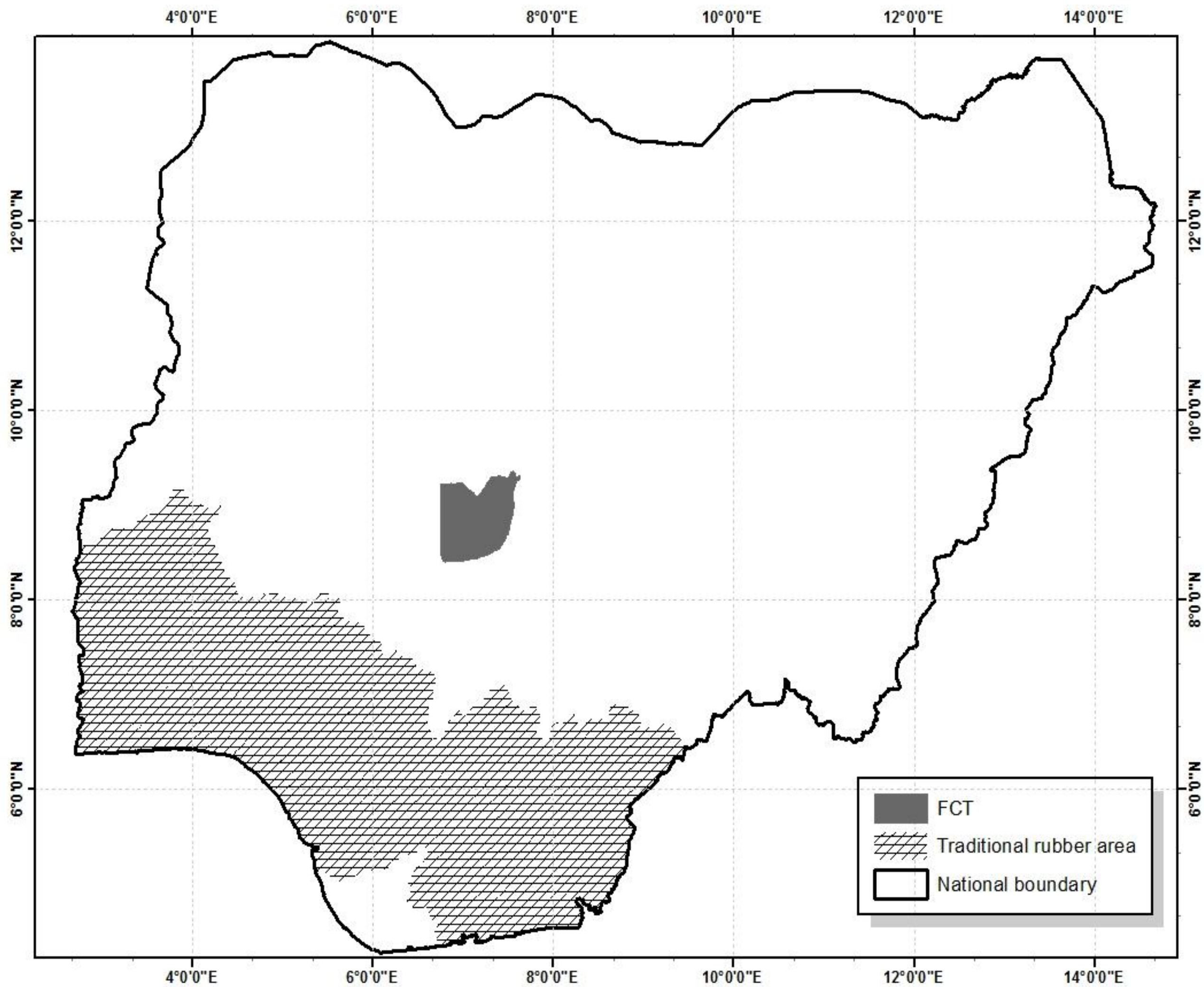


Fig. 2.2: Map of Nigeria showing rubber growing areas

consisting of unconsolidated sands and sandy clays now known as the Benin formation (Kogbe, 1975).

The traditional rubber growing areas of Nigeria are located in the Zones K, P, Q and R of the Agro-ecological Zones of Nigeria as classified by Ojanuga (2006). The Zone K is the Very humid Oban Plain, zone P described as the very humid Onitsha-Enugu Abakaliki Calabar lowland and scarpland , Zone Q was described as the very humid Lagos-Benin-Asaba lowlands while zone R comprises of the very humid and perhumid Niger Delta regions. Zone K comprised of the gently undulating to rolling terrains extending from the Bamenda highlands in Cameroon into the Cross- River State of Nigeria North of Calabar. The area is well supplied with rainfall (2600-3000 mm per annum) due to orographic effects of the Cameroon Mountains. The soils are derived from weathered Precambrian acidic igneous and metamorphic rock materials. However, A large percentage (about 80%) of the land area in this zone is proposed to be developed as the Cross River Natural Park and Support Zone (Holland *et al.*, 1989). The Zone P occupying the Cross River lowlands consist of flat to rolling plains developed on Cretaceous and Tertiary sediments (coastal plain sands). A plateau (Udi-Nssuka-Ankpa plateau) rising 20-50 m above the lowland constitutes the hydrological center for the streams and rivers which are either flowing west into the Niger River or east into the Cross River. The Zone is characterized by very hot humid tropical climate. It has a bimodal annual rainfall pattern with mean annual rainfall in some major towns (FDALR ,1985) given as Umuahia (2200 mm), Enugu (1800 mm) and Calabar (3000 mm). The soils vary according to the specific geological foundations in the area and they include alluvium of the Niger River, Bende-Ameki Sandstones with lignite formation in the South, Imo clay shale, upper and lower coal measures, false bedded sandstones, Enugu shale, Agwu-Udealor Shale, Eze Ako Shale and the Asu river group. The topography of the soils is described as suitable for permanent crops especially oil palm and rubber. Zone R comprises of the Sombreiro –Deltaic plains which is the remnant of the older Niger Delta of late Pleistocene to early Holocene age and the new Niger Delta. To the north of the Delta is the Coastal plain sands of the Oligocene-Pleistocene age, part of which are found in the Ogoni Sand Plains in the eastern part of the Delta.

Zone Q is relatively flat to very gently undulating plains developed on sedimentary rocks and littoral deposits towards the western part of Nigeria with altitudes rising from the Atlantic ocean to less 200 m above sea level except in Isan and Asaba areas where the Terrain rise steeply above 200m from the Niger Valley. The Zone consists of two major sub-divisions namely: (a) the coastal strip made up of a maze of numerous creeks, rivers, deltas, lagoons and parcels of littoral deposits (deep sands and muds) varying in width from about 20 km around Lagos to about 50 km South of Benin. This sub division is occupied freshwater and saline (mangrove) swamps. The main physical feature is poor drainage. (b) The sedimentary upland underlain by Tertiary and Cretaceous sands, clays, sandstone and shales which has the greatest width of about 200 km in the Asaba-Auchi axis close to the Niger River. This subdivision is well drained. Generally the zone is also characterized by a hot humid tropical climate with heavy rainfalls occurring from February to November in most years. Temperatures are high all year round with a mean annual temperature in the order of 26 ^{o}C Relative humidity is very high being more than 70 % per annum. The soils have developed from a variety of parent materials such as sedimentary rocks and recent fluvial and marine deposits. Some constraints to agricultural production in these soils identified by Ojanuga (2006) include among others high rainfall and the attendant strong leaching and erosion of the soils; low organic matter and essential plant nutrients; and low capacity of the soils to retain nutrients.

The marginal rubber growing areas (Fig. 2.2) falls within the Southern Guinea Savanah, the Northern Fringes of the Rainforest Belt and salt water mangrove swamp in the Niger Delta region. The following agro-ecological zones of Ojanuga (2006), are included:

(a) Zone J (Very humid Beli-Takum-Obudu Gembu High Plain) covering the central and souther parts of Taraba State, South east Benue State and the northern fringes of Cross-River State.

(b) Zone M (Humid Kishi-Ilorin-Kabba Plain) consisting mainly of the central part of the Southwestern Basement Complex Plain. Most of Kwara State, West part of Kogi State and the Northern Parts of Oyo State are in this Zone. Characterized by prominent rounded gneissic and granite inselbergs and flat topped quartzite ridges, The soils ranged from well developed Alfisols to Cambisols.

(c) Zone O (Humid Ankpa-Ortukpo-Shanger Tiv Lowland and Scarplands).

2.9.1 Rubber and soil classification

Major soils of the traditional rubber growing areas are Ultisols and Alfisols derived from geological formations such as crystalline rocks of Achaean age, sedimentary rocks of Tertiary age and recent / sub-recent alluvial sediments (Watson, 1989; Eshett, 1991; FDALR, 1995; Bhattacharya *et al.*, 1996). Majority of the earlier development of smallholding rubber in Asia and Africa are sited on areas chosen principally on the grounds of availability of land and convenience. However the commercial planters are guided by the condition of existing vegetation and freely draining soils on gently rolling terrain for easy access and avoidance of soil erosion. With time soil surveys in West Africa and Asia identified local associations and classified soils according to local nomenclatures or adopted national classification systems. Four main systems were particularly relevant to rubbers which are reviewed by Sanchez, (1976); Young, (1976) and Landon, (1984). The four systems are (a) da Costa, (1976) system developed in Brazil for the red-yellow podzolic soils and Latosols; (b) The soil map of Africa developed by the Commission for Technical Co-operation in Africa (CCTA) (D'Hoore, 1964); (c) the FAO-UNESCO soil map of the World (FAO, 1974) and (d) the 'Seventh Approximation' of Soil Taxonomy developed in the United States (Soil Survey Staff, 1975). However, most of these systems were correlated in the Revised Legend of the FAO/UNESCO Soil Map of the World (FAO, 1990a), which has been used as a basis for the development of the World Reference Base for soil Resources (WRB) (FAO 1998, FAO/ IUSS, 2006) with Keys that are mainly based on functionality and major soil units that that are easily identified by specifying briefly a limited number of diagnostic horizons, properties or materials.

Watson (1989), observed that while the hierarchical classification systems especially of the USDA Soil Taxonomy may facilitate pedological comparisons between different climatic zones and cropping areas, the details involved makes it unsuitable for comparison of fertility and production potentials of the rubber growing soils given the peculiarity of the rubber crop and the nature of the restricted zone of the tropics that supports rubber. Being a perennial tree crop, the effects of agronomic management practices on one hand and the adaptation of the tree to local soil and climatic features on the other, combine over the years to eliminate the finer effects of differences in local soil types with respect to their suitability for rubber cultivation. Rubber performance therefore may be similar on taxonomically different soils. Also it may be difficult to modify field management according to taxonomic phases within one planting unit. A further classification system grouping soils generally on the basis of crop performance rather than taxonomic considerations is required for rubber. Sys (1985), had put forward a capability classification based on the FAO Framework that defines orders, classes, sub-classes and units of land suitability according to the number and severity of limiting factors that are present. The orders are I and II for suitable and potentially suitable with severe (or very severe) limitations that can be corrected respectively while orders III are those with limitations that cannot be corrected and are therefore unsuitable for rubber cultivation. In Malaysia, classification of rubber performance has been made based on geomorphic and soil properties such as soil texture and slope; soil properties influenced by ground cover; soil nutrient status, and other characteristics that influence rubber (Chan and Pushparajah, 1972). Highest yields though subject to clonal variations, have been identified with free draining Oxisols, Ultisols and Alfisols with performance reducing with soils that are subject to drought, impeded drainage and lateritic conditions.

In Malaysia, extensive work has been done in evaluating and classifying soils of the rubber growing areas according to their productivity potentials (Chan and Pushparajah, 1972; Watson, 1989) while in Sumatra (Indonesia), environmental and traditional knowledge has been attempted to evaluate soils of the rubber growing areas and the factors that can sustain continuous rubber cultivation (Werner, 2000). In Nigeria however, evaluation for rubber has only been carried out in sporadic clientele-needs and interventionist approaches. A few efforts on suitability assessments of land were done as part of a larger study (e.g Fasina, 1997) while a few were done in the Northern parts of Edo State (Asawalam and Ugwa, 1991; Orimoloye *et al.*, 2006). Ugwa *et al.* (2006) attempted a larger area in the Southern parts of Nigeria but it involved only sampling in some large rubber estates. All the above mentioned cases were deficient in that firstly, they are based on adopted land quality requirements from literature and were not validated by yield records and secondly, pedological or soil management units (such as Soil Series) that could allow for extrapolation of suitability classes (as was done in Malaysia) were not considered. Also, the necessary participation of rubber farmers who are largely small holders (Abolagba *et al.*, 2004) and are not too 'schooled' to understand soil taxonomic units (such as Ultisols or Tropaquents) was lacking. Fortunately, there is a renewed interest in commodities and a government intervention through the Presidential Initiative on rubber programme. There is therefore a need to have an information database on soils for rubber cultivation, based on transferable soil management units as Soil series that can easily be understood by both Scientists and farmers so that the national target for rubber production to meet local consumption and be relevant in the international market by the year 2020 as envisioned by the Federal Government is to be attained.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study Areas:

This study was carried out in two locations within the conventional rubber growing belt of Nigeria namely:

1. Rubber Research Institute of Nigeria (RRIN) main station at Iyanomo (near Benin City), Ikpoba-Okha Local government Area of Edo State.
2. RRIN substation at Akwete, Ukwa West Local government Area of Abia State.

The two sites are indicated in Fig. 3.1

3.1.1 Size and locations

The Iyanomo study area (Plate 3.1) occupies a land area of 2070 hectares that has no record of a comprehensive soil inventory. It is situated about 29 kilometers away from Benin City. The main access road is through Obaretin Village situated at km 19, Benin- Sapele highway. The study area has a fairly rectangular shape. The Area is located within the co-ordinates of 5° 34'E and 5° 38'E Longitudes; 6° 08'N and 6° 11'N Latitudes bordered by Ogbekpen village (southwest); Benin Owena River Basin Development Authority [BORDA] (south east); Uhie village (Northeast) and Obayantor village (northwest).

The Akwete study area (Plate 3.2) covers an approximate area of 420 ha and is situated at the south west outskirts of Akwete town, about 12 kilometers away from Obehie junction along the Port Harcourt-Aba- Enugu Expressway. The Obehie – Akwete –Azumini trunk A road almost

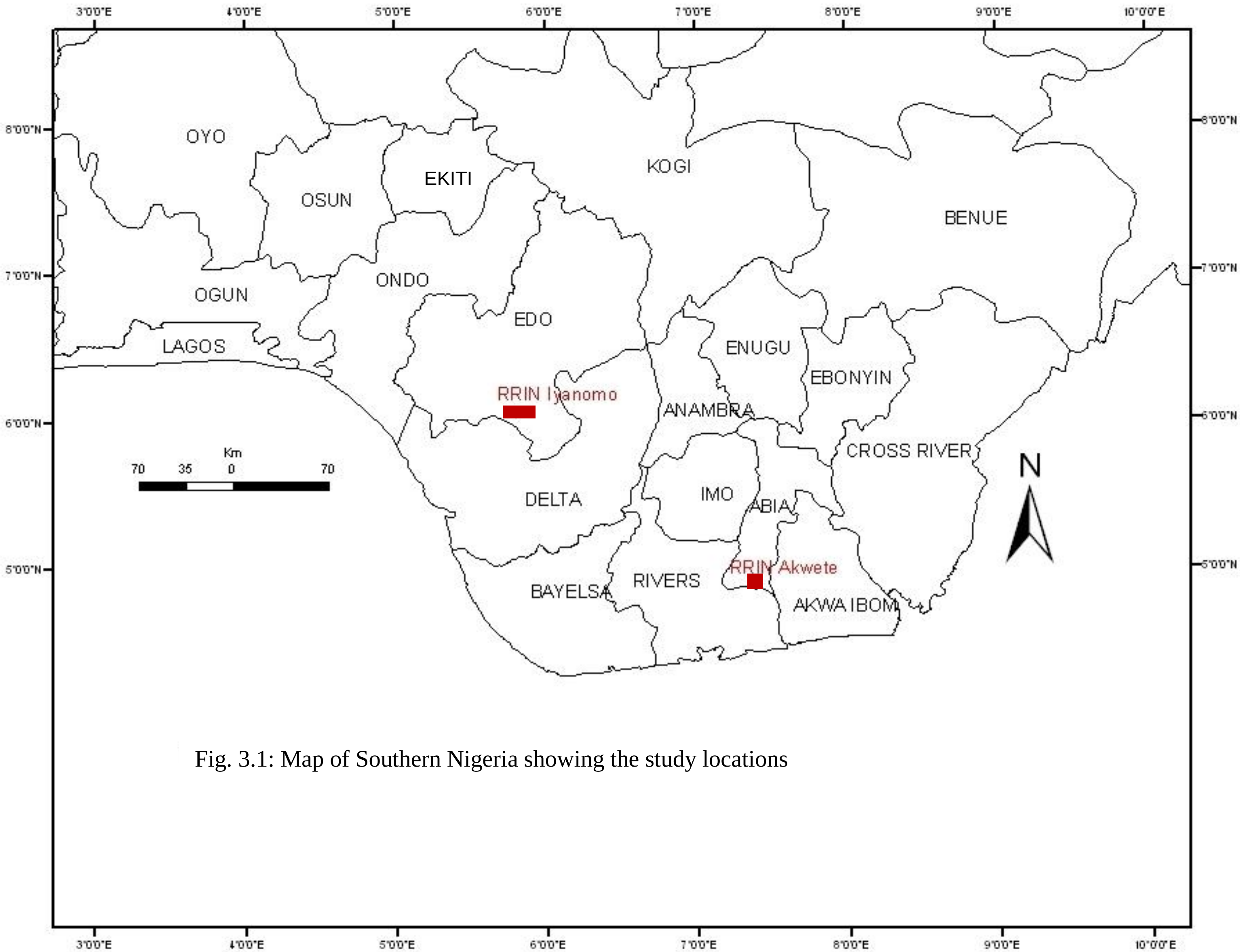


Fig. 3.1: Map of Southern Nigeria showing the study locations

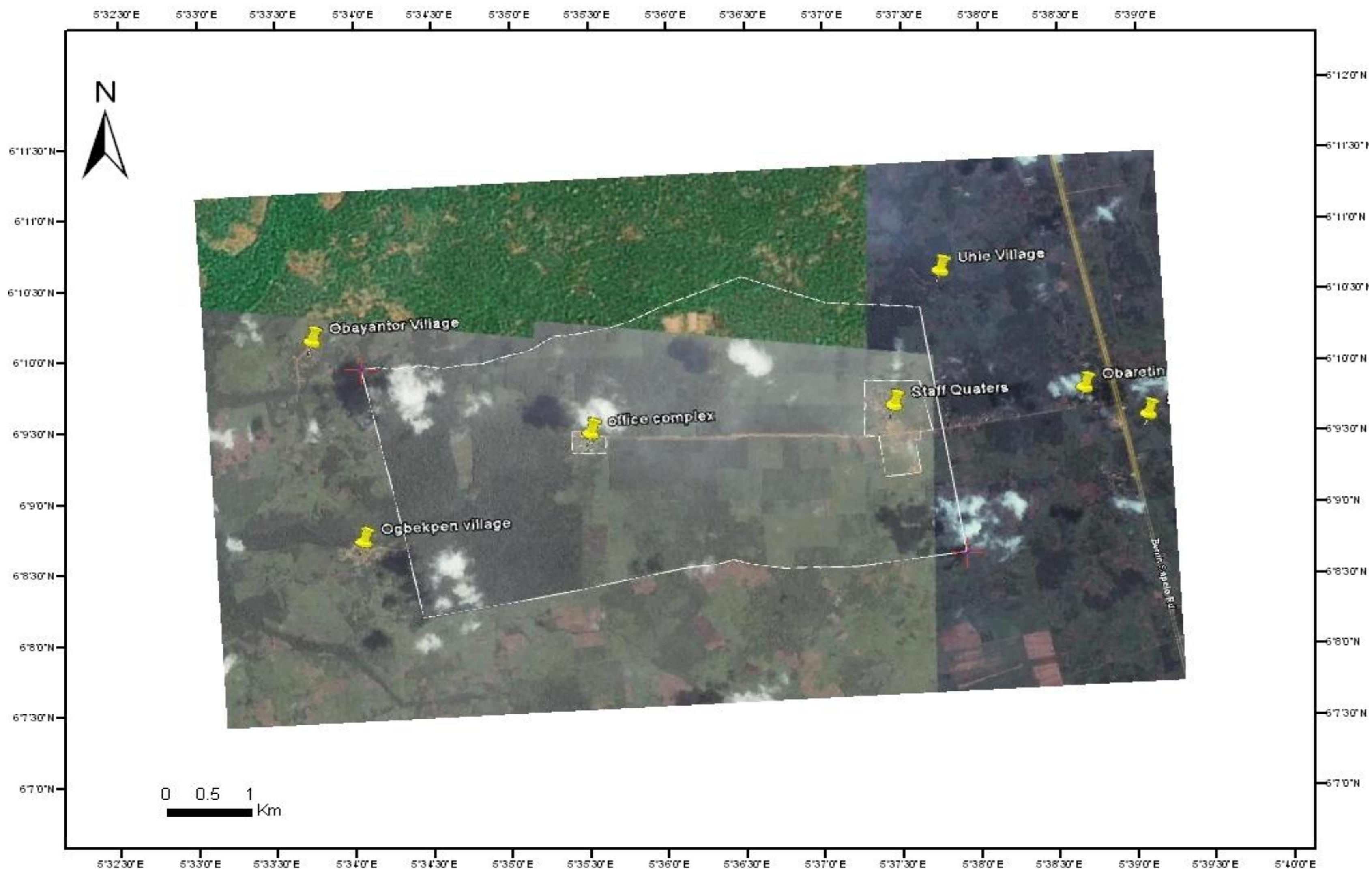


Plate 3.1: An aerial view of the Iyanomo study area at eye altitude of 8.125 km (Courtesy: Google Earth TM)

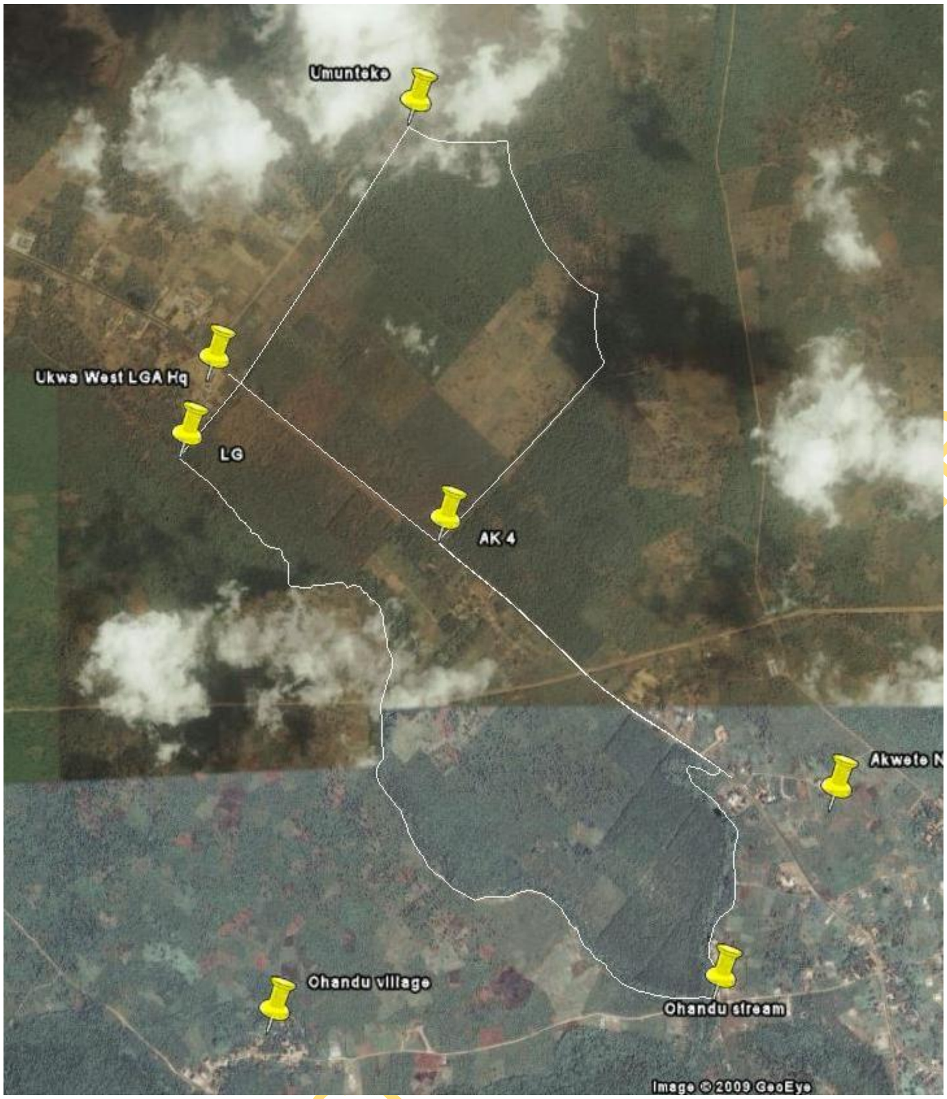


Plate 3.2: Aerial view of Akwete site at an eye altitude of 6.67 km (Courtesy: Google Earth TM)

bisects the study area. The area is irregularly shaped and is bounded on the west by the Ukwa West Local Government Headquarters, Okeipe, on the North by Umuteke, on the South and South West by Ohandu and on the East by Akwete New Residential Area. The area is located within the coordinates 7° 19'E to 7° 21' E and 4°53' N to 4°55' N.

3.1.2 Climate

The study areas are characterized by hot humid tropical climate with a dominant rainy season and two or three months dry season. Relative humidity (> 70 % average) is high almost throughout the year while sunshine hour vary widely between three (3) to nine (9) hours/day during the rainy and the dry seasons respectively. Rainfall is fairly distributed with 85 -95 % falling within the nine months from March to October. Mean annual rainfall is about 1952 mm in Benin city and 2164mm at Akwete and has a bimodal distribution at both locations, having two peak raining periods with a higher peak in July and the lesser peak in September and a short dry spell usually in August. May to October usually have an average of more than 16 raining days per month. However, the heavy torrential rains are less destructive than the fewer but stormy rains accompanied by violent thunderstorms during the months of December, January and February. Soil leaching is also strong in the months of April to October when rainfall exceeds evapotranspiration and soil moisture storage capacity which is estimated at 100 mm per one meter of soil (Ojanuga, 2006) and is lower than the rainfall amount during these months.

Temperature is usually high throughout the year. The mean annual temperature of about 26^{o}C and evapotranspiration of 1150 mm have been observed in Benin. The rainfall and temperature charts for Benin and Iyanomo are shown in Figs. 3.2, 3.3, 3.4 and 3.5.

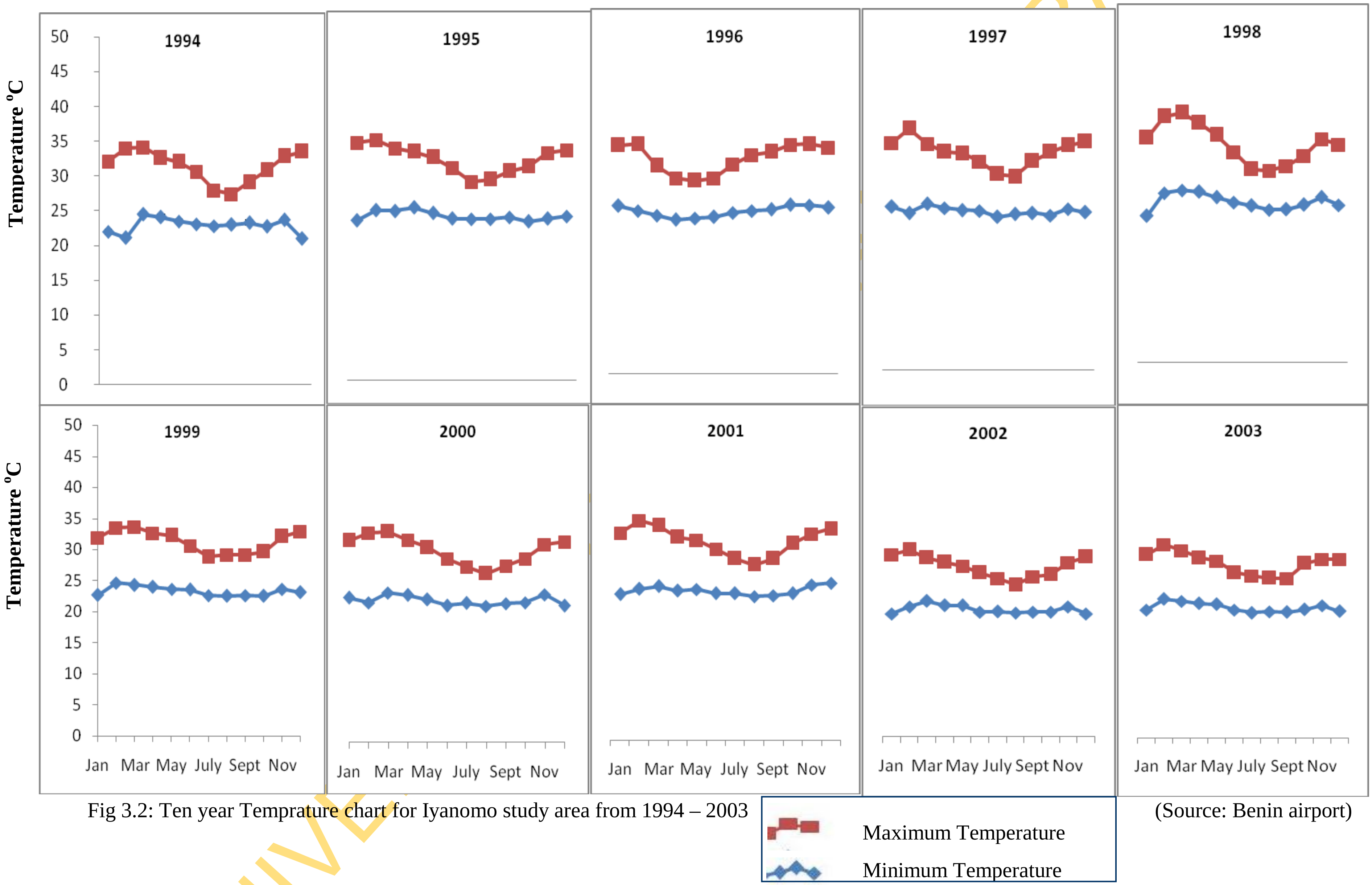


Fig 3.2: Ten year Temprature chart for Iyanomo study area from 1994 – 2003 (Source: Benin airport)

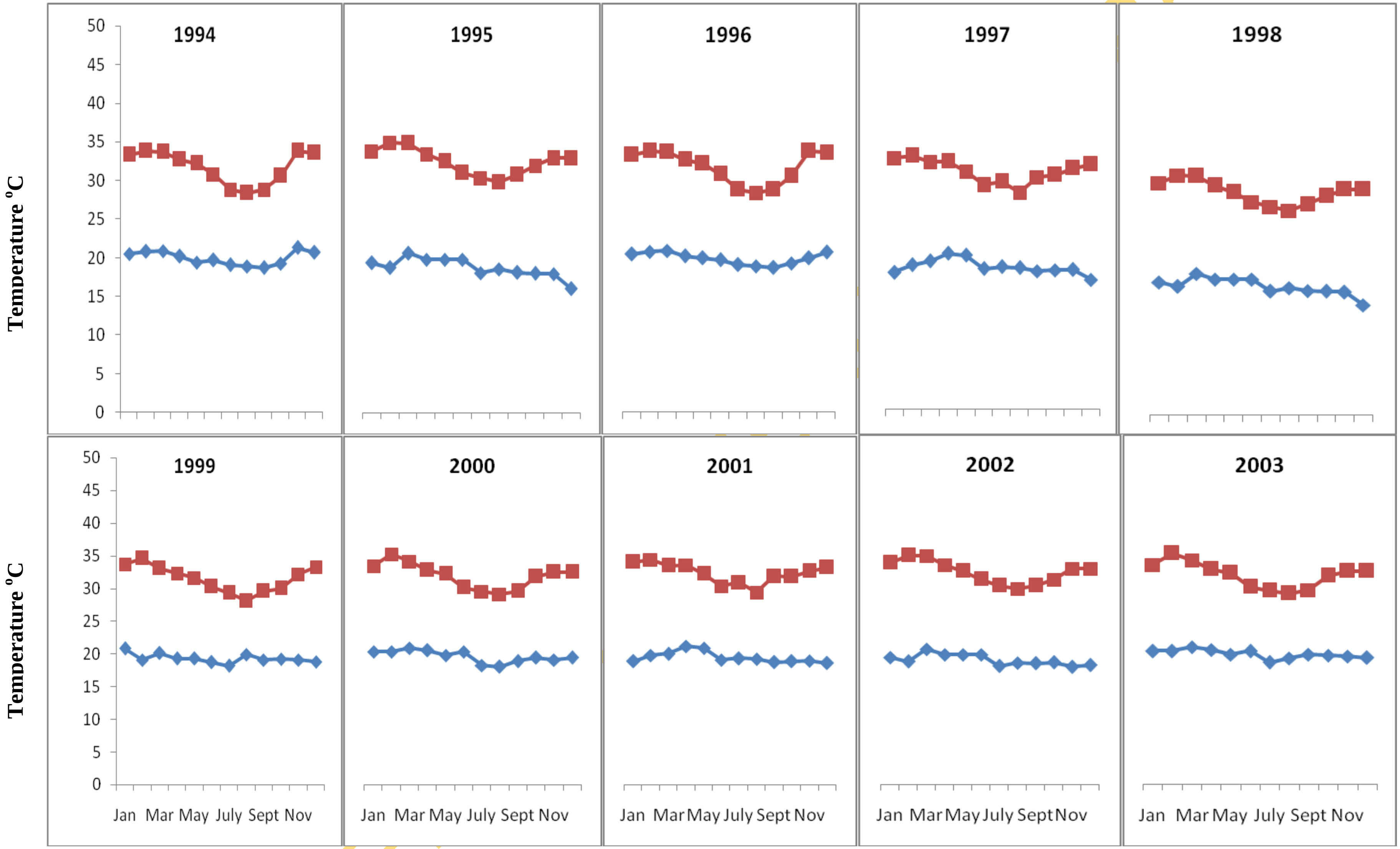
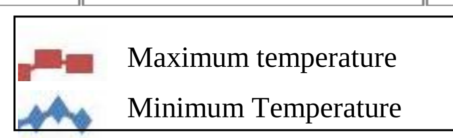


Figure 3.3: Ten year temprature chart for Akwete study area from 1994 – 2003



(Source: RRIN, Akwete)

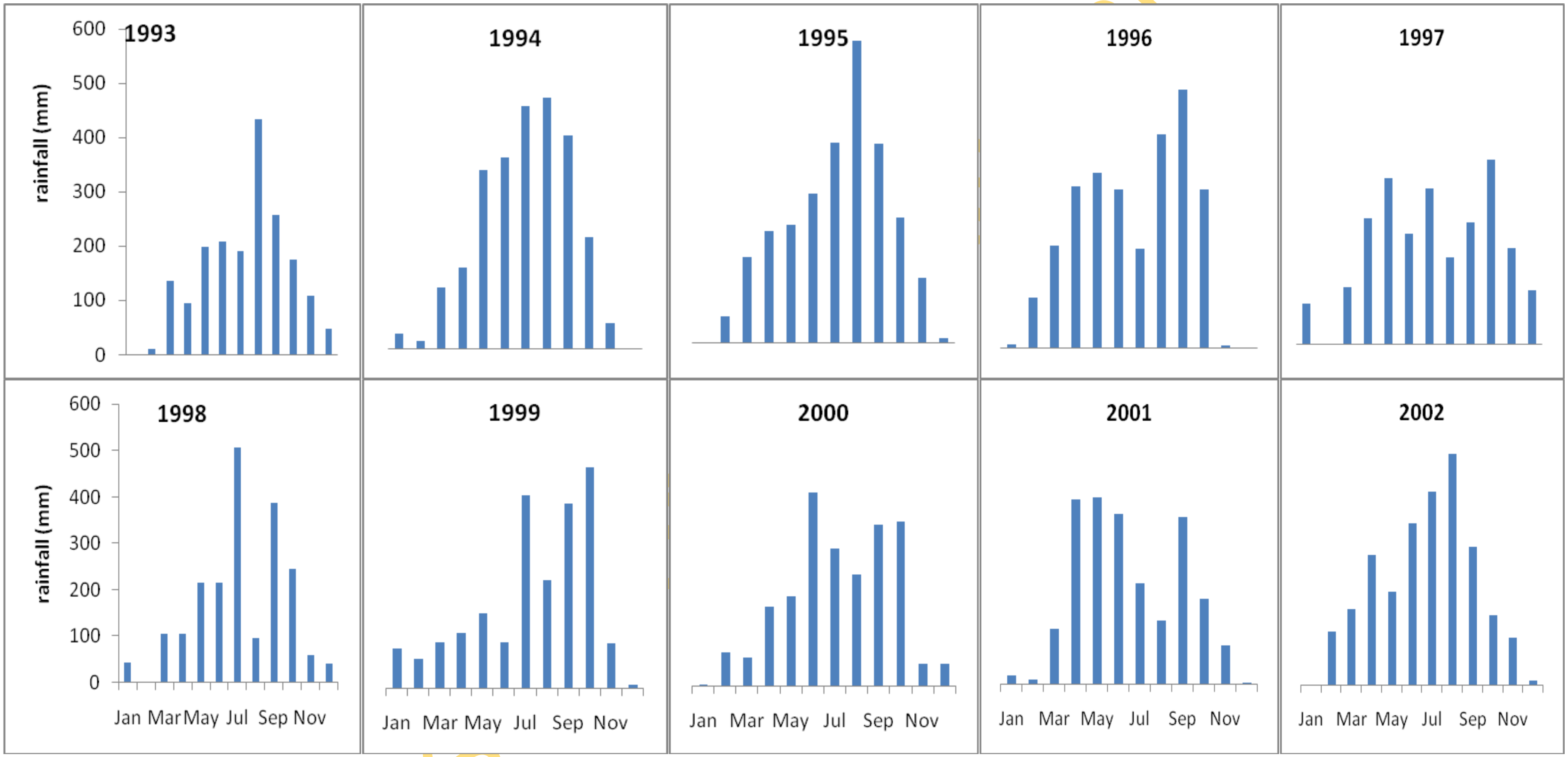


Fig 3.4: Ten year rainfall charts for Iyanomo 1993-2002 (Source: Benin airport)

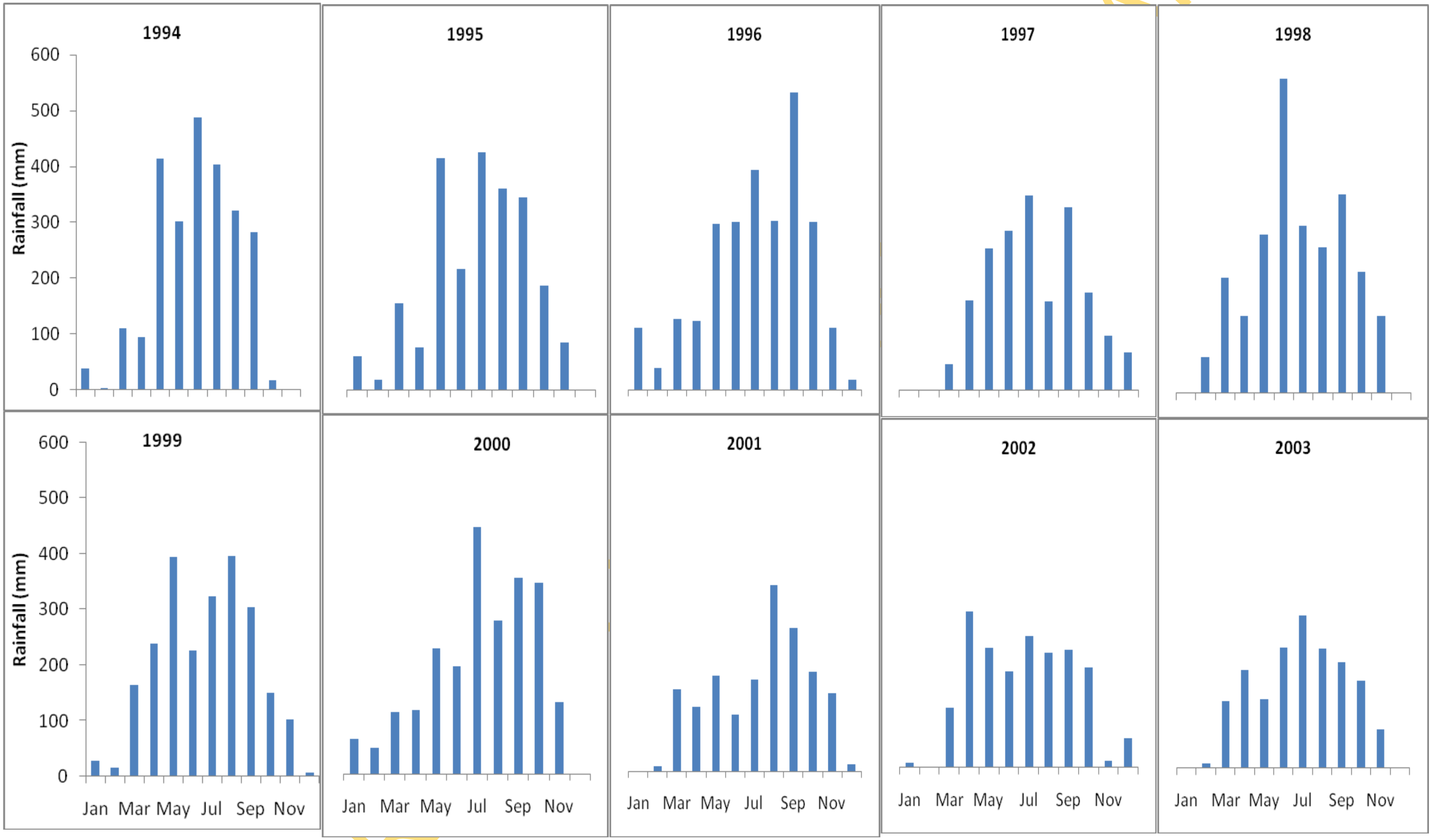


Fig 3.5: Ten year rainfall charts for Akwete 1994-2003 (Source: RRIN, Akwete)

3.1.3 Vegetation

Iyanomo

In their natural state, vegetation in the Iyanomo study site is a multistoried high tropical rainforest characterized by a multiplicity of tree species. The climax vegetation has been tremendously altered by the impact of uncontrolled forest exploitation and cultivation. Several topical tree species such as *Chrotalaria exelsa, Cieba petandra* etc. are still present at RRIN Mainstation Iyanomo, which preserves a reference vegetation close to the office complex. There are dense undergrowth of thorns, twines and broadleaves. Along the stream channels, cane grass (*Arundinaria gigantea,*), *Raphia hookeri*, bamboo trees (*Dracaena sanderiana*) and some ferns (*Dennstaedtia species*) are dominant while areas under cultivation and bush fallow are dominated by *Chromolaena odorata*, *Aspilia africana, Centrocema pubescence* and *Pueraria* species in addition to sporadic distribution of ferns.

Akwete

The Akwete area is also in the high rainforest agro-ecological zone. Though the natural vegetation has been altered by agriculture and urban development, such species as *Elaeis guiniensis, Khaya ivoriensis, Ashual baterii* and corkwood (*Musanga cecropioides*) trees are still predominant in the fallow plots at Akwete, *Ageratum conyzoides, Acanthospanum hispidium* and some *Euphobia species* constitute the major weeds in the rubber plantations in addition to volunteer seedlings of rubber. The dominant grasses in recent times are *Panicumm maximum* and *Pennisetum purpurum* which are colonizing lawns, roadsides and open spaces.

3.1.4 Geology

Iyanomo

The Iyanomo study site is underlain by parent materials of the Southern Nigeria sedimentary basin and falls within the area described as the ‘acid sands’ of southern Nigeria (Udo and Sobulo, 1981). The area is specifically on what was described as the ‘Benin Fasc’ of the sedimentary (sandstone) deposits of the Pleistocene age (Vine, 1959; Ojanuga *et al.*, 1981; Ojanuga, 2006).

The southern Nigeria sedimentary basin is partially divided into the eastern and western portions by a submarine basement ridge known as the ‘Okitipupa Ridge’ (Kogbe 1975). Whereas, the Eastern part experience transgression during the Albian, sedimentation did not begin in the western part until the terminal stages of the Cretaceous. A correlation between the western and the eastern portions of the basin has been by Jones and Hokey (1964) and is presented in Table 3.1

They were defined as the acidic soils occurring over sedimentary rocks in the humid region of southern Nigeria where high rainfall (>1500 mm per annum) promotes a marked leaching state of the soils.

Akwete

The Akwete Study area is part of the Coastal Plain Sands of the Niger Delta Basin. The name ‘Coastal Plain sands’ was introduced to indicate the extensive red earths and loose ill-sorted sands underlying the recent deposits of the Niger Delta and overlying the Eocine Bende Ameki group. The Niger Delta developed as a trough between Benin and Calabar caused by a rift fault during the Precambrian age (Weber, 1971). During the lowering of the sea level in the Pleistocene, The Niger River cut wide valleys through its own delta therefore; Kogbe (1975) believes that the Coastal Plain Sands are partly

Table 3.1: Geological correlation in Southern Nigeria

South Western Nigeria	Age	South Eastern Nigeria
Alluvium	Recent	Alluvium
Coastal Plain Sands	Pleistocene to Oligocene	Coastal Plain Sands
Ilaro Formation	Upper Eocene Middle Eiocene	Bende Ameki Group
	Lower Eocene	Imo Shale Group
Ewekoro Formation	Paleocene	Upper Coal Measures False –Bedded Sandstones Lower Coal Measures
Abeokuta Formation	Upper senonian	Asata nkporo Shale Group
	Senonian to Lower cruteceous	Awgu Ndeboh shale group
Crystalline Basement	Lower Paleozoic to Precambrian	Crystalline Basement

Source: Jones and Hokey (1964)

marine, estuarine, deltaic and fluvo-lacustrine in origin otherwise referred to as the 'Calabar Fasc' (Ojanuga *et al.*, 1981). While it is known that there is wide variability in the nature of the depositional environment in the Niger Delta regions, the geology of the area is unconsolidated sands and sandy clays which are represented in three stratigraphic units now known as the Benin, Agbada and Akata formations (Kogbe 1975, Ojanuga 2006).

3.2. Soil survey at Iyanomo

A rigid grid survey with 200 m x 200 m grid pattern was carried out at Iyanomo main station of the Rubber Research Institute of Nigeria. The choice of this grid pattern is twofold namely:

i. Previous experience and studies showed that soils of the Coastal Plain Sands (especially the land system type of the study area) exhibit a level of homogeneity that will make smaller grid size unnecessary as it is not likely to yield more information. (Fagbami, 1985; Fapounda, 1986).

ii. The total land area covers about 2070 hectares, majority of which have been demarcated into 200 x 200 m blocks with paths and some motor-able earth roads.

Identification observations of the soils were made using soil auger in each block at depths of 0 – 30, 30 – 60, 60 – 90 cm for physical and morphological properties such as colour, (using the Mussel Soil Colour Chart), texture and consistency by hand feel methods, effective soil depth, presence of concretions and soil drainage conditions, surface stoniness, slope gradients (%) and aspects. Slope properties and the coordinates of examination points were obtained with the use of Garmin Etrex Global Positioning System (GPS) handset. Variations in the observed morphological properties in the auger examination points were used to delineate the soils into Mapping Units. Each Mapping Unit and variants were further examined in detail by sinking modal profiles to depths ranging from 180 to 200 cm. A total of 10 soil profiles were dug at the Iyanomo site and they were described according to FAO (1990b) guidelines. Soil genetic horizons were sampled and processed for laboratory analysis.

3.3 Map purity study at Akwete

The Akwete sub-station has a soil map prepared by Kamalu *et al.,* (1991). The soil map was scanned and geo-referenced using the GPS, to coordinate some reference points. Two transects A-A and B-B, were laid out to cut across the soil mapping units (Fig. 3.6). Auger sampling was carried out at points 50 m apart along the transects at 0-15, 15-30, 30-60 and 60-90 cm depths for morphological characteristics. The morphological characteristics were coded (Table 3.4) for statistical analysis. Laboratory analysis was carried out for particle size analysis only. Variations within and between mapping units of the existing soil map were calculated. Map purity analysis of the mapping units was carried out using the method of Ogunkunle and Chikezie (1990). Thereafter, three soil profiles (each representing a mapping unit) were described for the purpose of detail characterization of the pedons and to determine some of the properties that were not available in the previous study.

3.4.1 Laboratory analysis

Soil samples were air dried and passed through 2 mm sieve. The soil samples were analyzed using the following standard laboratory procedures.

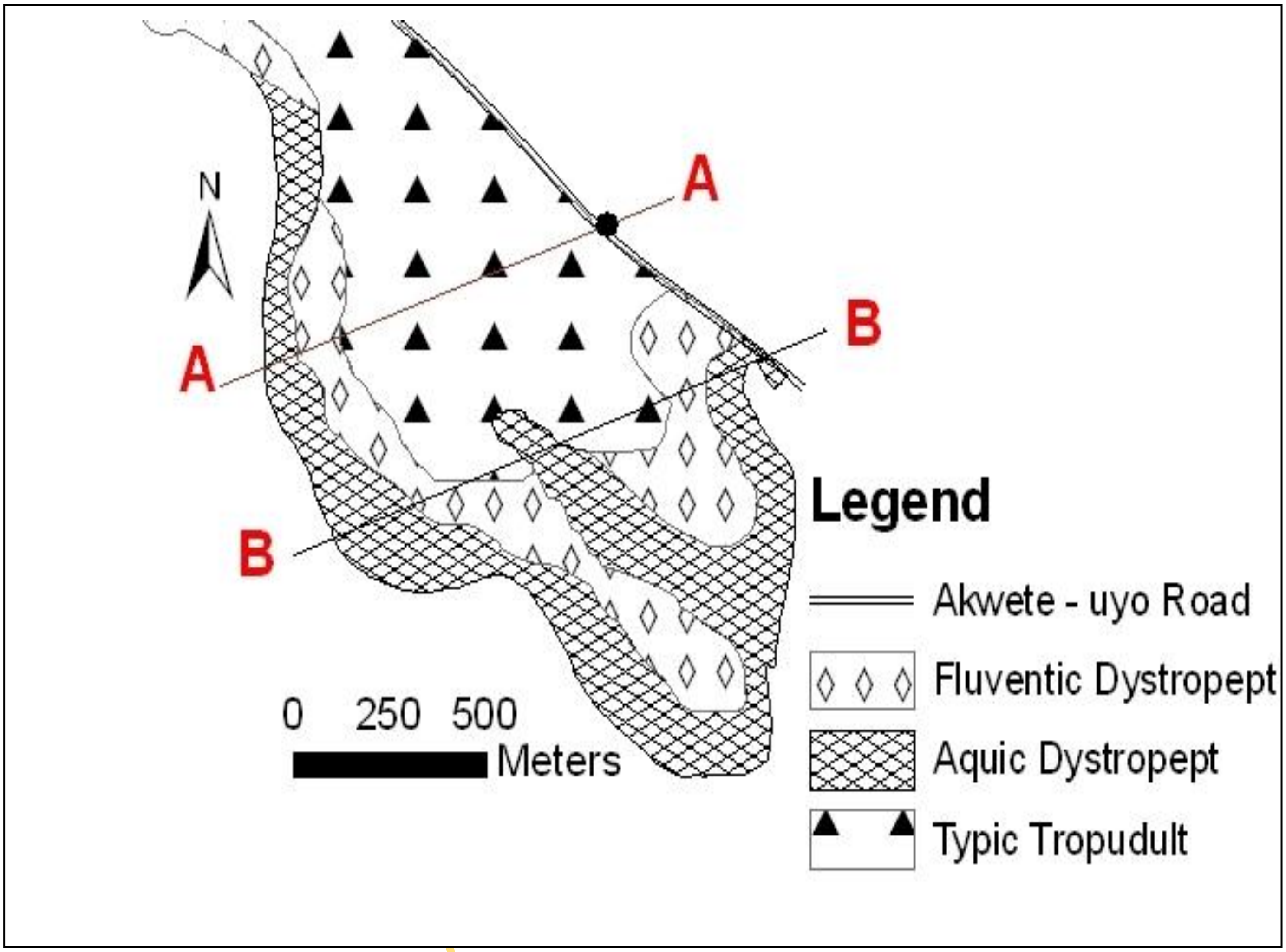


Fig. 3.6: A section of the soil map of Akwete (Kamalu, 1991) showing the transects A-A and B-B sampled for purity evaluation

Particle Size Analysis: Particle size analysis was carried out using the Bouyoucous hydrometer method (Gee and Or, 2002)

Bulk density: Soil bulk density as a ratio of the dry mass to volume was determined in triplicate from undisturbed core samples (Grossman and Reinsch, 2002).

Total Porosity: Total porosity was derived from the relationship of particle density to the bulk density using the formula 1- [ρs/ρb] x100. Where ρs = particle density and ρb = bulk density. The average particle density of mineral soils (1.65 kg m^{-3}) was used for the computation.

Hydraulic conductivity /Soil moisture characteristics: Saturated hydraulic conductivity was determined in the laboratory using undisturbed core samples that were saturated overnight, using the modified falling-head method suggested by Klute (1965). Soil moisture characteristics was determined by subjecting saturated core samples to 0, 10, 20, 30, 40, 50 and 60 cm suctions on a pressure plate apparatus.

Soil chemical analysis

Soil pH was determined potentiometrically in water and in KCl. In water, 10g of soil sample to 25ml of distilled water was added (ratio 1:2.5) while pH in KCl was also determined at a ratio 1:2.5 soil to solvent and the readings were taken using the glass electrode (Methler) pH meter buffered at pH 7. Organic carbon was determined by the Walkley-Black wet oxidation method (Walkley and Black, 1934). Exchangeable bases (Ca, Mg, K, Na) were extracted with IN NH_4OAC (pH 7). Exchangeable Ca and Mg were determined by atomic absorption spectrometer while K and Na by flame photometer (Black, 1965). Exchange acidity ($A1^{3+}$, H^+) was determined by titration of soil solution with IN KCI (Black, 1965). Extractable micronutrients, Mn, Zn, Cu and Fe were leached with 0.1N HCl using the method of Wear and Summer (1948), and were determined on the atomic absorption spectrophotometer. Effective CEC was computed by the summation of exchangeable bases (Ca, Mg, K and Na) and exchange acidity (Al and H).

3.5 Soil classification

Based on profile description and laboratory analysis, the soils were classified using the USDA Soil Taxonomy (Soil survey staff 2010), World Reference base for soil resources (FAO/IUSS, 2006) and at the series level using the system of Moss (1957), as modified by Ogunkunle (1983). Most terms were as defined by USDA and FAO systems as described by Landon (1984).

3.6 Land Evaluation

The suitability of the pedons for rubber was evaluated using the FAO Land Suitability Evaluation of according to the revised FAO framework (FAO, 2007). Three suitability evaluation approaches were employed namely:

Conventional Non Parametric Approach:

Pedons were placed in suitability classes by matching their characteristics with the land requirements for rubber using the modified suitability criteria for rubber proposed by Sys (1985) as modified by Sys *et al*., (1993) and Ugwa *et al.*(2006) (Table 3.2) to classify the Pedons into suitability orders. The

Table 3.2: Land suitability requirements for rubber cultivation (modified after Sys 1985)

Land Qualities	Suitability classes				
	S1	S2	**S3**	**N1**	**N2**
Climate (c)					
Annual rainfall	>2000	1500-2000	1250-1500	-	< 1250
Dry season (months)	1-2	3-4	5	>5	-
Mean annual max temp. (^{o}C)	29	25-29	22-25	-	< 22
Mean annual min. temp. (^{o}C)	>20	16-20	14-16	12-14	< 12
Relative humidity (%)	>75	65-75	60-65	-	< 65
Permanent soil limitations (s)					
Effective soil depth (cm)	200	150-200	100-150	50-100	50 or less
Texture §	SC, CL, SiCL	LC, fine SC, SiC	Coarse SCL, CL, SL	LS	S
Gravel (%) 0-15 cm	< 3-10	10-35	35-60	60-90	> 90
Physiography (t)					
Slope gradient (%)	0-3	3-8	8-20	20-35	> 35
Altitude (m)¶	< 200	200-500	500-600	600-800	> 800
Soil fertility (f)					
Subsoil pH	5-6	4.5-5	4-4.5	6.5-7	7.0
ECEC (cmol kg^{-1})	> 10	5-10	< 5	-	-
Base Saturation (%)	> 45	30-45	15-30	< 15	-
Available P (Bray P1) (mg kg^{-1})	> 15	10-15	5-10	< 3	-
Organic Carbon (%)	> 1.2	0.8-1.2	< 0.8	-	-
Wetness (w)					
Drainage	Well drained	Well drained	Mod – imperfect	Poorly drained	Very poorly drained
Depth to water table (cm)	> 200	150-200	-	-	-

§ Texture as defined by FAO/USDA in Ladon, 1984

¶ Experience in China (Huang and Zheng, 1983) showed that rubber may accommodate altitudes between 800-1000 m.

suitability class of a pedon is indicated by the most limiting factor. A suitability rating criteria (Table 3.3) proposed by Van Ranst *et al*. (1996) was also employed in the course of the study in comparison with the classical rating of Sys (1985)

a. Parametric Approach:

In the Parametric approach (after Ogunkunle, 1993), the limiting characteristics of each pedon were rated as contained in Table 3.4. The index of suitability is then computed using the equation:

$$IS = A \times \sqrt{B/100 \times C/100 \times \ldots F/100}$$

Where IS = Index of Suitability

A = the overall lowest characteristic rating

B , C, …F = the lowest characteristic rating for each land quality group

In Table 3.2, five land quality groups namely climate (c), soil limitations (s), Physiography (t), soil fertility (n) and wetness (w) are defined. Only one (the most limiting) member in each group was used because there are usually strong correlations among members of the same group. Potential Index of Suitability (ISp) is the envisaged suitability of land units for the Landuse (Rubber cultivation) after land improvements have been effected where possible or necessary. (Ogunkunle, 1993; Senjobi, 2001)

Table 3.3: Land suitability requirements for rubber based on land qualities (Modified from Van Ranst *et al.*, 1996)

Land Qualities	Suitability class and rating scale			
	S1	S2	S3	N
	1.0	0.85	0.60	0.40
Effective depth (cm)	>150	150-100	100-50	< 50
Available nutrients (0-25 cm) (f)				
Ca (cmol kg^{-1})	< 3.5	3.5-4.5	> 4.5	-
Mg (cmol kg^{-1})	< 0.7	0.7-0.9	> 0.9	-
K ((cmol kg^{-1})	> 0.2	< 0.2	-	-
ECEC (cmol kg^{-1})	> 6.0	< 6.0	-	-
Org. C (g kg^{-1})	> 10	< 10	-	-
pH	4.0-6.0	6.0-6.5	> 6.0 or < 4.0	-
Oxygen availability (o)				
Drainage class	well	Moderately well	Poorly	Very poorly
Water availability (w)				
Relative humidity (%)	80	80-60	60-40	< 40
Temperature regime				
Altitude (m)	< 250	250-400	400-500	>500
Workability	Easy	moderate	Difficult	Very difficult
Surface Texture	LS-L	SCL-SC	LC-C	Heavy Clay
Stoniness (%)	0-5	5-10	10-30	>30
Erodibility (e)				
Slope (%)	< 20	20-40	40-60	> 60

Table 3.4: Ratings of limiting factors of land quality for Parametric Suitability evaluation for rubber

Degree of limitation	Rating (%)	Suitability Class
Slight - None	100 -95	S11
Slight	94-85	S12
Moderate	84-55	S2
Severe	54-30	S3
1. Can be corrected	29-20	N1
2. Cannot be corrected	19-0	N2

b. GIS approach

An attempt to map the soils was made through krigging and inverse distance weighted (IDW) interpolation techniques. However, mapping is generally based on field observations which are mostly qualitative in nature. In order to use dichotomous, multistate ranked and unranked soil properties in a GIS environment, they must be suitably coded to render them comparable. It should be noted that spatial data for mapping and evaluation should be coded to reflect their proper rank or order. For the purpose of classification, field observations during the field auger examinations were coded into numerical values. The various categories of a particular soil property are arranged in the most logical manner according to the property's natural occurrence. In respect of the matrix colour hue for instance, the smallest rank was assigned to the values associated with the poorest drained soils (Table 3.5). By interpolation tools of ArcGIS 9.3 (ESRI 2008), each parameter group was taken and evaluated at a time to produce a suitability sub-map (e.g. ECEC was used for the fertility (f) group in Table 3.2). The overall suitability map was obtained by overlaying the suitability sub maps for each parameter land characteristic group. Two types of overlay were carried out which are:

i. Boolean overlay: This was performed with Query language (SQL) of true or false. It returns a map showing either suitable or non suitable.

ii. Weighted Overlay: a weight was allocated to each sub-map of the various parameters to show the relative importance of the parameter. Weights assigned must all add up to 1 (or 100 %)

Table 3.5: Ranking and coding of field variables for variability and interpolation analysis

Code	Soil properties				
	Colour Hue	Colour Value*	Colour chroma*	Texture	Consistency (moist)
0	-	-	-	Organic material	-
1	5Y	1	1	Sand	Loose
2	2.5Y	2	2	Loamy sand	Friable
3	10YR	3	3	Sandy loam	Moderate
4	7.5YR	4	4	Loamy	Firm
5	5YR	5	5	Sandy clay loam	Very firm
6	2.5YR	6	6	sandy clay	Extremely firm
7	10R	7	7	Loamy clay	
8		8	8	clay	

Matrix value and chroma are true values while others are coded by incremental classes

3.7 Indigenous knowledge on land evaluation

An assessment of the farmer perception of soil fertility and methods of evaluating the suitability of their land for rubber cultivation was made through the administration of structured questionnaires in three rubber growing communities namely Mbiri and Utagbuno farm settlements at Ika North and Ndokwa West LGA respectively in Delta State; and Iguoriakhi Farm settlement at Ovia South-West LGA of Edo State. A total of 69 questionnaires were returned and were coded and analyzed statistically for simple descriptive statistics and percentages. A copy of the structured questionnaire is shown in appendix IX. Field visit was made to Mbiri and Iguoriakhi where group interviews were conducted and surface soil samples were collected for laboratory analysis to correlate the scientifically derived soil fertility class with the traditional evaluation systems.

3.8 Field validation of rubber yield

Rubber latex collections for two consecutive seasons were monitored in 2005/2006 and 2006/2007 in some selected plots of existing rubber plantations in the study sites. A half-spiral alternating days tapping method (Saraswathyama *et al.*, 2000) was adopted. The yield potentials of the various clones under ordinary farmers' field conditions and the age of the plantation were used as baseline to validate the land evaluation for rubber in the various fields. The accuracy (practical value) of land classification was tested by comparing the actual yield obtained with the standard yield of the rubber clone in each field each soil class using the following relationship:

Yield Index (YI) = Actual yield / Standard yield x 100.

The index obtained is then compared with the recommended yield class for rubber for the suitability class of each Pedon suggested by Sys (1985) as modified by Watson (1989).

3.9 Assessment of weather and soil parameters on rubber yield

The effects of weather soil parameters on the yield of rubber were carried out in Iyanomo using correlation and path analysis. The weather parameters namely rainfall, evaporation, wind speed, minimum and maximum temperature, and Relative humidity (at 0900 and 1500 hours) over a 10 year period obtained from the Benin Airport Meteorological Station (1999-2005) and the Automated Weather Station at RRIN Mainstation, Iyanomo (2006-2008) were correlated with the yield data obtained from the Tapping Records of RRIN over the same period. Also yield data from specific fields collected from 2005-2007 and the soil parameter obtained from laboratory analysis of soil samples from the fields were also subjected to correlation analysis. The direct and indirect contributions of the weather and soil parameters to rubber yield were evaluated using Path Analysis (Gera *et al.*, 1999).

3.10 Assessment of Rubber plantation effects on the soil environment

The effect of rubber cultivation on the soil properties in relation to other land use alternatives in the study areas was examined. Rubber plantations were grouped according to their ages as Juvenile (1-10 years), Young rubber (11-29years) and old rubber (> 30years). Other land use types considered are Fallow/forest and arable cropping.

Composite and undisturbed core soil samples were collected from rubber plantations of the various age groups as well as the other land utilization types in three replicates. The soil samples as much as possible were restricted to the same soil series at each study location (i.e. Orlu series at Iyanomo and

Uyo series at Akwete). The soil samples were subjected to laboratory analysis for soil physical and chemical properties as described previously. Viable bacterial and fungal populations were estimated by dissolving one gram of each sample in 9 ml of sterile distilled water. Serial dilutions were made up to 10^{-6}. A 0.1ml portion was pour-plated in 20 ml of potato dextrose agar (PDA) and nutrient agar (NA) in three 9 cm Petri-plate replications. The media used for isolating bacteria and fungi were prepared according to standard procedures (Tuite, 1969).

3.11 Data Analysis

a. Descriptive statistics were computed for soil parameter at various depths at Akwete, purity of the soil map was calculated as percentage of the number of examined point that conformed to the taxonomic description of the mapping unit while variability within and between the mapping units were estimated using the coefficient of variation (CV).

b. The land classes by various methods and crop yield were ranked and the association between them was evaluated with Spearman's rank correlation coefficient.

c. Correlations (Pearson's coefficient) between individual soil parameters (profile and surface) and rubber yield and between individual soil properties were calculated.

d. Path coefficients were calculated to determine the direct and indirect influence of soil parameters and weather variables on rubber yield. Path coefficient was used instead of regression analysis to permit the separation of relative influence of one variable upon another as well as the direct contribution of parameters to the trend of measured interest.

e. The accuracy of land evaluation was tested by comparing data obtained when yield of rubber was compared with the standard yield obtainable from the clones of rubber from which the data was collected using the relationship:

Yield Index = Actual yield / standard yield x 100

f. One way Analysis of variance was used to determine the effects of land use types in rubber estate on soil properties. Means were separated by the Duncan Multiple Range Test (DMRT) at 0.05 probability level.

CHAPTER FOUR

RESULTS

4.1 Soil identification and classification at Iyanomo Study site

The major factor in land evaluation is the soil. Therefore, the physical, chemical and morphological characteristics of the soils are presented in this section. The soil taxonomic unit remains the major medium through which knowledge and information on a soil can be transferred among workers to enable the knowledge gained and the prediction of soil response to management be pragmatic from one place to another. The Iyanomo study site consists of a fairly gently undulating terrain with the highest elevation of 39 m above sea level (asl). Four mapping units were identified and described by modal soil profiles at Iyanomo. The four soil types were characterised and classified at series level as Ahiara, Kulfo, Orlu and Alagba series respectively. Table 4.1 shows the series and the corresponding higher categories (Soil Taxonomy and World Reference Base) classifications of the soils at Iyanomo as well as the area coverage. The soils belong to the Benin Fasc of the Coastal Plain Sands parent material as described by Vine (1957) and Ojanuga (2006). The location of each pedon along its typical toposequence in the Benin Fasc is as illustrated in Fig. 4.1. The soil map of the Iyanomo site is shown in Fig. 4.2.

4.2 Soil Properties and description at Iyanomo

Ranges in the soil morphological properties are given in Table 4.2, while some physical and physiographic properties of the modal profiles are presented in Table 4.3. Chemical properties within

Table 4.1: Taxonomic Classification of the rubber growing soils at Iyanomo

Pedons	Local classification (Moss 1957)	Soil taxonomy (Soil survey staff, 2010)	WRB* (FAO/IUSS, 2006)	Coverage Area (Ha)	(%)
A	Ahiara Series	Typic Dystrudept	Haplic cambisol (Eutric)	152.55	7.34
B	Kulfo series	Oxic Dystrudept	Haplic cambisol (Chromic)	406.54	19.59
C	Orlu Series	Rhodic Haplaudult	Acric Nitisol (Dystric)	1254.80	60.42
D	Alagba Series	Rhodic Haplaudult	Lixic Nitisol (Eutric)	262.78	12.65

* WRB = World Reference Base for soil resources

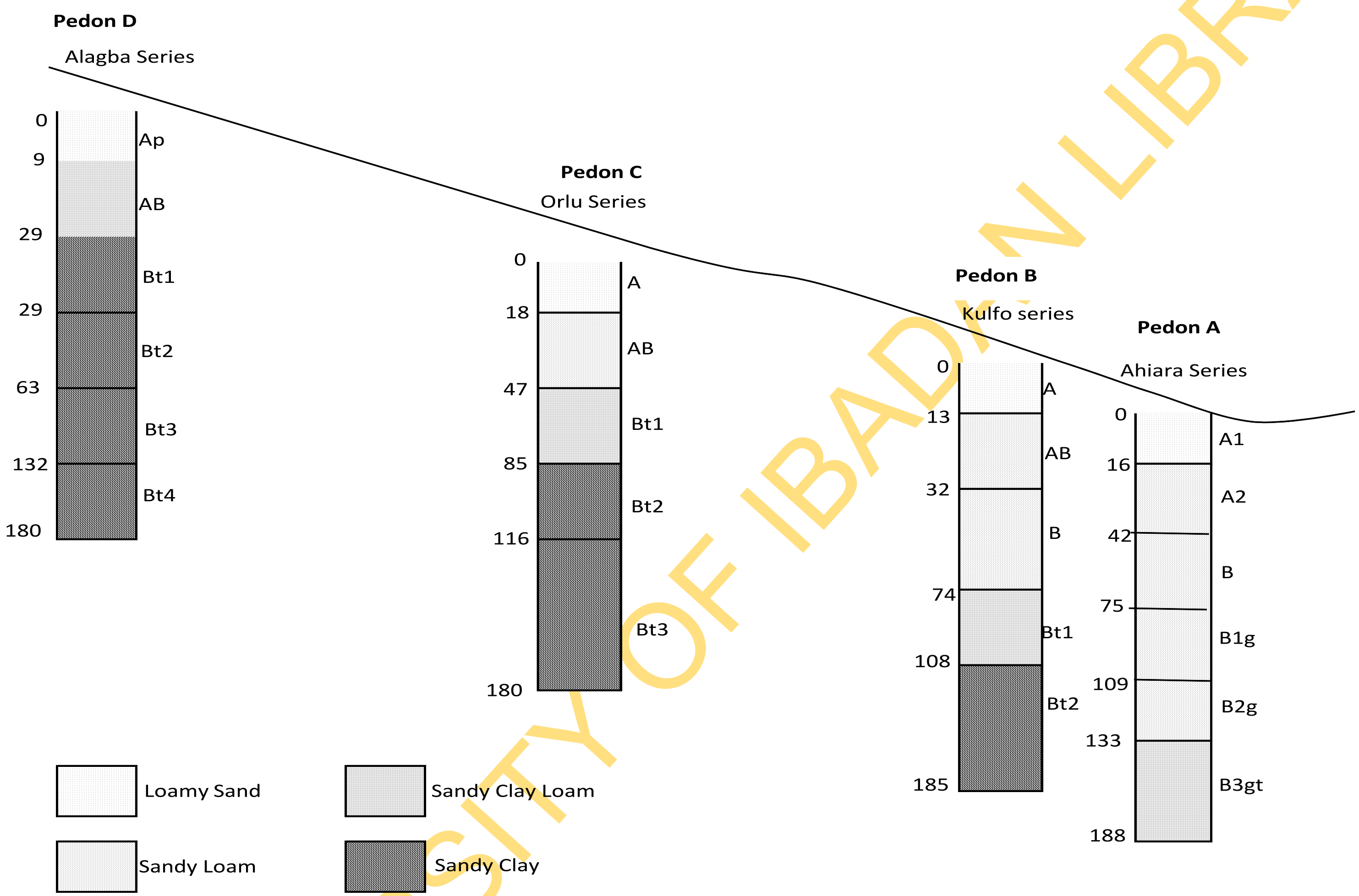


Figure 4.1: A typical toposequence of the Benin Fasc showing approximate locations of the soil pedons at Iyanomo

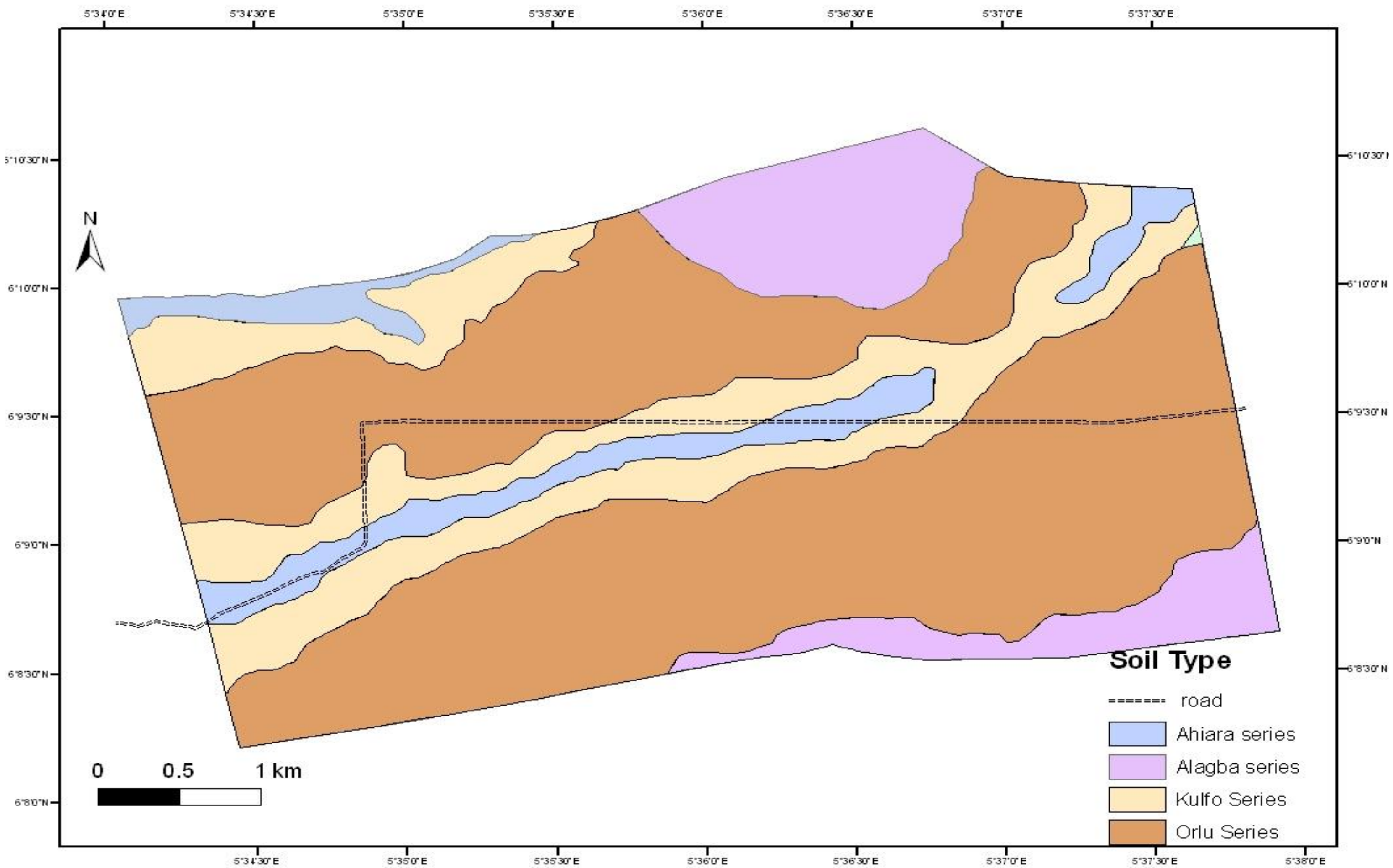


Fig. 4.2: Soil map of Iyanomo study area.

Table 4.2 Range in morphological properties of the rubber growing soils at Iyanomo

Properties	Soil type			
	Ahiara Series	Kulfo	Orlu	Alagba Series
Depth (cm)				
A horizon	0-42	32 - 43	18-32	0-29
B horizon	42-200	32-180	18-180	29-180
Colour (Moist)				
A Horizon	10YR 5/4 – 10 YR 5/6	7.5YR 3/2 – 5YR 4/4	7.5YR 4/4 - 2.5YR 4/8	5YR 3/4
B horizon	10 YR 6/6 - 7.5 YR 5/8	7.5YR 5/6 – 2.5YR 4/6	2.5YR 5/8 - 10R 5/8	2.5YR 5/6
Texture*				
A horizon	LS-SL	LS	LS-SL	SL
B horizon	SL -SCL	LS-SCL	SCL -SC	SC
Structure§				
A horizon	sg	1 m g to 2 m g	2 m cr to 2 m g	1 m cr to 2 m g
B horizon	sg to 2 1 g	1 m g to 1 sbk	1 m sbk to abk	1 m sbk to 2 abk
Gravel /Stoniness				
A Horizon	Nil	Nil	Nil	Nil
B Horizon	Nil	Nil	Nil	Nil

*LS = Loamy Sand, SL = Sandy loam, SCL = Sandy Clay Loam, SC = Sandy Clay
§ 1 = weak, 2 = Moderate, m = medium, sg = single grain, g = granular,cr = crumb, sbk = sub angular blocky, abk = angular blocky

Table 4.3: Range in some soil physical and physiographic properties of rubber growing soils at Iyanomo

Soil Series	Sand ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	Clay ($g\ kg^{-1}$)	Hydraulic cond ($cm\ min^{-1}$)	Porosity (%)	Effective Soil depth	Drainage class	Slope gradient (%)	Erosion	Physiographic position
Ahiara Series	776.8-881.8	1.2 -21.2	11.4 - 21.5	0.01-0.7	33.58-52.83	>200	2	0-3	Nil	Lower slope
Kulfo Series	750.8-840.8	0.60-40.6	118.6-213.6	0.07-0.80	31.7 – 46.41	>200	3	3-6	slight	Middle Slope
Orlu Series	745.8-875.8	0.60-5.60	123.6-253.6	0.03-0.22	36.98- 49.06	>200	4	3-5	Nil	Upper Slope/ Middle Slope
Alagba Series	615.2-755.2	12.8-32.8	192.0-352.0	0.04-0.31	38.82-47.94	> 200	4	0-2	Nil	Upper slope

Table 4.4: Soil chemical properties of the feeder root zone (Approx 0-25 cm) at Iyanomo site

Soil Sreies	pH (H_2O)	Or g C	Total N	Avail P (mg/ kg)	Ca	Mg	Na	K	ECEC	ECEC Clay	Base Sat	Fe	Zn	Mn	Cu
		(g/ kg)			(cmol kg^{-1})						(%)	(mg/kg)			
Ahiara	4.48	10.8	3.90	49.27	1.60	0.50	0.11	0.06	4.25	37.28	58.11	94.50	20.5.	175.90	6.90
Kulfo	4.13	14.6	2.00	26.39	1.30	0.10	0.13	0.16	3.68	31.03	45.92	105.70	27.9	185.30	7.70
Orlu	4.02	23.3	1.50	22.29	1.10	0.80	0.12	0.06	4.57	36.97	45.52	125.90	34.30	203.8	8.60
Alagba	5.65	30.00	3.92	24.05	1.40	0.92	0.67	0.25	5.58	29.06	58.86	110.50	33.90	181.5	8.40

the feeder root zone is shown in Table 4.4. Brief descriptions of the soil series are presented below while details of the properties of each pedon are presented in Appendices I and II.

4.2.1 Ahiara Series

This is a coarse sandy soil located in the lower slopes of Iyanomo study site. The soils are yellowish brown soils overlying a reddish yellow to light brownish sub soils (Plate 4.1). The sand ranges between 776.8 and 881.8 g $kg^{-1}$and textural distribution down the profile was a gradual transition from loamy sand to sandy clay loam. Silt content is low as is usually the case with soils of the Coastal Plain Sands. No mottling was observed and the soils occurred in strips along streams and depressions. The bulk density ranges from 1.25 to 1.76 kg m^{-3} increasing with depth. The soil is well drained and in spite of the proximity to the stream, there were no evidence of reducing properties in the profile. The chemical properties of the feeder root zone as presented in Table 4.4 showed that soil reaction (pH) is strongly acidic at 4.5 and Organic carbon is 10.8 g kg^{-1}. Effective Cation Exchange Capacity (ECEC) of 4.25 cmol kg^{-1} and base saturation of 58.11 % are obtained in the soils. Extractable micronutrients obtained in Ahiara Series are 6.9, 20.5 94.5 and 175.9 mg kg^{-1} of Cu, Zn, Fe and Mn respectively. These values showed that the soils are rich in Fe and Mn which are important factors in the chemistry of the soils in the region.

4.2.2 Kulfo Series

The soils in this Series are also sandy located in the middle slope position along the toposequence. Colour ranges from dark brown at the topsoil to yellowish red subsoils (Plate 4.2). The upper

Plate 4.1: Profile of Ahiara Series [Typic Dystrudept or Haplic cambisol (Eutric)] Block K12, Iyanomo

Plate 4.2: Soil profile of Kulfo Series [Oxic Dystrudept or Haplic Cambisol (Chromic)] Block L12

40 cm of the profile is loamy sand overlying a sandy loam to sandy clay loam with increase in textural content down the profile. Sand content decreases gradually but irregularly from 750.80 to 840.80 g kg^{-1}. Clay content increases from 118.6 to 213.6 g kg^{-1} down the profile. The distribution of sand and clay is somewhat similar to Ahiara but with differences in matrix colour. Silt content is very low ranging between 0.6 and 40.6 g kg^{-1}. Bulk density ranged from 1.32 to 1.67 kg m^{-3} increasing down the profile. The chemical properties within the feeder root showed an acidic soil reaction (pH of 4.35) and organic carbon of 14.6 g kg^{-1} concentrated at 0-30 cm depth. The low organic carbon levels in acid sandy soils have been attributed to high decomposition rate due to high temperatures. ECEC and base saturation are 3.68 cmol kg^{-1} and 45.92 % respectively (Table 4.4). The exchangeable bases are low in value and the base saturation indicates that the exchange sites on the soil colloids are mostly occupied by reserved acidity. Micronutrients values show the preponderance of Mn and Fe with values of 185.3 mg kg^{-1} and 105.7 mg kg^{-1} respectively at the feeder root zone (0-30 cm). Zn and Cu were lower with values of 27.9 and 7.7 mg kg^{-1} respectively.

4.2.3 Orlu Series

The soils in this series are located in the middle slope position along the toposequence immediately after Alagba Series. Colour ranges from dark reddish brown at the topsoil to reddish brown to red subsoil (Plate 4.3). The upper layer of the profile is sandy loam textured overlying Sandy Clay loam to sandy clay subsoils. Sand content decreases gradually from 875.8 to 745.8 g kg^{-1}. Clay content increases from 123.6 to 253.6 g kg^{-1} down the profile. Clay illuviation is well expressed in the profile. Silt content is very low ranging between 0.6 and 5.6 g kg^{-1}. Bulk density ranged from 1.32 - 1.67 kg m^{-3} increasing down the profile. The chemical properties showed an average pH value of

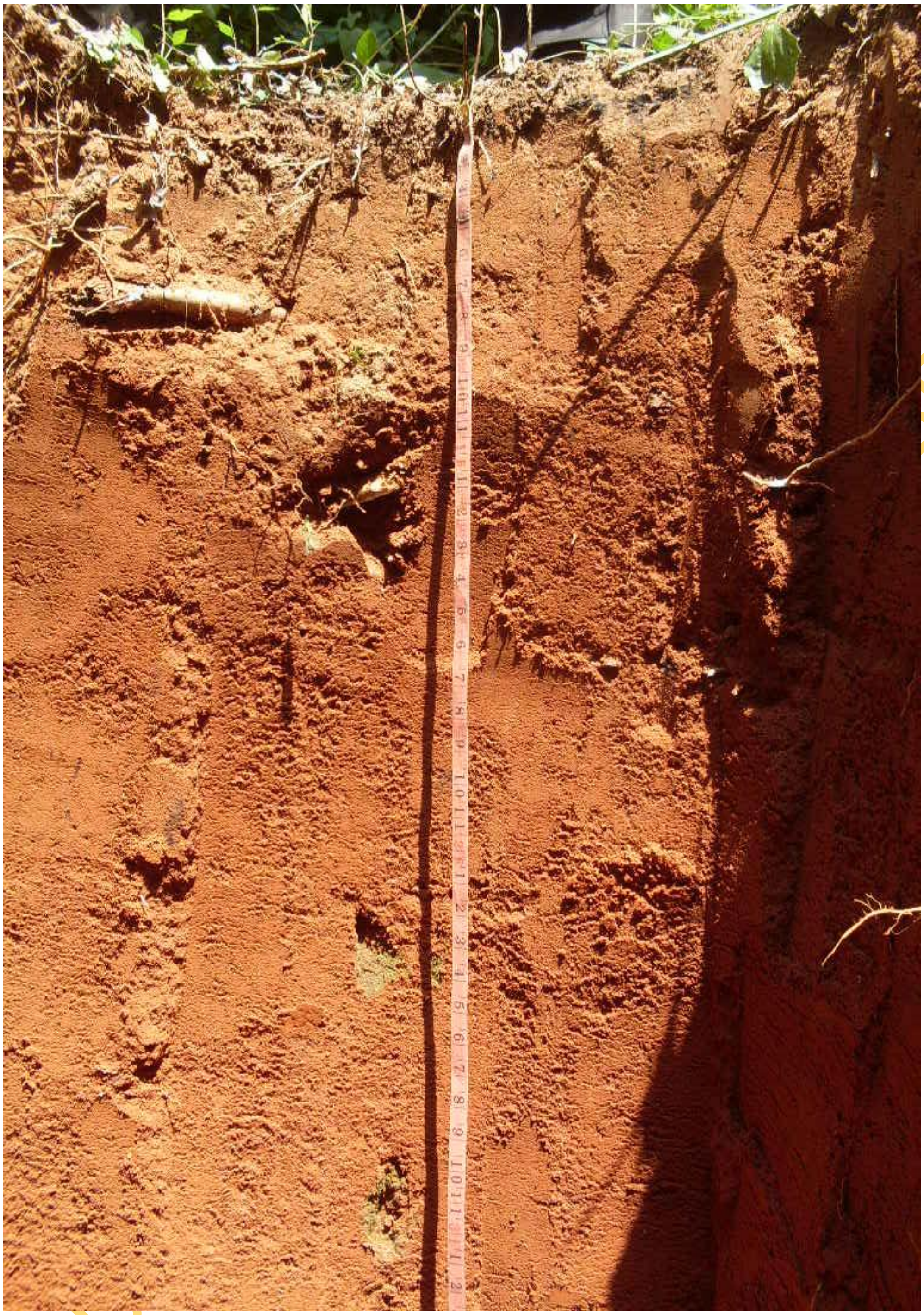


Plate 4.3: Soil profile of Orlu Series (Rhodic Haplaudult or Acric Nitisol (Dystric) at Block MN1, Iyanomo

4.35 which is strongly acidic (Fig. 4.3). Organic carbon was about 23.3 g kg^{-1} at the topsoil. ECEC and base saturation were of 4.57 cmol kg^{-1} and 45.52 % respectively. Low exchangeable bases base saturation could be due to leaching or low exchange sites on the soil colloids probably occasioned by the low activity clay types which are occupied by cations and Al saturation. Micronutrients values show the preponderance of Mn ranging in value between 175.9 to 203.6 mg kg^{-1}, Fe is between 83.4 to 105.9 mg kg^{-1}. Zn values are from 19.8 – 34.6 mg kg^{-1} and Cu ranges from 6.8 to 8.6 mg kg^{-1} in the profile but at the upper layer, micronutrients were 125.9, 34.3, 203.8 and 8.6 mg kg^{-1} for Fe, Zn, Mn and Cu respectively.

4.2.4 Alagba Series

The soils in this series are located in the upper slope position along the toposequence. Colour ranges from dark reddish brown at the topsoil to reddish brown to red subsoil (Plate 4.4). The upper layer of the profile is sandy loam textured overlying Sandy Clay loam with an appreciable increase in clay content down the profile. Sand content decreases gradually from 755.80 to 615.20 g kg^{-1} while clay content increases from 212.5 to 352.80 g kg^{-1} down the profile. Alagba series is the most clayey of all soils of the study area with sandy clay loam appearing at the very surface in several examination points. Silt content is low but higher than other soil types encountered ranging from 12.8 to 32.80 g kg^{-1}. Bulk density ranged from 1.32 to 1.67 kg m^{-3} increasing down the profile. The chemical properties showed lower acidity than others with a pH range of 5.65 and 5.08. Organic carbon content was 30.0 g kg^{-1} at the top horizon or 0-30 cm depth. The organic carbon levels are low but for rubber and acid sandy soils, this value is good enough. ECEC and base saturation ranges from

Plate 4.1: The soil profile of Alagba series [Rhodic Haplaudult or Lixic Nitisol (Eutric)] at Iyanomo.

2.46 – 5.58 cmol kg^{-1} and 37.39 - 58.06 % respectively in the profile but were 5.58 cmol kg^{-1} and 58.6 % ECEC and base saturation respectively at the feeder root zone. The base saturation indicates that the exchange sites on the soil colloids are moderately occupied by cations. Micronutrients values show the preponderance of Mn ranging in value between 150.9 to 220.6 mg kg^{-1}, Fe is between 83.4 to 105.9 mg kg^{-1}. Zn values are from 19.8 – 34.6 mg kg^{-1} and Cu 6.8 – 8.6 mg kg^{-1}. Distribution of micronutrients show higher contents at the feeder root zone from 0-30 cm depth

4.3 Map purity study at Akwete

The purity of the previous soil map of the Akwete study area was evaluated by purity analysis and the variation between and within the established mapping units. A copy of the original map is shown in Fig. 4.3. The purity analysis is presented in Table 4.5 while the coefficients of variation between and within mapping units are shown in Tables 4.6 and 4.7 respectively. The location of the transects for sampling were selectively based on the soil mapping units and the orientation of the land area as there is the likelihood that some mapping units may not be represented if a random transect method was adopted. Though some soil parameters were determined in the laboratory, identification of soil properties that are used for delineation of soils into mapping units took place in the field based on the observed characteristics of the soils, parent material and physiographic position. Since soils of the study area occur on gentle slopes and are of uniform geological origin, the soil properties used for this purity study were limited to observable physical and morphological characteristics of the soils (colour, soil texture and consistency). Purity study showed that mapping units E, F, and G have 77.7 %, 55.5 % and 80.0 % purity respectively.

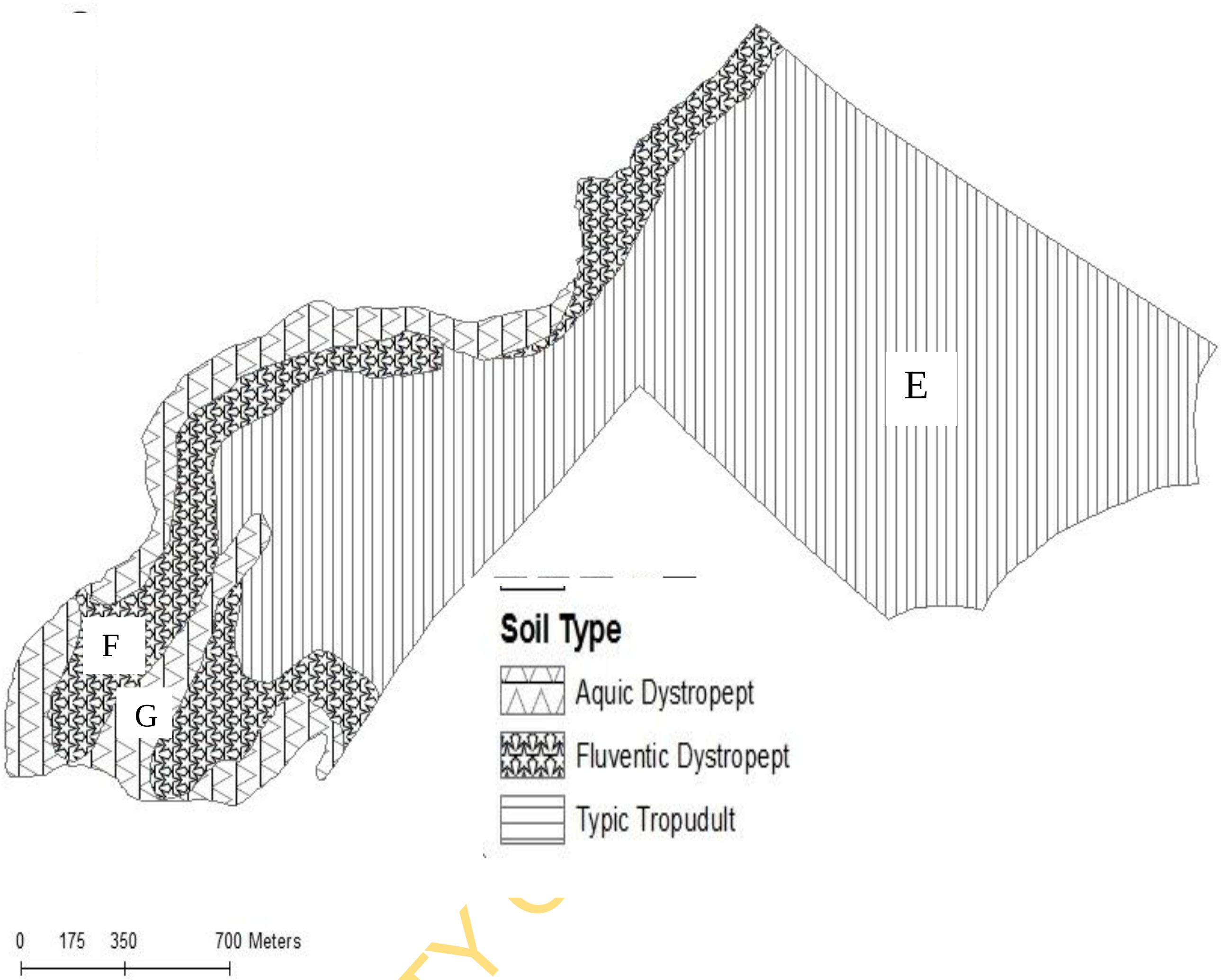


Fig. 4.3: The soil map of Akwete site produced by Kamalu *et al.* (1991) showing mapping units E, F and G

Table 4. 5: Purity of Map units at Akwete study area

Mapping Unit	No of points examined	No of points that conform	% Purity
E	18	14	77.77
F	9	5	55.55
G	5	4	80.00
Total	32	23	71.88

Table 4.6: Estimated variability of soil properties between the soil mapping units at Akwete

Soil properties	depth	mean	variance	Standard deviation	Standard error	Coefficient of variation (%)
Colour Hue	0-15	2.47	0.58	0.76	0.13	31.41
	15-30	2.38	0.76	0.87	0.15	36.66
	30-60	2.25	0.84	0.92	0.16	40.70
	60-90	3.06	1.74	1.23	0.23	43.05
Colour Value	0-15	3.91	0.09	0.30	0.05	7.58
	15-30	3.84	0.52	0.72	0.13	18.82
	30-60	4.25	0.45	0.67	0.12	15.81
	60-90	4.00	0.00	0.00	0.00	0.00
Colour Chroma	0-15	2.59	0.25	0.50	0.09	19.24
	15-30	2.25	0.45	0.67	0.12	29.87
	30-60	4.48	2.39	1.55	0.27	31.94
	60-90	5.94	1.93	1.39	0.25	23.41
Field texture	0-15	1.47	0.26	0.51	0.09	34.52
	15-30	1.81	0.16	0.40	0.07	34.52
	30-60	2.91	0.80	0.90	0.16	40.95
	60-90	2.72	0.21	0.46	0.08	16.80
Consistency (Moist)	0-15	1.66	0.23	0.48	0.09	16.80
	15-30	2.00	0.00	0.00	0.00	0.00
	30-60	2.00	0.00	0.00	0.00	0.00
	60-90	2.00	0.00	0.00	0.00	0.00

Table 4.7: Coefficient of variation within the soil mapping units at Akwete

Mapping Unit	Depth	Hue	Value	Chroma	Texture	Consistency
E	0-15	08.00	10.00	0.00	20.91	0.00
	15-30	16.31	14.80	0.00	0.00	0.00
	30-60	23.23	0.00	0.00	11.19	0.00
	60-90	0.00	0.00	0.00	0.00	0.00
F	0-15	16.63	0.00	17.64	0.00	33.07
	15-30	50.07	10.35	0.00	37.95	0.00
	30-60	0.00	17.63	35.04	0.00	0.00
	60-90	0.00	0.00	33.07	17.64	0.00
G	0-15	34.99	0.00	0.00	0.00	0.00
	15-30	14.40	0.00	34,23	0.00	0.00
	30-60	0.00	21.07	20.33	34.23	0.00
	60-90	0.00	0.00	0.00	15.97	0.00

The co-efficient of variability (CV) for colour Hue, value and chroma among the soil mapping units are 31.41 - 43.05 %, 0.0 -18.82 % and 19.24-31.94 % respectively. The CV for field texture ranges from 16.80% to 40.95 % while the CV for consistency under moist conditions are very low, ranging from 0.00 – 16.80 %. However, within the soil mapping units, the highest CV of 34 .99 % occurred with the colour hue at 0-15 cm depth in mapping unit G. This mapping unit also has variability of 34.23 % in chroma at 15-30 cm depth and 34.23 % in field texture at 30-60 cm depth. Classifying the variabilities according to the method of Wilding and Drees (1983), 85% of the total no of variables considered in mapping Unit E has very high homogeneity with CV less than 15 %. Mapping unit F however had about 55 % while mapping unit G had homogeneity of about 76 %. While it may be argued that the high CV values of the mapping units F and G is due to the very low number of points tested for the variability as permitted by the transect method of sampling, it may be suggested the boundaries of mapping unit F be adjusted. However the three mapping units are valid and are the basis of further analysis in this study.

4.4 Soil identification and classification at Akwete Study site

The terrain of the Akwete Substation study site is a gently sloping to nearly flat land with gradient 2-3 % and a south facing slope aspect. A typical toposequence is shown in Fig. 4.2. The three soil mapping units previously identified were further described and classified at Series level. They correlate with the Uyo, Calabar, and Etinan respectively belonging to the Calabar Fasc of Coastal sediments parent materials. The soil classification in lower (Series) and higher categories are as presented in Table 4.2 while the extent of each soil type is shown in the soil map (Fig. 4.5).

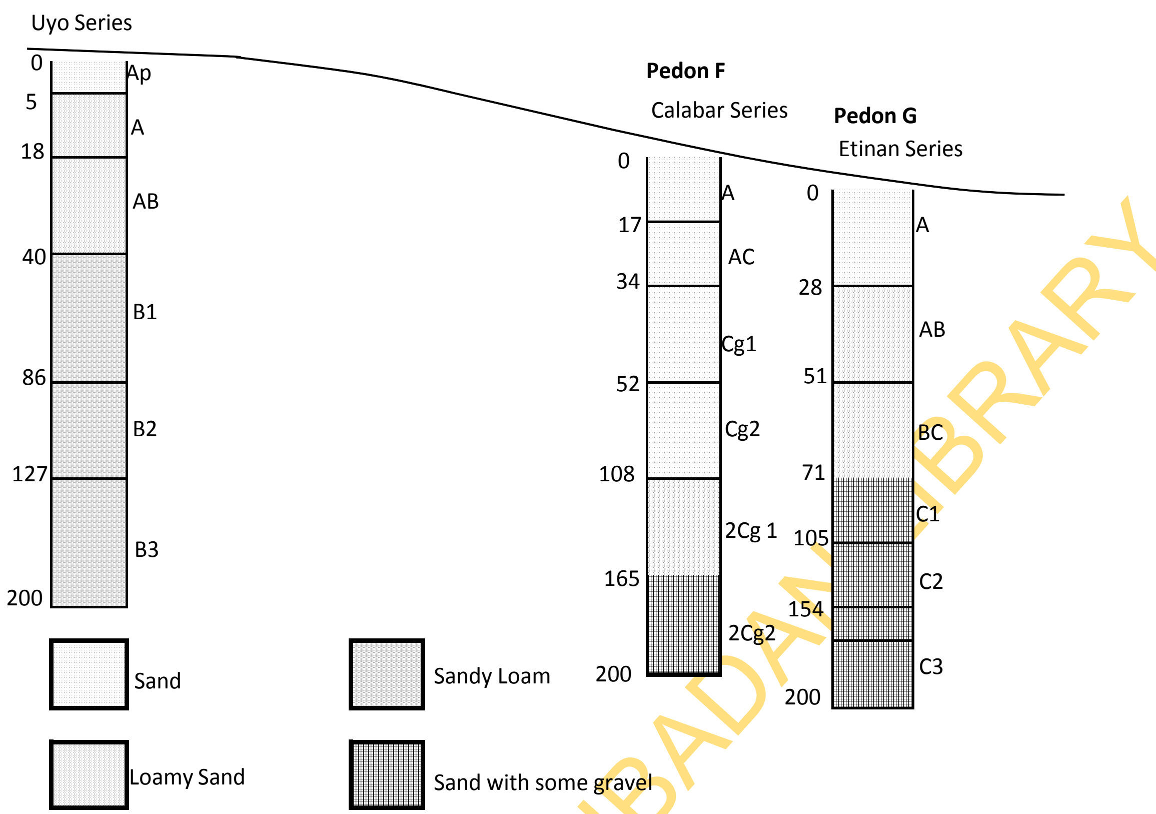


Fig. 4.4: A typical toposequence of the Calabar Fasc showing approximate locations of the soil pedons at Akwete

Table 4.8: Taxonomic Classification of the soils at Akwete study area

Pedons	Local classification (Moss 1957)	USDA Soil Taxonomy	IUSS (WRB) (FAO/IUSS, 2006)	Coverage Area (Ha)	(%)
E	Uyo Series	Arenic Kandiudult	Nitosol (Dystric)	225.06	71.03
F	Calabar Series	Fluvaquentic Dystrudept	Gleyic Cambisol	48.30	15.20
G	Etinan Series	Aquic Dystrudept	Endogleyic Cambisol (Dystric)	44.21	13.92

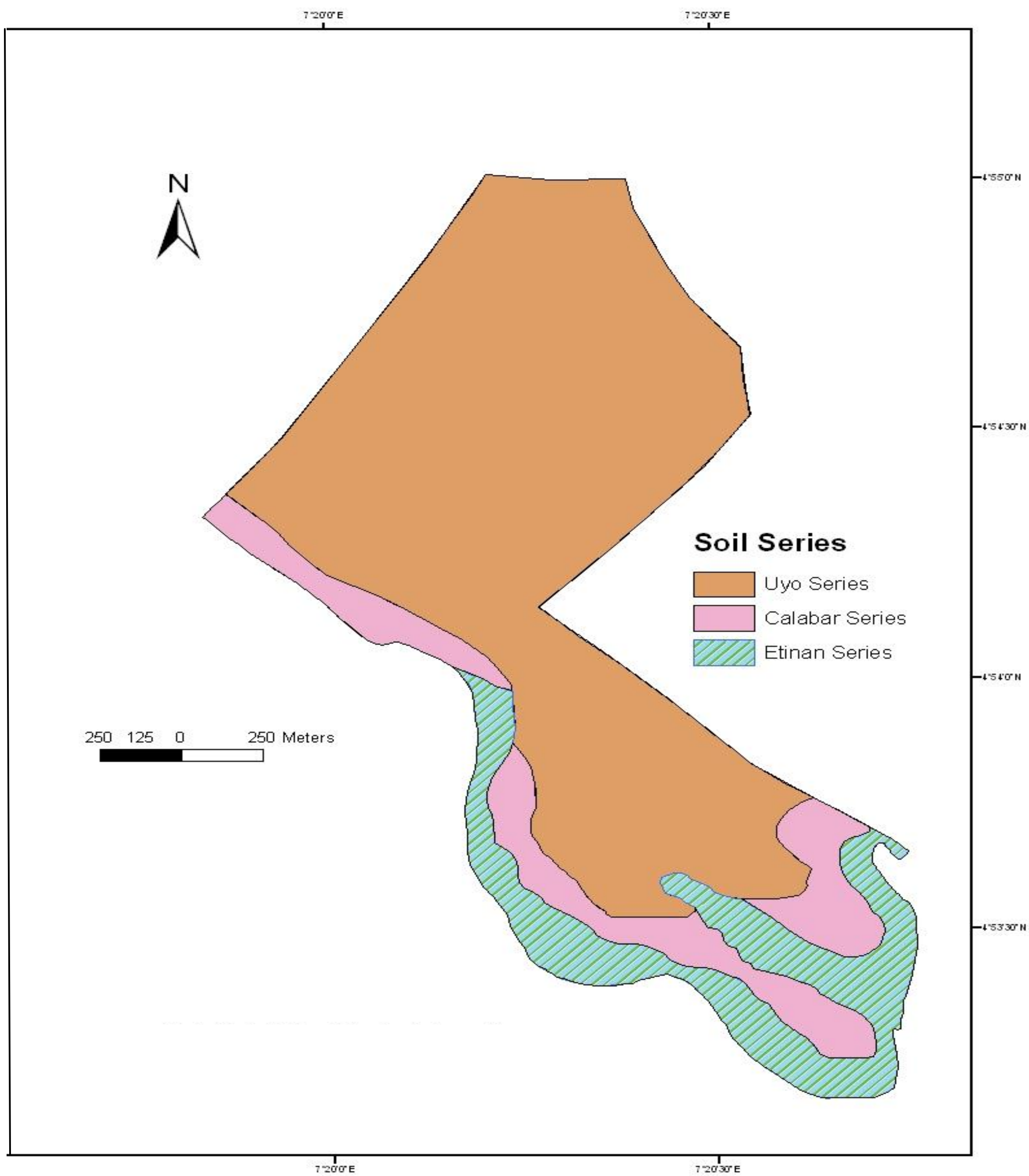


Fig. 4.5: A soil map of Akwete study area

The soils belong to the Ultisol and Inceptisol soil orders in the USDA Soil Taxonomy while in World Reference Base system they belong to the Acrisols and Cambisol Soil Orders. The Ultisol or Acrisols (Uyo Series) covered a total land area of 222.23 Ha representing 75 % of the studied area while the Cambisol (Calabar and Etinan Series) occupied a total land area of 120.24 hectares or 24.80 % of the total land area. It is noteworthy that the Cambisols are located at the lower slopes close to the stream in Akwete.

4.5 Soil properties and description at Akwete

Some ranges in the soil morphological properties are presented in Table 4.9. Some physical and physiographic features are presented in Table 4.10 while the chemical properties of the surface (feeder root zone) are presented in Table 4.11 Details of the morphological, Physical and chemical characteristics are in Appendices III and IV. Brief descriptions of the soils are as follows

4.5.1 Uyo Series

The soils of this Series are well drained, deep and developed with evidence of argillic B horizons. They occur on flat to gently sloping areas on the upper slope of the catena (Fig. 4.11). Surface soils are dark greyish brown (10 YR 4/2) with Sand to Loamy sand texture overlying dark yellowish brown to light reddish brown Sandy loam to Sandy Clay Loam sub soil (Table 4.9). The structure ranges from weak fine granular in the surface to sub angular blocky in the subsoil. The soils have no gravelly or hard pan layer that can impede crop root growth. Horizon boundaries are smooth and clear. Also no mottling or concretion was observed down the profile.

Table 4.9: Range in morphological properties of the rubber growing soils at Akwete

Properties	Uyo Series	Calabar Series	Etinan Series
Depth (cm)			
Surface	0 - 18	0-17	0-28
Sub surface	18-200	17-200	28-200
Colour (Moist)			
Surface	10YR 4/2 – 10 YR 3/3	5Y 4/2	10YR 3/2 - 2.5Y 4/4
Sub surface	10 YR 3/8 - 7.5 YR 5/8	10YR 4/4– 5YR 7/2	2.5Y 5/4 – 5Y 6/6
Texture*			
Surface	S	S	S
Sub surface	SCL	SL	S
Structure§			
Surface	1 m g to 1 f g	Sg	2 f g
Sub surface	1 f sbk to 1 m sbk	sg to bk	1 f g to 1 m g
Gravel/ stoniness			
Surface	Nil	Nil	Nil
Sub surface	Nil	6 %	8 %
Mottles			
surface	Nil	Nil	Nil
subsurface	Nil	Faint	2.5YR 5/8

*LS = Loamy Sand, SL = Sandy loam, SCL = Sandy Clay Loam, SC = Sandy Clay
§ 1 = weak, 2 = Moderate, m = medium, sg = single grain, g = granular, sbk = sub angular blocky, bk = blocky

Table 4.10: Some soil physical and physiographic properties of rubber growing soils at Akwete

Soil Series	Sand	Silt	Clay	Porosity (%)	Effective Soil depth	Drainage class	Slope gradient (%)	Erosion	Physiographic position
	(g kg^{-1})								
Uyo	860.0-950.0	8.08-28.60	22.0-112.	45.28-55.47	200	Well	0-3	Nil	Upper/middle Slope
Calabar	930.0-980.0	8.08-18.0	2.0-52	36.98-51.32	188	Moderate /poor	3-6	Slight	Lower slope
Etinan	900.0-.0940	8.0-28.0	32-92	32.45-58.87	>150	poor	2-5	Nil	Lower Slope

Table 4.11: Soil chemical properties of the feeder root zone (Approx 0-25 cm) at Akwete site

Soil Series	pH (H_2O)	Org C (g/kg)	Total N (g/kg)	Avail P (mg/kg)	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	Na (cmol kg^{-1})	K (cmol kg^{-1})	ECEC (cmol kg^{-1})	Base Sat (%)	Fe (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)
Uyo	4.60	18.8	2.53	8.4	0.96	0.32	0.07	0.22	3.25	48.31	83.0	4.12	37.2	2.6
Calabar	4.90	14.5	2.02	7.4	1.92	0.48	0.04	0.02	5.48	44.89	68.6	6.75	36.8	3.7
Etinan	4.70	23.9	3.13	10.0	0.96	0.48	0.12	0.09	4.74	34.81	85.6	3.20	52.5	1.6

The Uyo series soils have porosity ranging from 45-55% (Table 4.10) with a greater proportion of macro-pores. In the feeder root zone (Table 4.11), the soils have pH of 4.6, available P of about 8.4 mg kg^{-1}, organic carbon greater than 2.5 g kg^{-1} and exchangeable cations of 0.96, 0.32, 0.07 and 0.22 cmol kg^{-1} Ca, Mg, Na and K respectively. ECEC and Base saturations were 3.2 cmol kg^{-1} and 46 % respectively. Extractable micronutrients values of 2.7, 4.12, 83.0 and 37.2 mg kg^{-1} Cu, Zn, Fe and Mn respectively. Other detailed physical and chemical properties are shown in appendices III and IV.

4.5.2 Calabar Series

These soils are found along the bank of a seasonal stream. These soils cover about 42.38 ha representing 14.32 % of the Akwete study area. The soils showed some evidence of seasonal water accumulation with gleying, reducing properties and some concretions which are products of pedogenic processes at about 130 cm depth. This is believed to have resulted from the physiographic position that are characterised with micro depressions along the catena. Colour at the surface is dark brown with patches of gray graduating irregularly to dark yellowish brown and olive yellow down the profile. Field texture revealed coarse sand to loamy sand top soil overlying sandy subsoils. The soils are structureless single grains at the top with an irregular range of single grain to blocky structure down the profile. Gravel concentration of 6 % was encountered (Table 4.9).

Chemical properties of the feeder root zone (Table 4.11) showed that the soils are very acidic at pH of 4.9; organic C and total N are 14.5 and 2.02 g kg^{-1} respectively while available P of 7.4 mg kg-1 was obtained. Basic cations of 1.92, 0.48, 0.04 and 0.02 cmol kg^{-1} for Ca, Mg, Na and K respectively, are available for plant root absorption. ECEC stands at 5.48 cmol kg^{-1} and base saturation was 44.89 %

Extractable micronutrients (Fig. 4.11) showed that Fe is more abundant at 68.6 mg kg^{-1} in preference to Cu Zn and Mn which are 3.7, 6.75 and 36.8 mg kg^{-1} respectively.

4.5.3 Etinan Series

This soil type occupies about 10.48 % of the study area and occurred at the lower slope positions of the catena almost the stream and rivulets. Bare "white" sands with ferns and some tree species are visible in the fallow areas. The matrix colour ranges from olive brown (2.5Y 4/4) to olive yellow (5Y 6/6) down the profile with few to moderate reddish mottles (2.5 YR 5/8) from 78 cm depth. The profiles are characterised by horizons with sharp and wavy boundaries. Field texture is sandy at the surface soils with slight but haphazard increase in fine earth materials down the profile. Surface soil structure is single grains (structureless) while down the profile some granular structures were observed. As expected, the soils are very porous (32.45-58.87 %) and judging by the sandy nature, it may consist mainly of macro-pores. Drainage is seasonally poor. The topsoil has a higher amount of available P (10 mg kg^{-1}) than the other Pedons (Table 4.13). Soil reaction is also very acidic (pH 4.7) with organic C and total N of 23.9 and 3.13 g kg^{-1} respectively. Exchange able cations are 0.96, 0.48, 0.12 and 0.09 cmol kg^{-1} for Ca, Mg, Na and K respectively with ECEC value of 4.75 cmol kg^{-1}. Base saturation was 34.81 %. Extractable micronutrients values of 1.6, 3.2, 85.6 and 52.5 mg kg^{-1} for Cu, Zn, Fe and Mn respectively were recorded (Table 4.11).

4.6 Soil mapping with GIS

Figures 4.16 - 4.18 show the spatial distribution of soil matrix colour Hue, Value and chroma respectively at 0-15cm and 30-60cm depths respectively by point interpolation

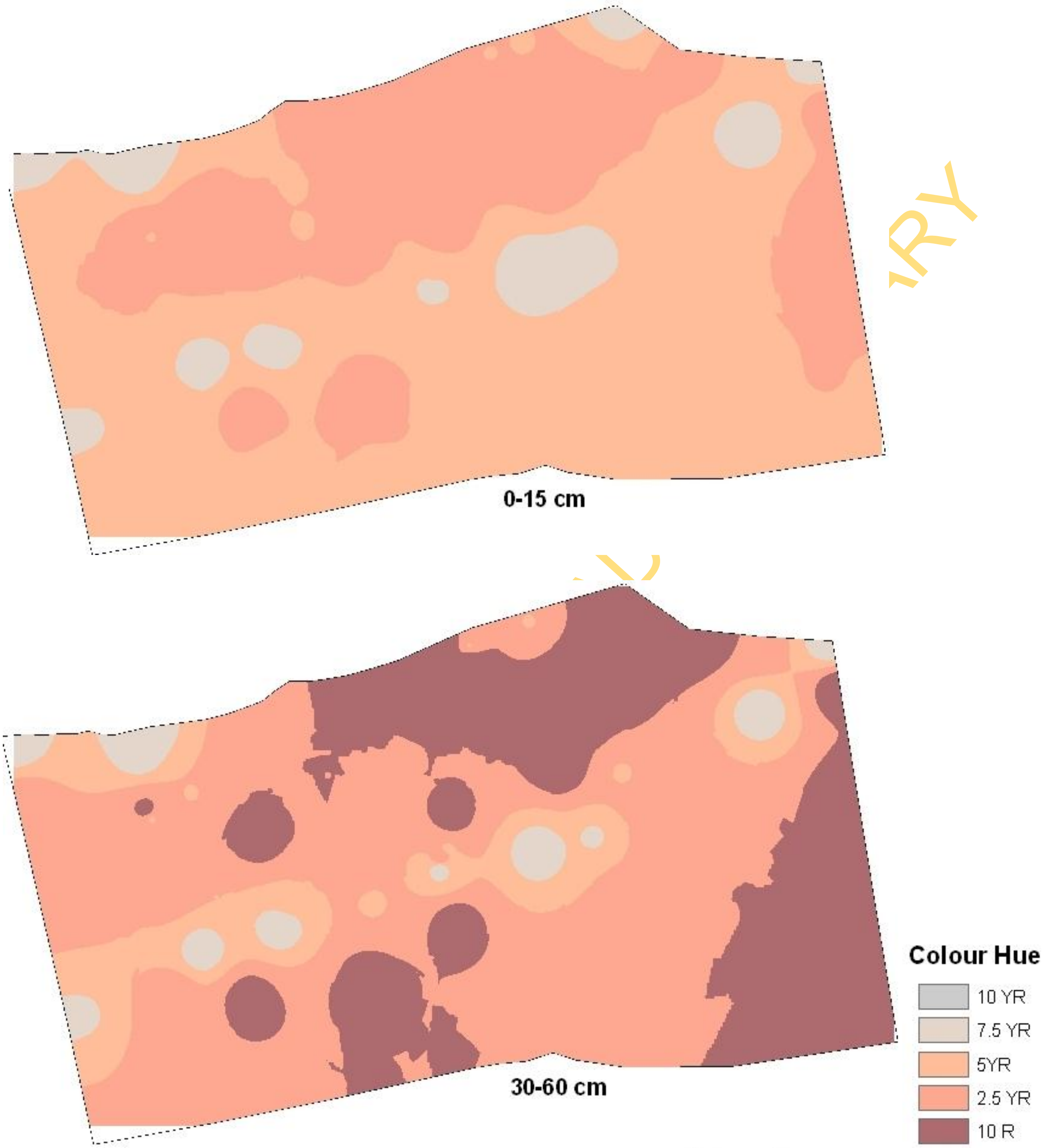


Fig. 4.6: Spatial distribution of the colour (Hue) of the soils at Iyanomo.

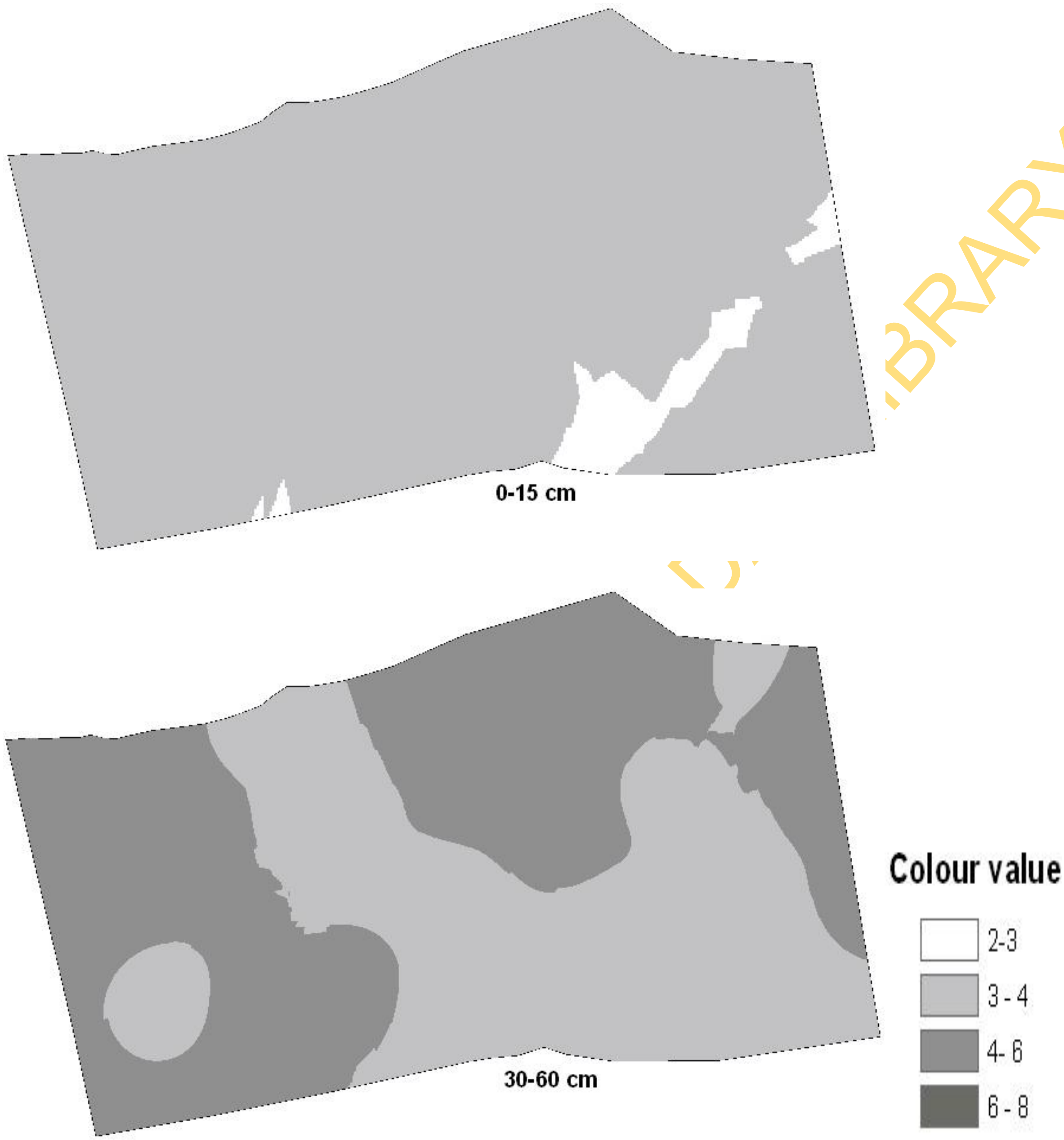


Fig. 4.7: Spatial distribution of colour value Colour value of soils at Iyanomo

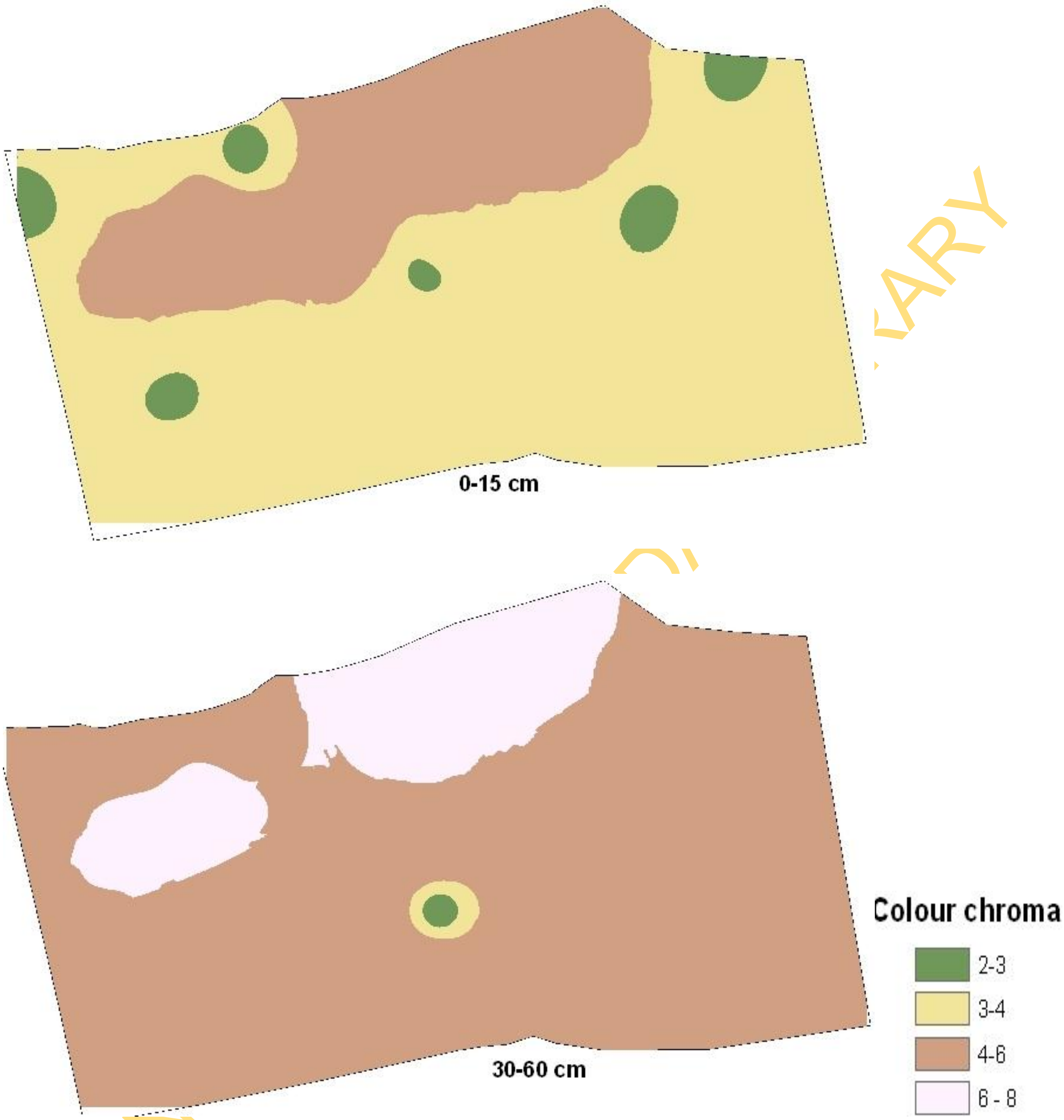


Fig. 4.8: Spatial distribution of colour chroma of the soils at Iyanomo

technique. The soils are reddish in colour with Colour hue mostly graduating from 10 YR -5YR at the upper layers to 2.5YR -10R at the lower horizons. Colour values and chroma also increased down the profile. Colour values between 3 and 4 dominated the upper horizons while value ranges of 4-6 are abundant in the 30-60 cm and 60-90 cm depths. Similarly, Chroma of 3-4 with patches of lower chroma (less than 3) at valley bottoms could be observed in the surface soils. Colour chroma values of 4-6 were more in the 0-15 cm depths while higher chroma of 6-8 was present in some areas at 30-60 cm depths.

The spatial distribution of soil texture and consistency are presented in figures 4.9 and 4.10 respectively. The surface soils 0-15 cm is occupied by light textures of Loamy Sand (LS) to Sandy Loam (SL). The soil texture increased in finer materials as we go down the profile with predominance of loam (L), sandy clay loam (SCL) and sandy clay (SC) at 30-60 cm. Consistency (moist) in the surface layer was mostly friable while the proportion of moderately firm, firm and very firm increased down the profile.

A soil map of Iyanomo site produced by overlay procedure of interpolated field point observations is shown in Figure 4.11. There were some differences in the shape of Ahiara Series which came out as discrete non continuous patches along the stream banks.

Application of the point interpolation method for soil mapping in Akwete study site produced the spatial distribution of field observed morphological attributes of the soils presented in Figs 4.12 – 4.16. There is not much variation in colour hue as we move down the profile (Fig. 4.12). There is a predominance of the 10YR hue in all the four depths considered. 2.5 Y was more at the 0-15 cm depth

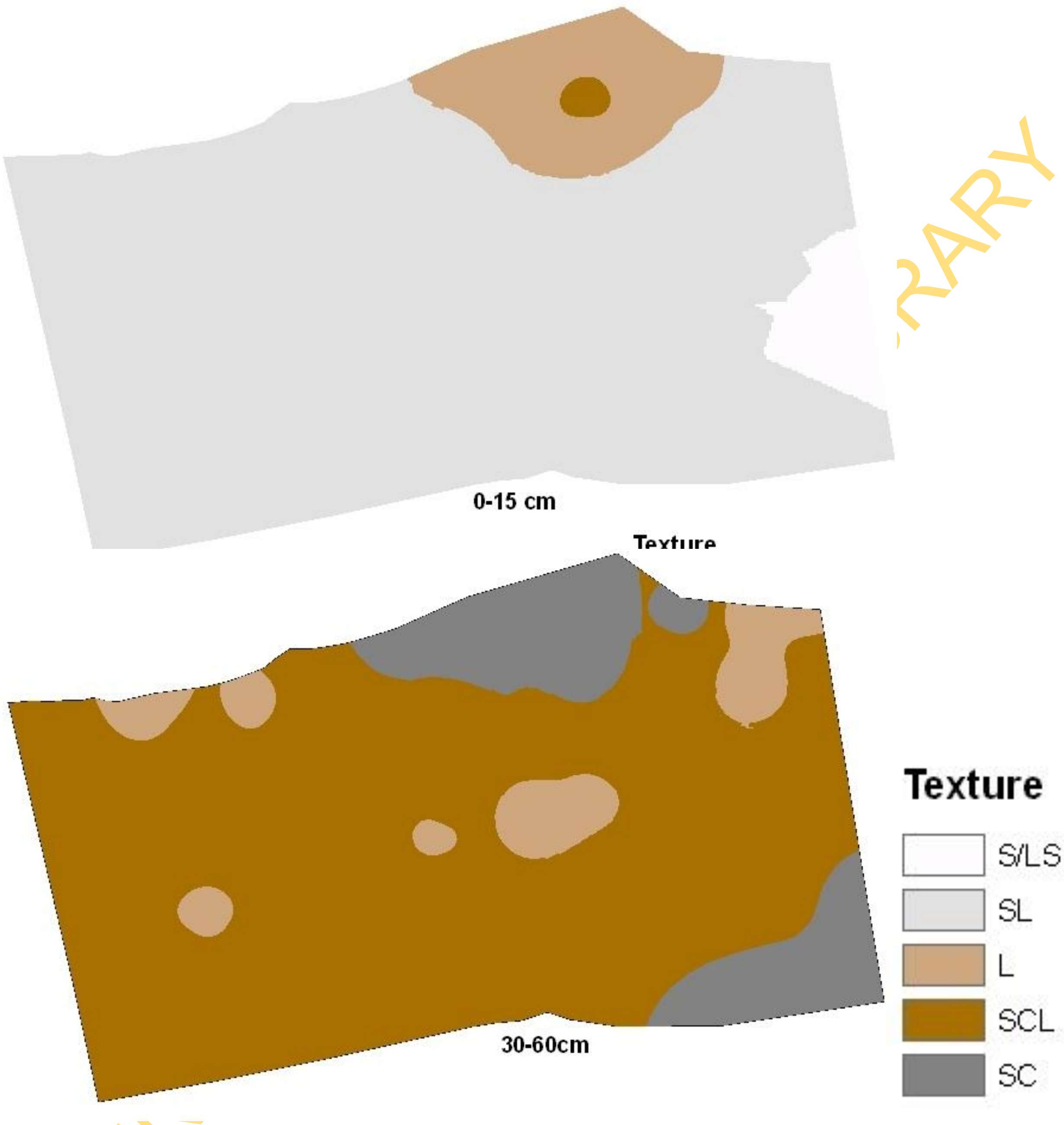


Fig. 4.9: Spatial distribution of texture of the soils of RRIN Mainstation, Iyanomo

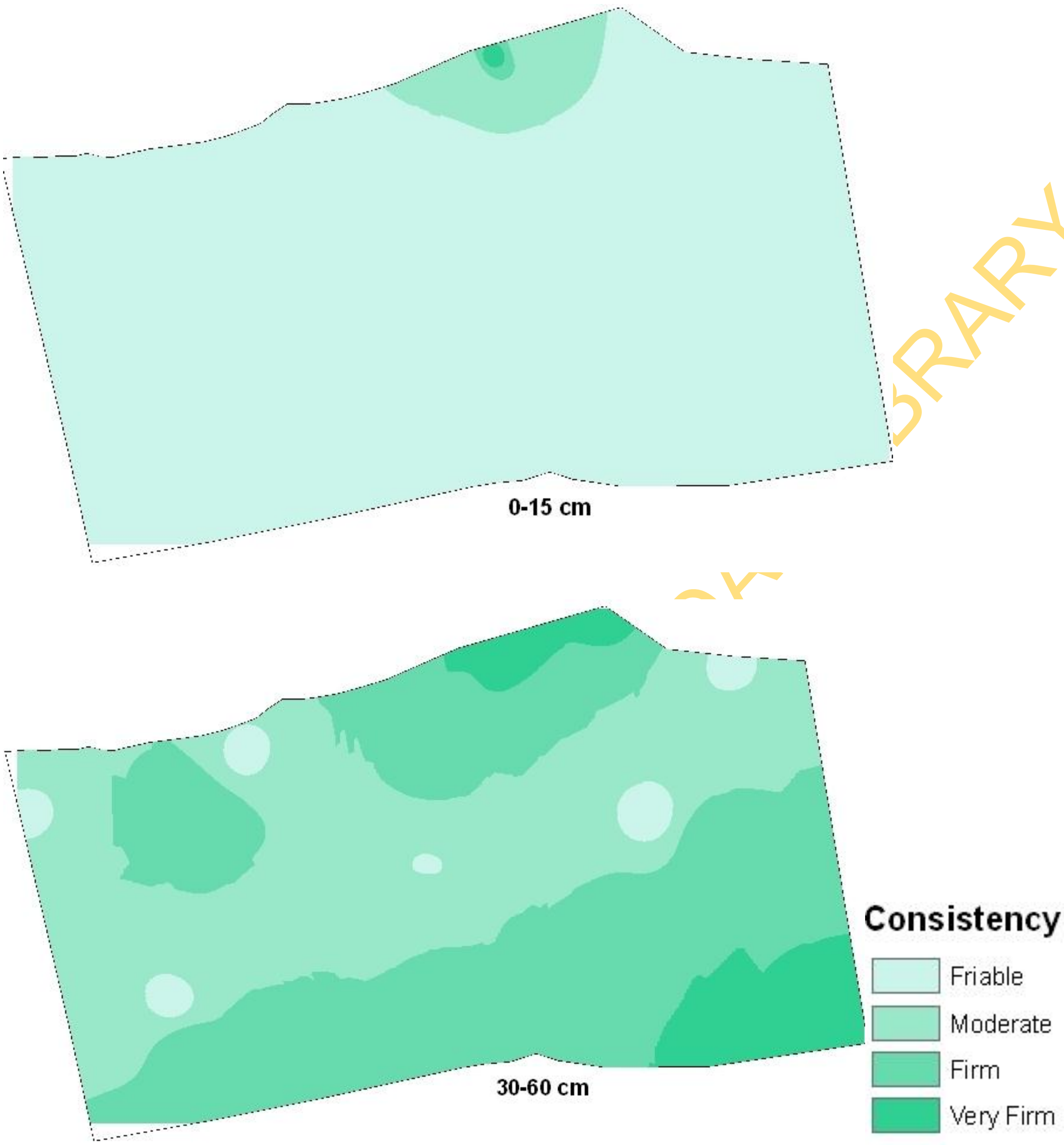


Figure 4.10: Spatial distribution of consistency (moist) of the soils of RRIN Mainstation, Iyanomo.

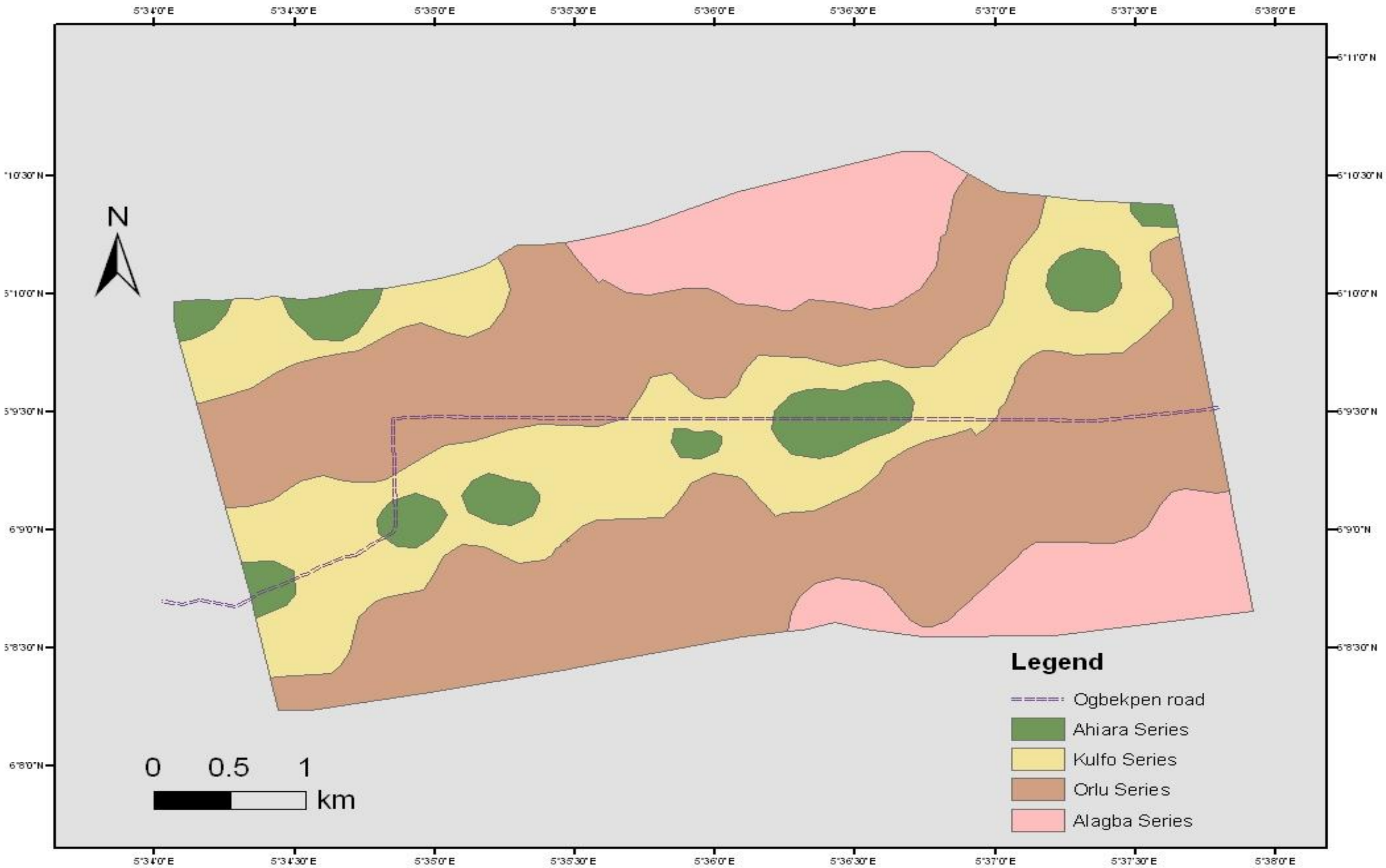


Fig. 4.11: Soil map of Iyanomo study obtained by overlaying Interpolated layers of soil properties

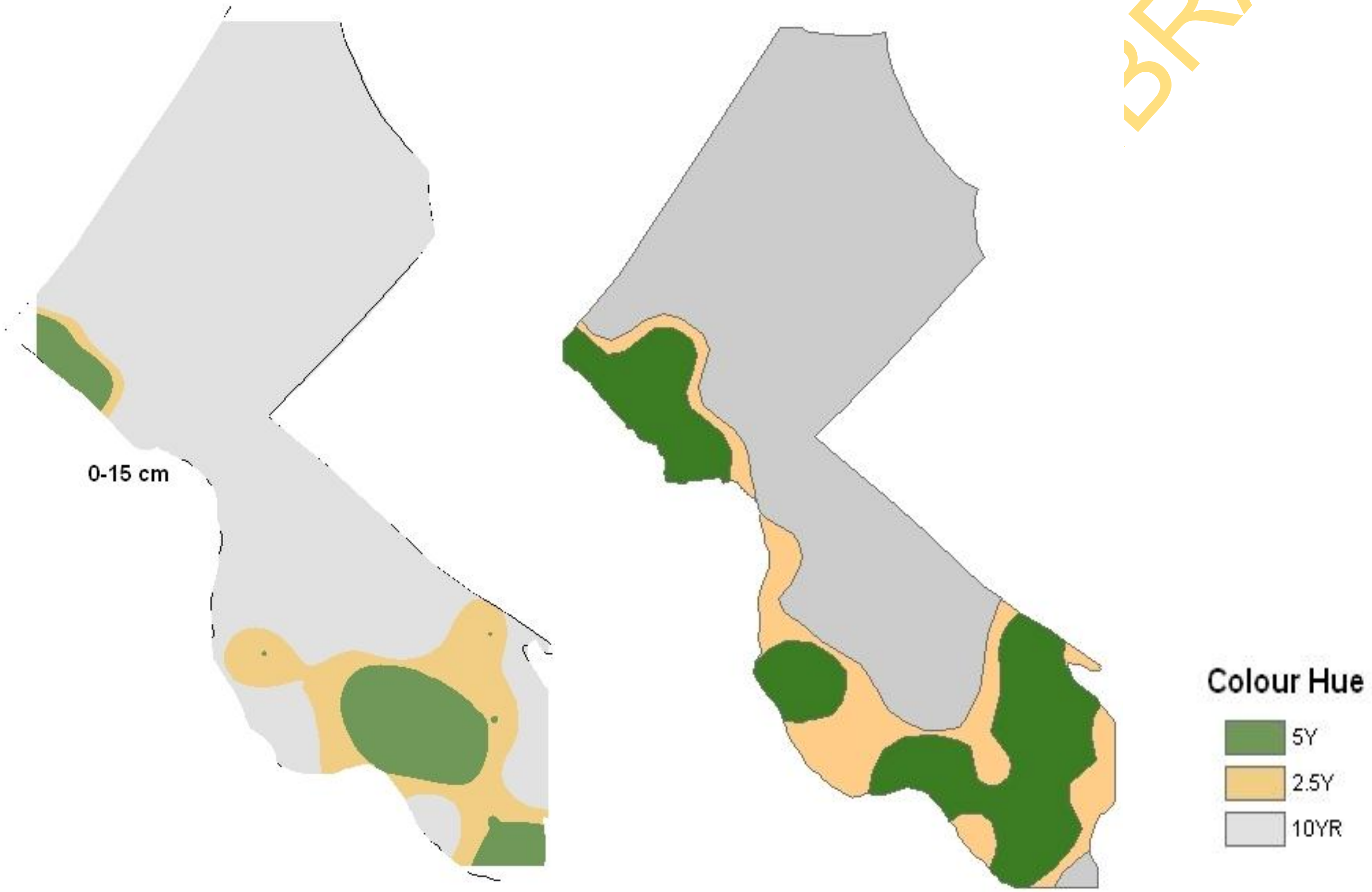


Fig. 4. 12: Spatial distribution of colour Hue of the Akwete study site at 0-15, 15-30, 30-60 and 60-90 cm depths

Fig. 4. 13: Spatial distribution of colour value of the Akwete study site at 0-15 and 30-60 cm depths

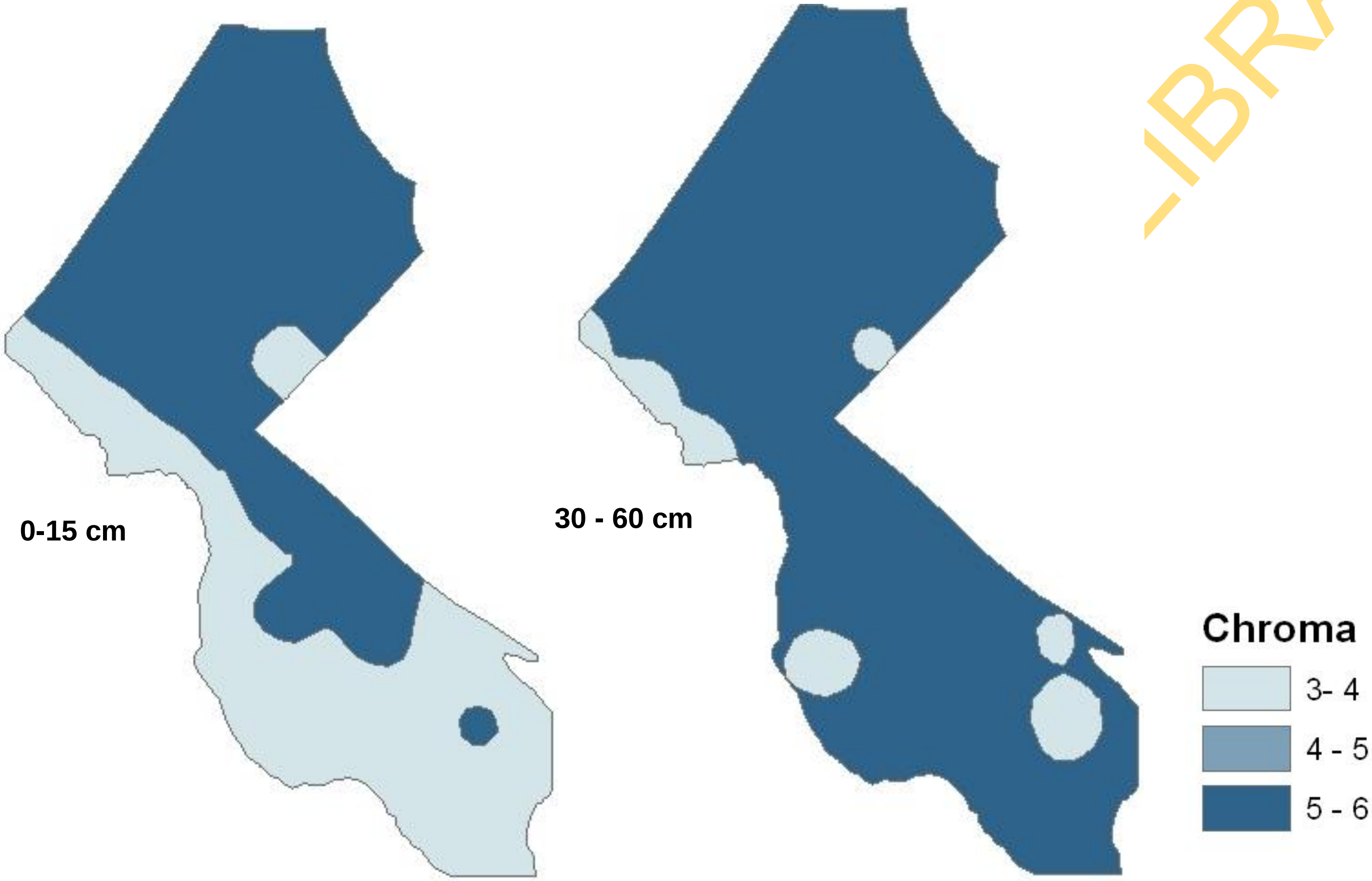


Fig. 4. 14: Spatial distribution of colour Chroma of the Akwete site at 0-15 and 30-60 cm depths

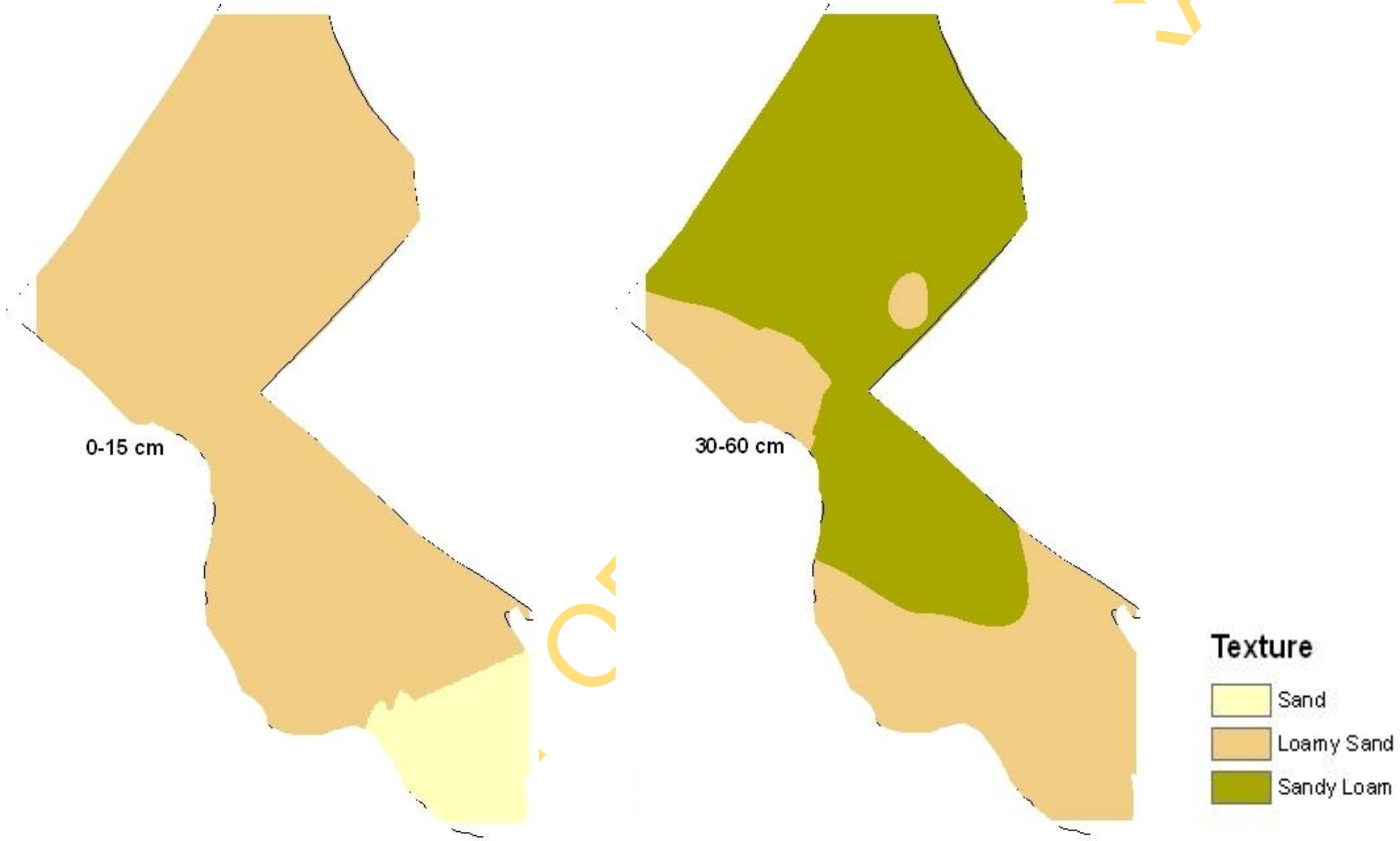


Fig. 4. 15: Spatial distribution of soil texture of Akwete site at 0-15, 15-30, 30-60 and 60-90 cm depths

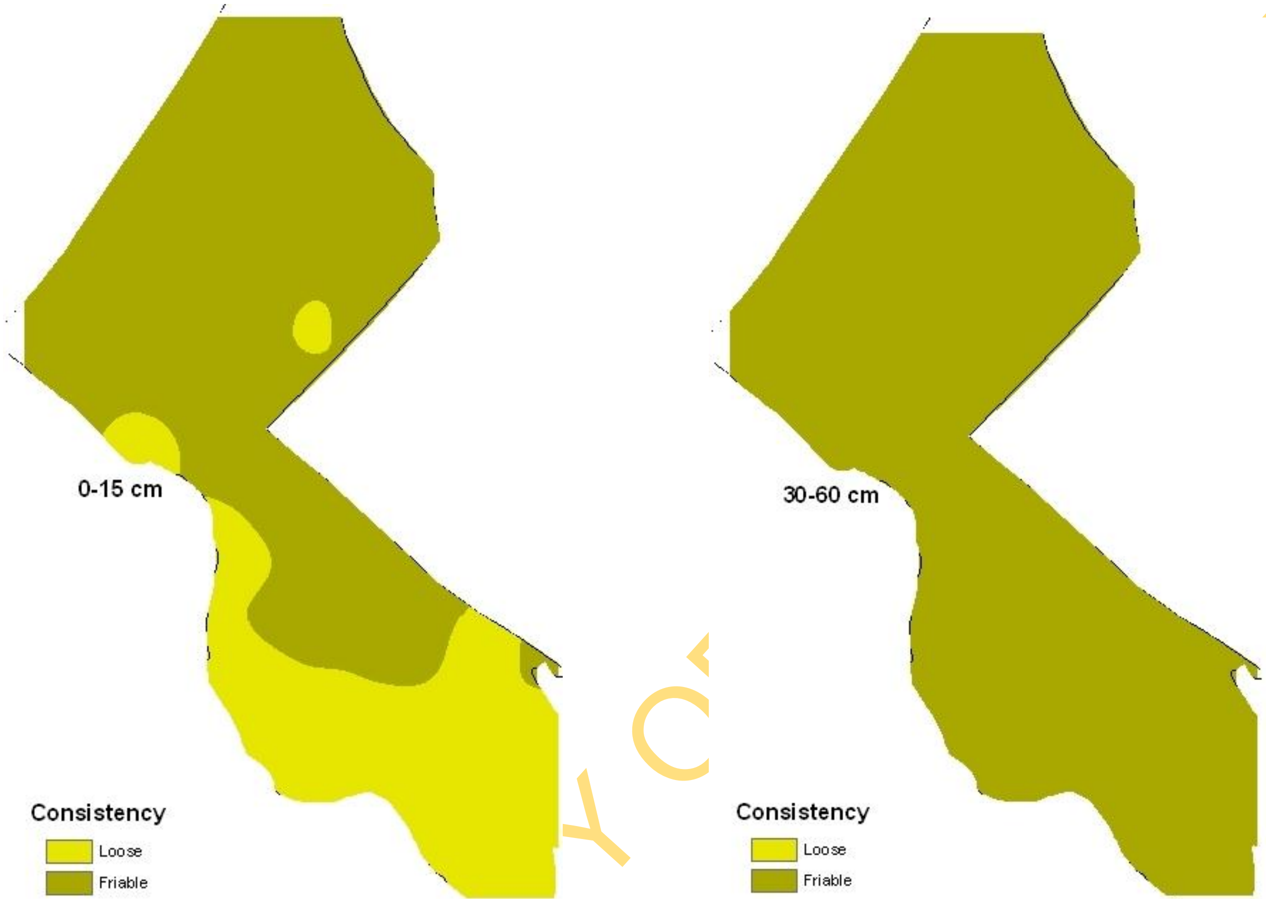


Fig. 4. 16: Spatial distribution of consistency of the Akwete site at 0-15 and 30-60 cm depths

than the others while 5Y was higher at 15-30 cm and 30-60 cm depths than 0-15 and 60-90 cm depths. Colour value (Fig. 4.13) of 4-6 dominated the upper 0-15 cm and 15-30 cm depths while lower colour values 3- 4 appeared first at 15-30cm and increased downward till 60-90 cm where it covered the whole area. The colour chroma (Fig. 4.14) showed an irregular pattern with depths.

Soil textural distributions at various depths are presented in Fig 4.15. The soils showed a textural pattern at various depths. While a higher proportion of loamy sand with sandy texture at the southern end of the field was observed at 0-15cm depth, 15-30 cm is entirely covered by the loamy sand texture. The 30-60 cm layer is shared between Loamy sand and sandy Loam while the sandy Loam texture covered the entire area at 60-90 cm depths. The spatial distribution of soil consistency (moist) is shown in Figure 4.16. The consistency is mostly friable at the 0-15 cm depth but the southern portions were loose at moist conditions. However, from depths 15-30 cm, 30-60 cm and 60-90 cm, all the soils showed friable consistency.

A soil map produced by overlay procedure of interpolated field point observations is shown in Figure 4.17. There were some differences in the shape and extent of the soil Series when compared with the soil map obtained from conventional soil survey.

4.7 Comparison between conventional and interpolated soil maps

A comparison between the soil maps obtained from conventional method and GIS interpolation methods are presented in Tables 4.12 and 4.13. At Iyanomo, the point interpolated map showed an increase in the hectarage covered by Kulfo and Alagba Series while there was a decrease in the area covered by Ahiara and Orlu Series whereas at Akwete, there was a decrease in the area covered by Uyo series while the areas covered by Calabar and Etinan Series increased by about 50 % was attributed to Calabar Series

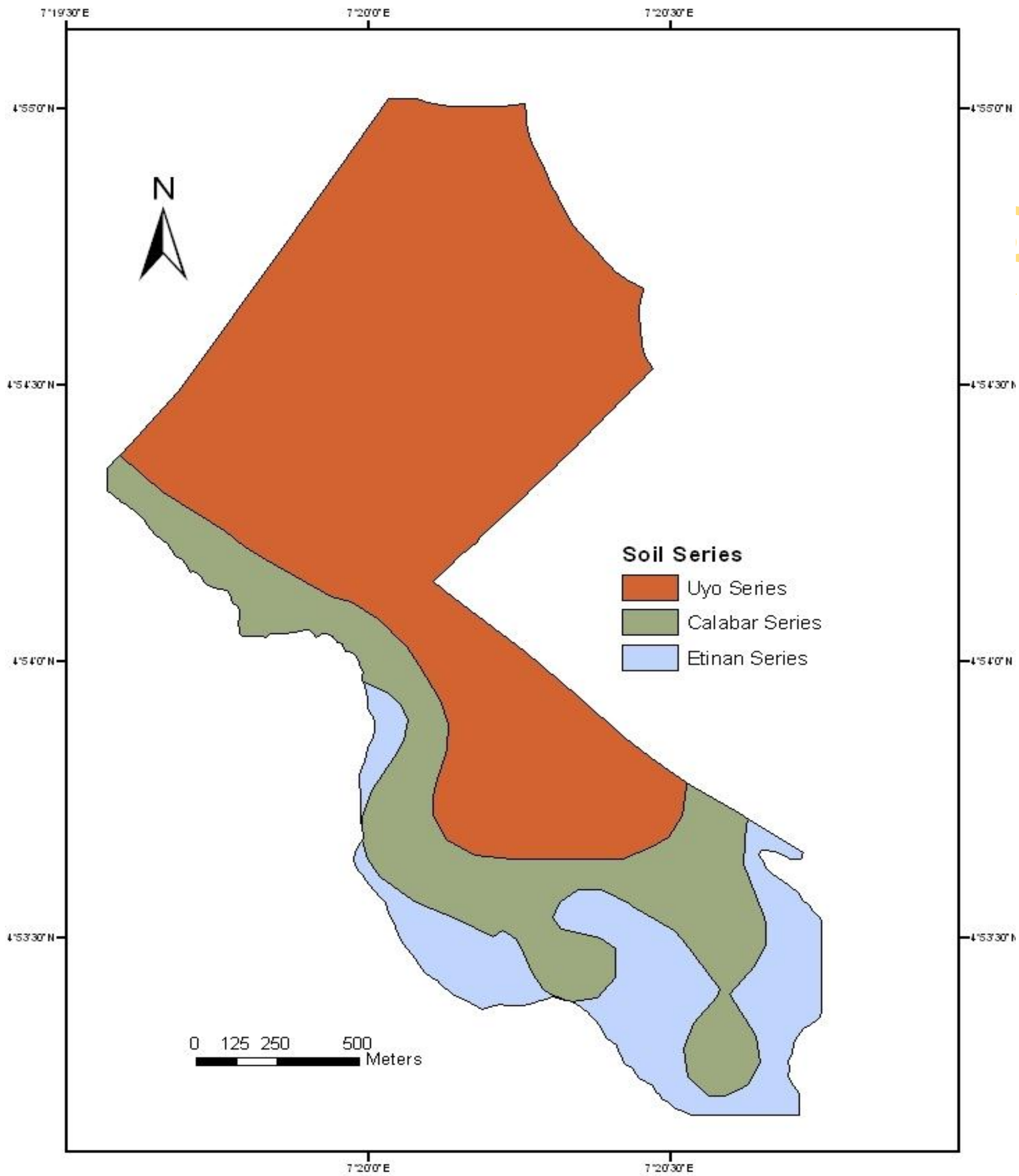


Figure 4.17: Soil map of Akwete study area obtained by interpolation analysis

Table 4.12: Comparison between soil maps obtained from conventional and point interpolation methods

Soil Series	Conventional soil map		Point Interpolation map	
	Total coverage area			
	(Ha)	(%)	(Ha)	(%)
Iyanomo				
Ahiara	152.55	7.43	123.03	5.92
Kulfo	406.54	19.59	547.07	26.34
Orlu	1254.80	60.42	1033.98	49.79
Alagba	262.78	12.65	372.07	17.92
Akwete				
Uyo	225.06	71.03	205.02	64.68
Calabar	48.30	15.20	69.70	21.99
Etinan	44.21	13.92	42.23	13.32

Table 4.13: Paired correlation and t test between conventional and point interpolated soil maps

	Paired Differences			t	df	Sig
Correlation (r)	Mean	Std. Deviation	Std. Error Mean			
.97**	5.2800	118.2990	44.7128	.118ns	6	.910

** Significant at 0.01 probability level

Table 4.13 revealed that the changes are only marginal when compared by t-test. With a t-value of .118 and a strong correlation (r = 0.97), the conventional survey method and the point interpolation technique agree strongly in mapping the soils of Iyanomo and Akwete study areas.

4.8 Land Suitability Evaluation for rubber

Following the FAO framework on land evaluation with the modified land qualities required by rubber defined by Sys (1985), further modifications were made to the land quality requirements by Sys *et al.*, (1993) and Van-Ranst *et al.* (1996). The land requirements for grouping land into suitability classes have been shown in Table 3.2 and 3.3. The matching of the land qualities of the various soil series with suitability evaluation (Non parametric) for rubber at Iyanomo is presented in Table 4.14. Alagba series and Orlu series were moderately suitable for rubber with climate (length of dry season) and soil subsurface texture as the identified limitations. The S2 class covers 73 % of the total land area. Kulfo and Ahiara series covering a total 26.93 % of the site were found to be marginally suitable for rubber cultivation. The main limitation is the subsoil texture. The land suitability evaluation at Akwete is presented in Table 4.15. Uyo Series was found to be marginally suitable (S3) with surface and subsurface soil texture as major limitations as well as soil fertility. Uyo and Calabar series are not suitable due to ratings of their textural properties that are below the requirements for rubber.

Parametric suitability classification (potential and actual) for rubber in Iyanomo and Akwete are presented in Tables 4.16 and 4.17 respectively. Actual suitabilities for Alagba and Orlu series are S2 (moderately suitable) with Suitability Index of 82.98 and 63.75 respectively while Kulfo and Ahiara series are marginally suitable with Suitability Index of 42.75 and 45.44 respectively.

Table 4.14: Land quality and Suitability (Non Parametric) classification for rubber at Iyanomo

Land characteristics*		Ahiara Series	Kulfo Series	Orlu Series	Alagba
	Months of Dry season	3-4 (S2)	3-4 (S2)	3-4 (S2)	3-4 (S2)
	Annual Rainfall	1952 (S2)	1952 (S2)	1952 (S2)	1952 (S2)
c	Max Temp. °C	32.72 (S1)	32.72 (S1)	32.72 (S1)	32.72 (S1)
	Min Temp. °C	23.55 (S1)	23.55 (S1)	23.55 (S1)	23.55 (S1)
	Relative Humidity (%)	78.2 (S1)	78.2 (S1)	78.2 (S1)	78.2 (S1)
	Effective soil depth (cm)	150-200 (S2)	>200 (S1)	>200 (S1)	>200 (S1)
s	Surface Texture	LS (S2)	LS (S2)	SL (S1)	L (S1)
	Subsurface texture	SL (S3)	SL (S3)	SCL (S2)	SC (S1)
	Gravel & Stones (%)	0 S1	0 S1	0 S1	0 S1
t	Altitude (m)	38 (S1)	42 (S1)	48 (S1)	51 (S1)
	Slope (%)	1-2 (S1)	3-4 (S1)	3 (S1)	2 (S1)
	Soil Reaction (Subsoil pH)	4.97 (S2)	4.59 (S2)	5.22 (S1)	5. 9 (S1)
	(ECEC) (c mol kg^{-1})	4.75 (S2)	3.08 (S2)	2.87 (S2)	7.23 (S1)
f	B. Saturation (%)	91.30 (S1)	92.21 (S1)	91.63 (S1)	83.46 (S1)
	Avail P (mg kg^{-1})	18.77 (S1)	21.11 (S1)	26.98 (S1)	24.04 (S1)
	Organic Carbon (g kg^{-1})	18.00 (S1)	19.40 (S1)	16.50 (S1)	30.00 (S1)
w	Drainage	Mod Well drained (S2)	Well Drained (S1)	Well Drained (S1)	Well Drained (S1)
	Depth to Water Table	150 - 200 (S2)	> 200 (S1)	> 200 (S1)	> 200 (S1)
suitability Class **					
	Actual	S3sw	S3sc	S2cs	S2c
	Potential	S3s	S3sc	S2c	S2c

*
c = climate
s = soil parameters
t = topography
f = soil fertility
w = wetness

**
S2 = moderately suitable
S3 = marginally suitable

Table 4.15: Non-Parametric Land Suitability classification for rubber at Akwete

	Land characteristics*	Uyo Series	Calabar Series	Etinan Series
	Months of Dry season	2-3 (S1)	2-3 (S1)	2-3 (S1)
	Annual Rainfall (mm)	2164.6 (S1)	2164.6 (S1)	2164.6 (S1)
c	Max Temp. °C	31.62 (S1)	31.62 (S1)	31.62 (S1)
	Min Temp. °C	19.23 (S1)	19.23 (S1)	19.23 (S1)
	Relative Humidity (%)	82.2 (S1)	82.2 (S1)	82.2 (S1)
	Effective soil depth (cm)	>200 (S1)	>200 (S1)	>200 (S1)
s	Surface Texture	LS (S3)	S (N1)	S (N1)
	Subsurface texture	SL (S3)	S (N1)	S (N1)
	Gravel & Stones (%)	0 S1	0 S1	0 S1
t	Altitude (m)	23 (S1)	19 (S1)	15 (S1)
	Slope (%)	1-2 (S1)	3 (S1)	3 (S1)
	Soil Reaction (Subsoil pH)	4.50 (S2)	4.80 (S2)	4.80 (S2)
	ECEC (cmol kg^{-1})	3.25 (S3)	5.48 (S2)	4.74 (S3)
f	B. Saturation (%)	48.31 (S1)	44.89 (S2)	34.81 (S2)
	Avail P (mg kg^{-1})	13.40 (S1)	3.40 (S1)	20.00 (S1)
	Organic Carbon (g kg^{-1})	18.00 (S1)	19.40 (S1)	16.50 (S1)
w	Drainage	Mod Well drained (S2)	Well Drained (S1)	Well Drained (S1)
	Depth to Water Table	> 200 (S1)	> 200 (S1)	150 - 200 (S2)
Suitability Class**				
	Actual	S3sf	NS	NS
	Potential	S3s	NS	NS

*
c = climate
s = soil parameters
t = topography
f = soil fertility
w = wetness

**
S2 = moderately suitable
S3 = marginally suitable
NS = not suitable

Table 4.16: Parametric suitability evaluation for rubber at Iyanomo study site

	Land characteristics	Ahiara Series	Kulfo Series	Orlu Series	Alagba Series
c	Months of Dry season	S12 (85)	S12 (85)	S12 (85)	S12 (85)
	Annual Rainfall	S11 (95)	S11 (95)	S11 (95)	S11 (95)
	Max Temp. ^{o}C	S11(100)	S11(100))	S11(100)	S11(100)
	Min Temp. ^{o}C	S11(100)	S11(100)	S11(100)	S11(100)
	Relative Humidity (%)	S11(100)	S11(100)	S11(100)	S11(100)
s	Effective soil depth (cm)	S12 (85)	S11 (100)	S11 (100)	S11 (100)
	Surface Texture	S12 (85))	S12 (85)	S11 (95)	S11 (100)
	Subsurface texture	S2 (60)	S2 (75)	S12 (85)	S11 (100)
	Gravel & Stones (%)	S11 (100)	S11(100)	S1 (100)	S1 (100)
t	Altitude (m)	S11 (100)	S11 (100)	S11 (100)	S11 (100)
	Slope (%)	S11 (100)	S11 (100)	S11 (100)	S11 (100)
f	Soil Reaction (Subsoil pH)	S2 (85)	S2 (85)	S11 (95)	S11 (95)
	(ECEC) (c mol kg^{-1})	S2 (75)	S2 (60)	S2 (75)	S12 (90)
	B. Saturation	S11 (100)	S11 (100)	S11 (100)	S11 (100)
	Avail P (mg kg^{-1})	S11 (100)	S11 (100)	S11 (100)	S11 (100)
	Organic Carbon (g kg^{-1})	S11 (100)	S11 (100)	S11 (100)	S11 (100)
w	Drainage	S12 (90)	S11 (100)	S11 (100)	S11 (100)
	Depth to Water Table	S11 (100)	S11 (100)	S11 (100)	S11 (100)
Aggregate suitability Class**					
	Actual	S3 (45.44)	S3 (42.75)	S2 (63.75)	S2 (82.98)
	Potential	S3 (49.78)	S3 (55.48)	S2 (76.50)	S2 (82.98)

*
c = climate
s = soil parameters
t = topography
f = soil fertility
w = wetness

**
S2 = moderately suitable
S3 = marginally suitable

Table 4.17: Parametric Land Suitability classification for rubber at Akwete

	Land characteristics	**Uyo Series**	**Calabar Series**	**Etinan Series**
	Months of Dry season	S11 (95)	S11 (95)	S11 (95)
	Annual Rainfall (mm)	S11 (100)	S11 (100)	S11 (100)
c	Max Temp. ^{o}C	S11 (100)	S11 (100)	S11 (100)
	Min Temp. ^{o}C	S11 (100)	S11 (100)	S11 (100)
	Relative Humidity (%)	S11 (100)	S11 (100)	S11 (100)
	Effective soil depth (cm)	S11 (100)	S11 (100)	S11 (100)
s	Surface Texture	S3 (40)	N (35)	N (35)
	Subsurface texture	S3(60)	N (35)	N (35)
	Gravel & Stones (%)	S11 (100)	S11 (100)	S11 (100)
t	Altitude (m)	S11 (100)	S11 (100)	S11 (100)
	Slope (%)	S11 (100)	S11 (100)	S11 (100)
	Soil Reaction (Subsoil pH)	S12 (85)	S12 (85)	S12 (85)
	(ECEC) (c mol kg^{-1})	S3 (60)	S12 (85)	S2 (75)
f	B. Saturation	S11 (100)	S2 (80)	S2 (80)
	Avail P (mg kg^{-1})	S11 (100)	S2 (75)	S11 (100)
	Organic Carbon (g kg^{-1})	S11 (100)	S11 (100)	S11 (100)
w	Drainage	S11 (100)	S12 (95)	S2(85)
	Depth to Water Table	S11 (100)	S11 (100)	S2 (85)
	Aggregate suitability Class			
	Actual	S3 (34)	NS (29.54)	NS (27.23)
	Potential	S3 (34.98)	S3 (31.45)	NS (28.13)

*
c = climate
s = soil parameters
t = topography
f = soil fertility
w = wetness

**
S2 = moderately suitable
S3 = marginally suitable
NS = not suitable

Potential suitability classes of the soil series are the same as their actual suitability classes with suitability indices (SIp) of 82.98, 76.50, 55.48 and 49.78 for Alagba, Orlu, Kulfo and Ahiara series respectively. Suitability ratings by the criteria of Van Ranst *et al.* (1996), is shown in Appendix VI. The suitability maps of Iyanomo and Akwete sites are presented in Figs. 4.18 and 4.19 respectively while the summary of the land suitability evaluation is presented in Table 4.18.

4.9 GIS Suitability evaluation.

The Boolean overlay showed that all the soil units at Iyanomo and Akwete are suitable for rubber cultivation; therefore, the map is not displayed. Interpolation of the point data were reclassified according to the requirements for rubber. Figs. 4.20 and 4.22 showed the reclassified interpolated maps based on ECEC, pH, Organic carbon and soil texture for Iyanomo and Akwete respectively. The suitability maps by weighted average overlay are presented in Figs. 4.21 and 4.23 for Iyanomo and Akwete respectively. All the soil units at Iyanomo and Akwete were moderately suitable in terms of ECEC content while they were very suitable with respect to soil pH and organic carbon contents. However, some of the soils were not uniform in their suitability with respect to surface texture. Since loamy sand to loam was mentioned as S1, the soils that fall into SCL and S are classified as S2. The overlay analysis assumes equal importance among the parameters considered therefore the areas overlain by sand at Akwete and areas with sandy clay loam at Iyanomo constituted the controlling factors in the suitability classification by weighted average overlay analysis. However, the GIS analysis took cognisance of each point on its own merit; therefore, suitability evaluation did not follow the delineations of soil series or mapping units at both Iyanomo and Akwete. The coverage of each suitability class is presented in Table 4.19.

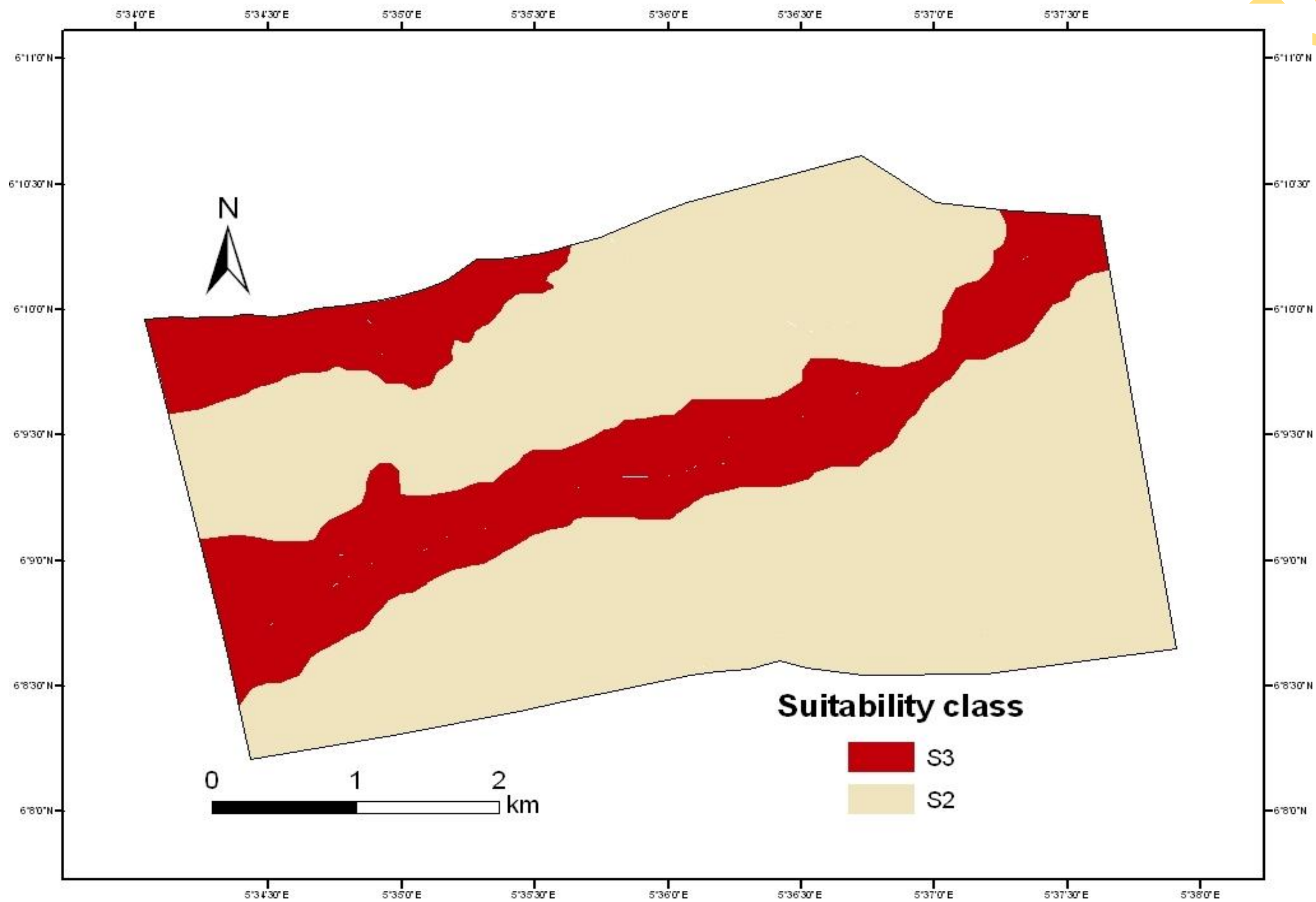


Fig. 4.18: Land Suitability map for rubber at Iyanomo

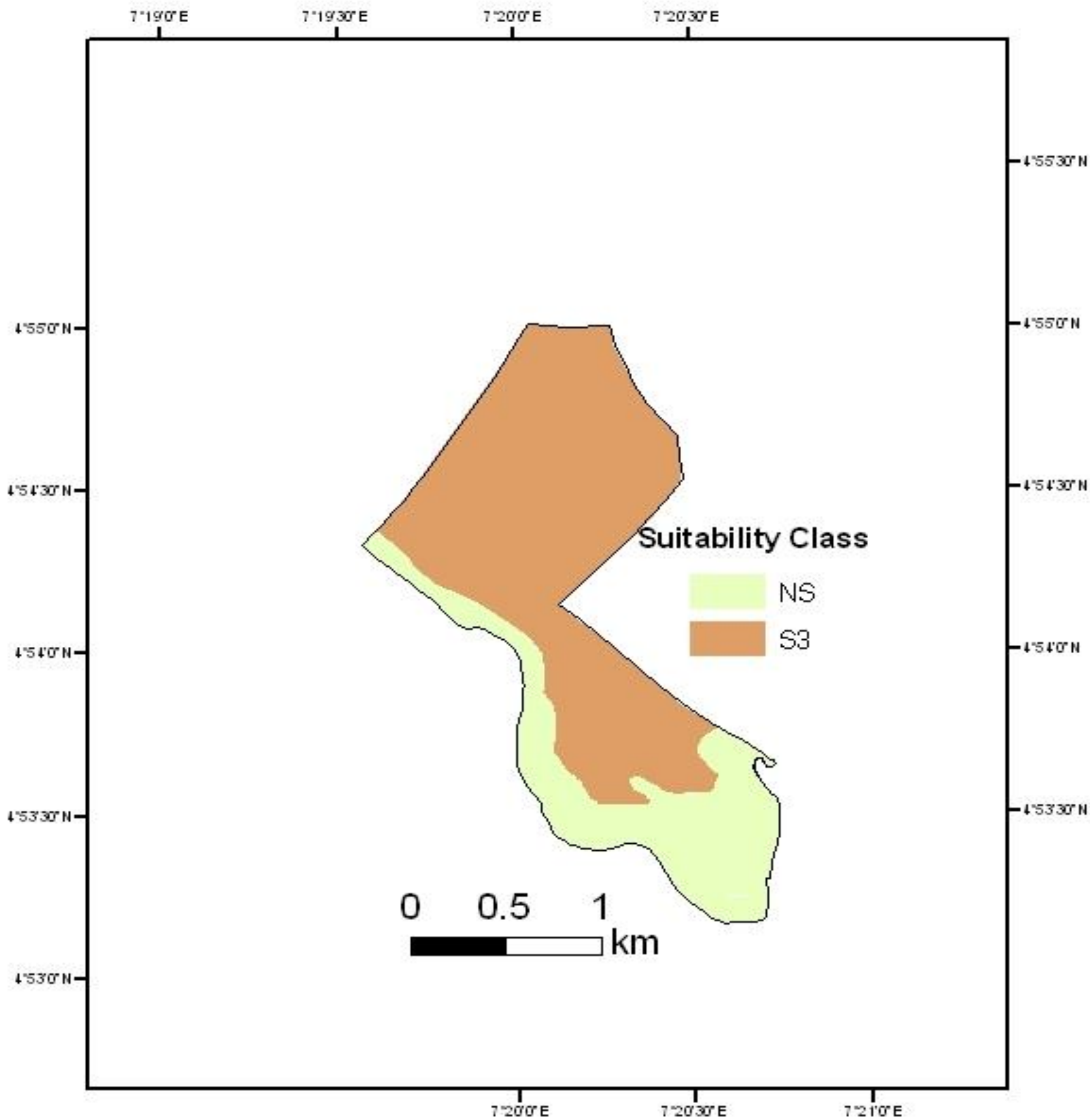


Figure 4.19: Land Suitability map for rubber at Akwete study area

Table 4.18: Summary of the suitability evaluation for rubber in Iyanomo and Akwete study areas

Location	Suitability classes					
	S11	S12	S2	S3	NS2	NS2
Iyanomo	-	-	1517.58	559.09	-	-
Akwete	-	-	-	225.06	92.51	-
Total	0.00	0.00	1517.58	559.09	92.51	0.00
Proportion (%)	0.00	0.00	63.66	32.89	3.88	0.00

Fig. 4.20: Suitability classifications of Iyanomo soils by selected soil parameters (ECEC, Organic Carbon, Soil pH and Soil texture)

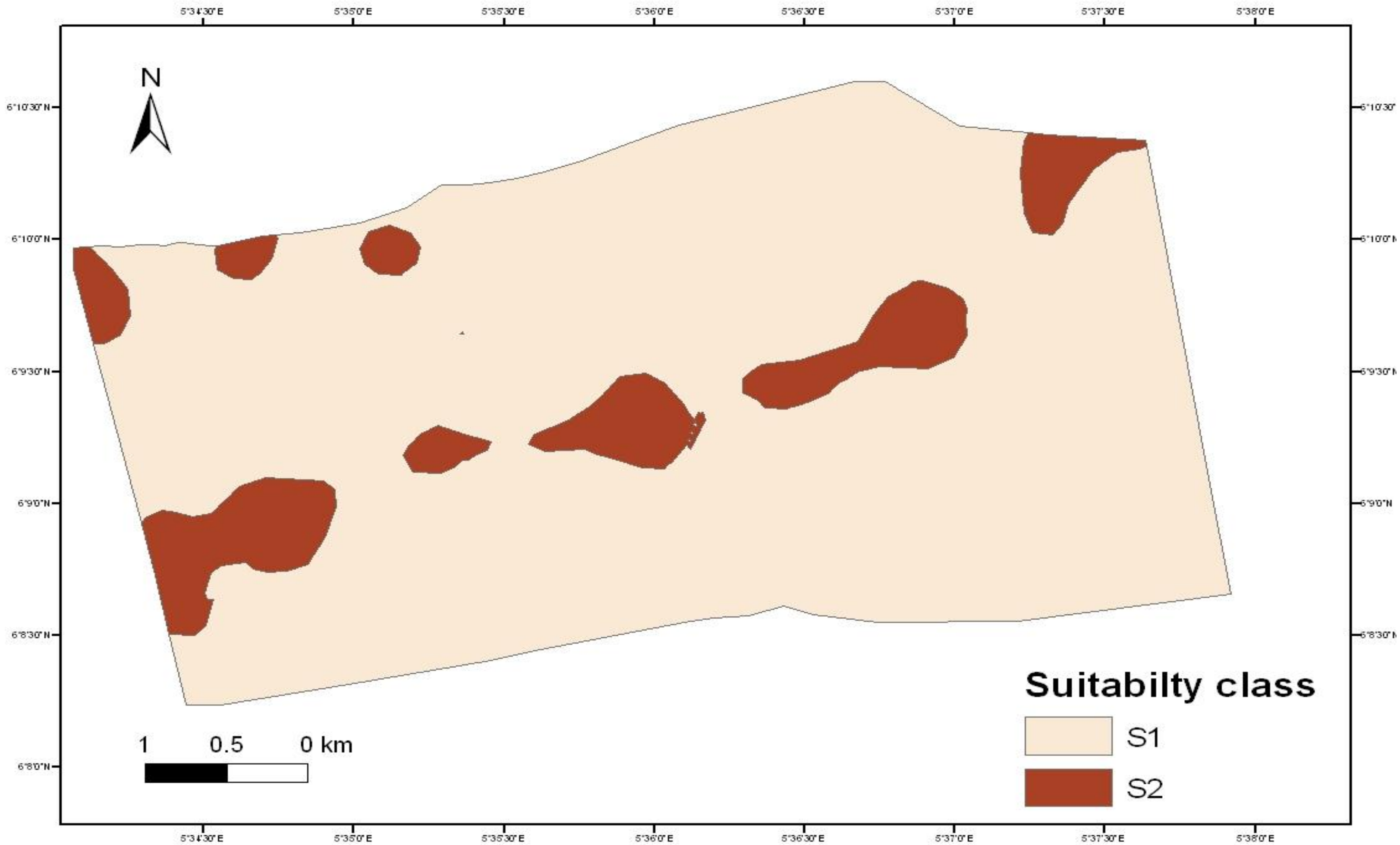


Fig. 4.21: Suitability map of Iyanomo by GIS weighted overlay analysis

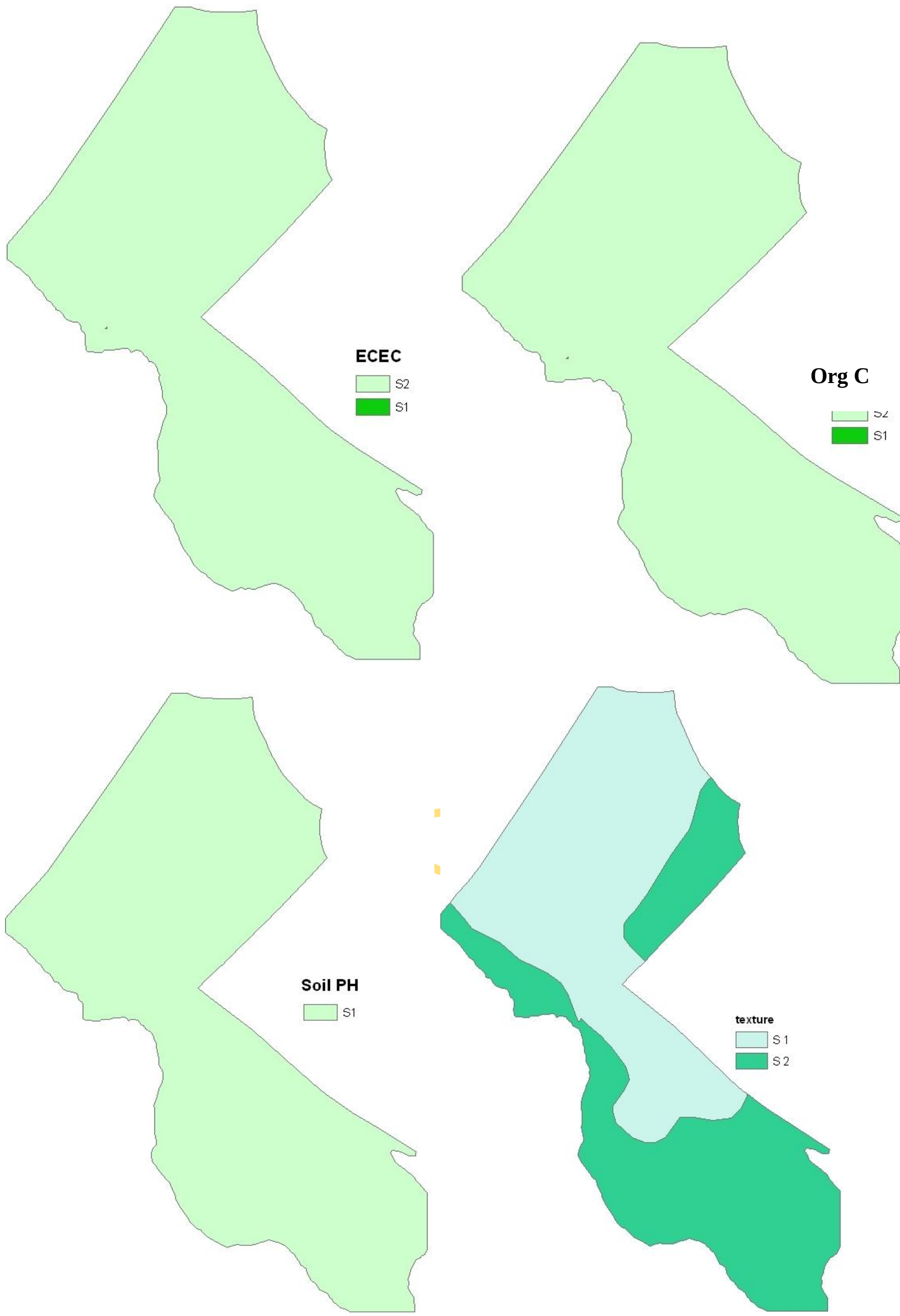


Fig 4.22: Suitability classification of Akwete soils by selected soil parameters (ECEC, Organic Carbon, Soil pH and Soil texture)

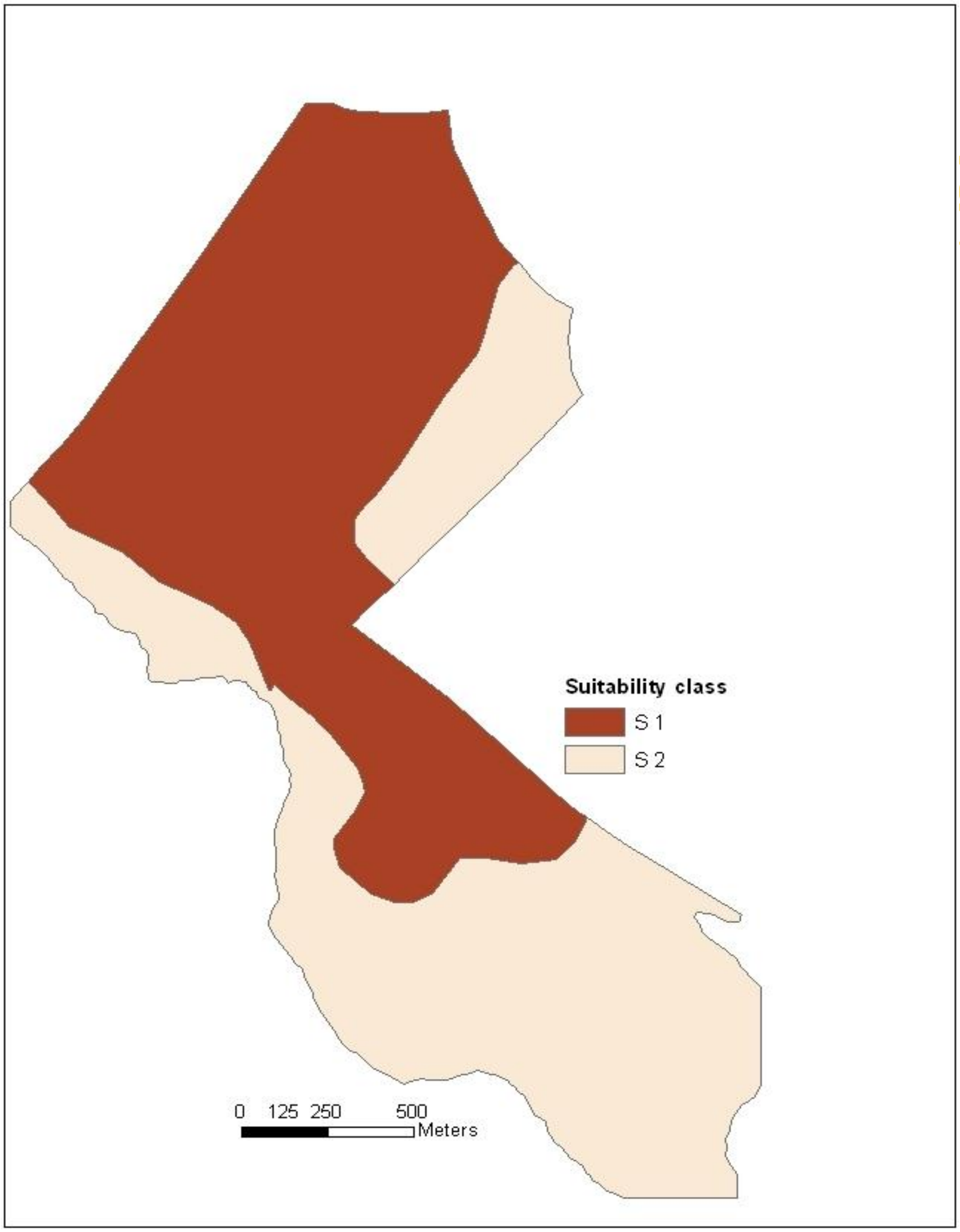


Figure 4.23: Suitability map of Akwete by GIS weighted overlay analysis

Table 4.19: Area coverage of GIS suitability analysis at Iyanomo and Akwete study sites.

Location	Suitability class			
	S1		S2	
	Area (ha)	Coverage (%)	Area (ha)	Coverage (%)
Iyanomo	1822.43	88.01	248.16	11.98
Akwete	167.41	52.76	149.45	47.24
combined	1989.84	83.35	397.61	16.65

4.10 Yield analysis

Rubber is a perennial tree crop. Though, the yield is obtained in either latex volume or coagula weight, the real value is calculated based on the dry rubber content of the latex or coagula. The yield of rubber depends on some factors which are mainly the genetic potential of each rubber clone, the age of the rubber, edaphic and climatic conditions and the management input. The genetic yield potentials of some popular rubber clones planted by rubber farmers in Nigeria are presented in Table 4.20. Genetic improvement programmes of Research Institutes have increased the yield potential of rubber from about 350 kg/ha/yr of landraces to about 2500 – 3000 kg/ha/yr in the improved rubber clones. It is also known that age is an important factor in the yield of tree crops irrespective of the clone. The yield trend of rubber inferred from a 33 years yield data consisting of many clones obtained from large rubber estates in Nigeria by Aigbekaen and Nwagbo (1999) is shown in Fig. 4.24. Rubber begins to yield maximally at about the eighth year of tapping which corresponds to the 14th or 15th year after planting and continued to yield maximally till the 19th year of tapping or 26th to 27th year after planting.

The actual yield and yield index from each of the soil classes are shown in Table 4.21. The age of the rubber at the point of data collection falls within the bracket of 14 – 30 years at which point rubber is expected to yield maximally at 100 % therefore the yield factor is 1. Table 4.22 shows the suitability ranking of the soil series, the actual yield and the yield index of rubber in the 2005/2006 and 2006/2007 cropping seasons

Table 4.20: Estimated yield potentials of some popular rubber clones planted in Nigeria

Rubber Clone	Origin	Estimated yield (Dry rubber) kg/ ha/ year	Authors
RRII 105	India	2490	Nazeer *et al.* (1989)
RRII 203	India	2537	Nazeer *et al.* (1989)
RRIM 600	Malaysia	2200	Marahukalam *et al.* (1992)
RRIM 623	Malaysia	1622	Saraswathyama *et al.* (2000)
RRIM 628	Malaysia	1019	Saraswathyama *et al.*(2000)
RRIM 701	Malaysia	1845	RRIM, (1992)
RRIM 703	Malaysia	1726	RRIM, (1983)
PB 28/59	Malaysia	2275	RRIM, (1992)
PB 217	Malaysia	1780	RRIM, (1992)
PB 233	Malaysia	2485	Saraswathyama *et al.* (2000)
PB 255	Malaysia	2391	Saraswathyama *et al.* (2000)
GT 1	Indonesia	1840	RRIM, (1970)
PR 261	Indonesia	1838	RRIM, (1992)
PR 255	Indonesia	2520	Rubber Board, (1997)
RRIC 100	Sri-Lanka	1754	Fernando, (1984)
NIG 800	Nigeria	2679	Omokhafe and Nasiru, (2005)
NIG 801	Nigeria	2229	Omokhafe and Nasiru, (2005)
NIG 802	Nigeria	2014	Omokhafe and Nasiru, (2005)
NIG 803	Nigeria	1167	Omokhafe and Nasiru, (2005)
NIG 804	Nigeria	1964	Omokhafe and Nasiru, (2005)
NIG 805	Nigeria	1944	Omokhafe and Nasiru, (2005)
Local (Unselected)	Landrace	361	RRIN, (1995)

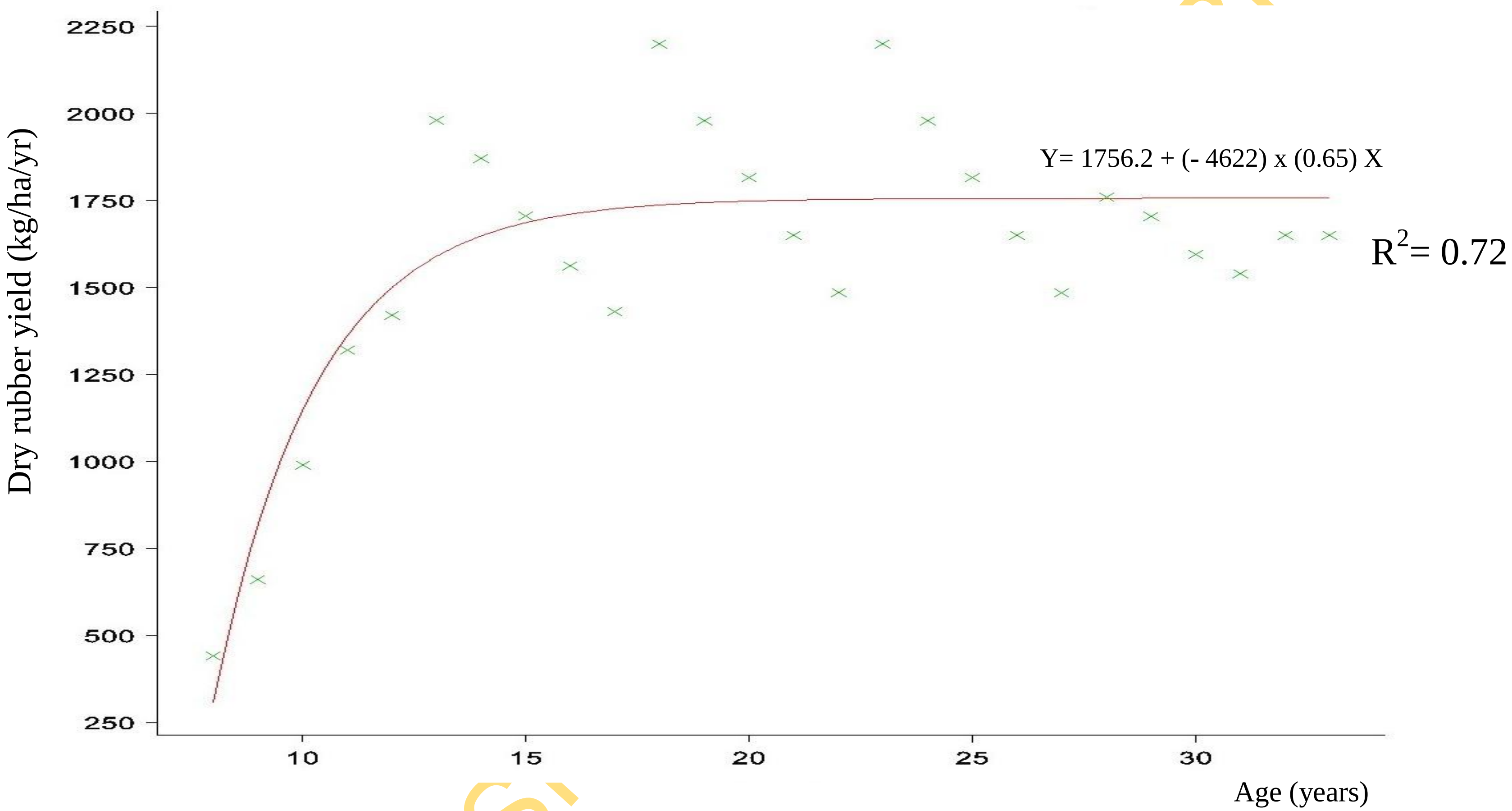


Fig. 4.24: Relationship between age and yield of rubber [Inferred from Aigbekaen and Nwagbo, (1999)]

Table 4.21: Actual yield and yield index of rubber at Iyanomo and Akwete in 2005/2006 and 2006/2007 seasons

Soil Series	Field/Location	Rubber clone	Actual yield (kg/ha/year)		Age factor	Yield Index	
			2005/2006	2006/2007		2005/2006	2006/2007
			Iyanomo				
Ahiara	Iyanomo L12	NIG 800	2124.67	2018.72	1	79.28	75.33
Kulfo	Iyanomo M16	RRIM 600	2728.97	2182.14	1	124.04	99.18
Orlu	Iyanomo OP8	GT 1	2295.38	2513.19	1	109.37	136.58
Alagba	Iyanomo QR 16	RRIM 628	2012.50	1988.34	1	197.49	195.09
			Akwete				
Uyo	Akwete	GT1	1683.09	1439.26	1	91.47	78.21
Calabar	Akwete	GT1	1616.34	1219.80	1	87.83	66.25
Etinan	Akwete	GT1	1724.03	1533.58	1	93.69	71.41

Table 4.22: Ranking of soil series and yield of rubber at Iyanomo and Akwete

Soil Series	Non-parametric		Parametric		Actual yield		Yield index	
	Actual	Potential	Actual	Potential	2005/2006	2006/2007	2005/2006	2006/2007
				Iyanomo				
Ahiara	4	4	4	4	3	3	7	5
Kulfo	3	3	3	3	1	2	2	3
Orlu	2	2	2	2	2	1	3	2
Alagba	1	1	1	1	4	4	1	1
				Akwete				
Uyo	5	5	5	5	6	6	5	4
Calabar	7	7	6	6	7	7	6	7
Etinan	6	6	7	7	5	5	4	6

4.11 Relationship between land class and rubber yield

The relationship between the land class from parametric and non-parametric land classification are shown in Table 4.23. The correlation co-efficient values ranged from perfect correlation (r = 1) among the land classes to 4.29 ns in the yield parameters. There were positive and highly significant correlations in the rankings of the soil series by both actual and potential evaluation procedures. There were also high correlations between the yield index and the evaluation procedures in 2006/2007 cropping season. The actual yields that did not take into consideration the genetic yield potentials of rubber were not significantly correlated with the rankings of the soil series in both seasons.

4.12 Relationship between soil parameters and rubber yield

The correlation matrix between soil parameters and rubber yield are shown in Appendix VIII. All the soil parameters of the profile and surface soil samples were correlated with each other and with the rubber yield to check the relationship between individual soil characteristic and rubber yield. Those parameters that are significant to the dry rubber yield or other soil variables were selected for further analysis and are presented in Table 4.25. Surface bulk density and K significantly affected rubber yield negatively (r = - .679 ** and - .506 * respectively) at 0.01 and 0.05 probability levels. On the other hand, surface soil porosity (0-15 cm) and subsoil porosity (15-30 cm) positively affected the yield of rubber (r = .683 ** and .500* respectively).

Table 4.23: Spearman's rank correlation co-efficient among land classification procedures and rubber yield

	Non Parametric		Parametric		Actual rubber yield		Rubber yield index	
	Actual	Potential	Actual	Potential	2005/2006	2006/2007	2005/2006	2006/2007
	1	2	3	4	5	6	7	8
1	1.00							
2	1.00**	1.00						
3	.964**	.964**	1.00					
4	.964**	.964**	1.00**	1.00				
5	.714ns	.714ns	.643ns	.643ns	1.00			
6	.750ns	.750ns	.679ns	.679ns	.964**	1.00		
7	.714ns	.714ns	.643ns	.643ns	.464ns	.429ns	1.00	
8	.964**	.964**	.929**	.929**	.607	.643ns	.786*	1.00

*, ** correlation significant at 0.05 and 0.01 levels respectively

Table 4.24: comparison between suitability and yield indices of the soils of Iyanomo and Akwete in the 2005/2006 and 2006/2007 cropping seasons

Soil Name	suitability class (Sys 1985)		Suitability Class (Parametric)		Suitability class (Van Ranst *et al.*, 1999)		Yield index/class 2005/2006		Yield index/ class 2006/2007	
	Actual	Potential	Actual	Potential	Actual	Potential	index	class	index	class
					Iyanomo					
Ahiara	S3	S3	S3	S3	S2	S2	79.28	S1	75.33	S1
Kulfo	S3	S3	S3	S3	S2	S1	124.04	S1	99.18	S1
Orlu	S2	S2	S2	S2	S2	S1	109.37	S1	136.58	S1
Alagba	S2	S2	S2	S2	S2	S1	197.49	S1	195.09	S1
					Akwete					
Uyo	S3	S3	S3	S3	S2	S2	91.47	S1	78.21	S1
Calabar	NS	NS	NS	S3	S3	S2	87.83	S1	66.25	S1
Etinan	NS	NS	NS	NS	S2	S2	93.69	S1	71.41	S2

Table 4.25: Correlations matrix of selected relevant soil parameters to rubber yield

	Sand	B/density 0-15 cm	B/ density 15-30 cm	Porosity 0-15 cm	Porosity 15-30cm	K	Base saturation	Rubber Yield
Sand	1.000	-.163	-.001	.150	-.012	-.551*	.324	.303
B/ density 0-15 cm		1.000	.882**	-.998**	-.881**	.031	-.127	-.679**
B/ density 15-30 cm			1.000	-.884**	-.994**	-.137	-.019	-.490
Porosity 0-15 Cm				1.000	.884**	-.026	.142	.683**
Porosity 15-30					1.000	.140	-.017	.500*
K						1.000	-.027	-.506**
Base saturation							1.000	.216
RubberYield								1.000

* Significant at the 0.05 level, ** Significant at the 0.01 level

The direct and indirect contributions of the individual soil parameters to the observed rubber yield were determined by path analysis. The Path coefficient analysis is presented in Table 4.26. It is interesting to note that though the correlation between subsoil bulk density and yield was not significant, the direct effect of subsoil bulk density (1.482) is higher than all other variables but it was affected by the negative indirect effects that subsoil porosity (-1.409) and surface porosity (- 0.346). Among the variables considered, subsoil porosity, surface porosity, subsurface bulk density and base saturation had direct positive influences on the yield or other variables while sand, surface bulk density and K had negative direct effects. The residual effect showed that 24.36 % variables were not accounted for by the Path coefficient (Table 4.26)

4.13 Relationship between weather parameters and rubber yield

The relationships between weather variables and rubber yields over a ten year period were also tested with correlation and path analysis as shown in Tables 4.27 and 4.28 respectively. Most of the weather parameters showed a negative correlation with rubber yield. Rainfall has the highest negative correlation (r = - 340**). This is probably due to the loss of many tapping days and latex wash-off during the years of heavy rainfall. Relative humidity (RH) at 0900 and 1500 hours also correlated negatively with yield. This is as a result of the close relationship between rainfall and RH. The path analysis however reveals that maximum temperature had the highest direct effect (0.666) with relative humidity also having positive direct effects.

Table 4.26: Direct (Diagonal) and indirect effects of relevant soil characteristics to rubber latex yield (kg/ha)

Soil Characteristics	Sand	B/density 0-15 cm	B/ density 15-30 cm	Porosity 0-15 cm	Porosity 15-30cm	K	Base Saturation
Sand	**-0.175**	0.028	0.0001	-0.026	0.002	0.096	-0.057
B/ density 0-15 cm	0.050	**-0.330**	-0.291	0.330	0.291	-0.01	0.042
B/ density 15-30 cm	-0.001	1.31	**1.482**	-1.310	-1.470	-0.20	-0.028
Porosity 0-15 Cm	0.058	-0.39	-0.346	**0.392**	0.346	-0.010	0.056
Porosity 15-30	-0.017	-1.24	-1.409	1.253	**1.418**	0.198	-0.024
K	0.314	-0.02	0.078	0.015	-0.08	**-0.571**	0.015
Base saturation	0.068	-0.03	0.004	0.030	-0.0036	0.006	**0.212**
‘r’ with yield	0.303	-0.679**	-0.49	0.683**	0.500*	-.506**	0.216

Residual effect = 24.36, ** significant at the 0.01 level * significant at the 0.05 level

Table 4.27: Correlations matrix of weather variables to rubber yield over a ten year period at Iyanomo

	Rainfall	Evaporation	Wind Speed	Max temp	Min temp	RH 09[§]	RH 15[§§]	Rubber Yield
Rainfall	1.000	-.436**	.103	-.708**	-.372**	.668**	.790**	-.340**
Evaporation		1.000	.388**	.697**	.519**	-.466**	-.541**	.081
Wind Speed			1.000	.232*	.346**	-.059	-.005	-.139
Max temp				1.000	.665**	-.806**	-.883**	.167
Min temp					1.000	-.202*	-.332**	-.105
RH 09						1.000	.915**	-.245**
RH 15							1.000	-.261*
Rubber Yield								1.000

§ RH 09 = relative humidity at 0900 hrs, §§ RH 15 = relative humidity at 1500 hours
** Correlation is significant at the 0.01 level * Correlation is significant at the 0.05 level

Table 4.28: Direct (Diagonal) and indirect effects of weather variables to rubber latex yield (kg/ha) at Iyanomo

	Rainfall	Evaporation	Wind speed	Max temp	Min temp	RH 09	RH 15
Rainfall	**-0.466**	0.203	-0.048	0.330	0.173	-0.311	-0.368
Evaporation	0.008	**-0.020**	-0.008	-0.014	-0.101	0.009	0.011
Wind speed	-0.004	-0.016	**-0.041**	-0.009	-0.014	0.002	0.0002
Max temp	-0.411	0.464	0.154	**0.666**	0.443	-0.537	-0.588
Min Temp	0.202	-0.281	-0.187	-0.360	**-0.542**	0.109	0.180
RH 09	0.084	-0.059	-0.007	-0.101	-0.025	**0.126**	0.115
RH 15	0.307	-0.210	-0.002	-0.343	-0.129	0.356	**0.389**
‘r’ of rubber yield	-0.340**	0.081	-0.139	0.167	-0.105	-0.245**	-0.261*

Residual effect = 42.67 ***** Correlation is significant at the 0.05 level, ****** Correlation is significant at the 0.01 level

4.14 Effect of rubber and related Landuse types on soil properties

The effects of rubber cultivation and some associated land use types including young rubber aged 3-10 years old (Plate 4.5), middle-aged rubber of 12-20 years old (Plate 4.6), old rubber above 25 years old (Plate 4.7), Fallow/ forest (Plate 4.8) and arable farming (Plate 4.9) land use types on surface soil properties at the Iyanomo study area are presented in Tables 4.29 and 4. 30.

There were no significant changes in Available P, Ca, Na, K, Cu Mn and Zn (Table 4.29). However, soil pH, organic carbon exchangeable acidity, ECEC, Base saturation and Fe showed some significant differences among the land use types considered. The lowest soil acidity (highest pH) of 4.7 was obtained at the young rubber plots while the lowest pH of 4.41 was obtained in the old rubber plots. The pH values obtained from the old rubber compared favourably with the 4.48 value obtained from the forest soils. While the highest organic carbon of 33.4 g kg^{-1} was obtained in the fallow, Ca and exchangeable acidity and Mg are highest in the fallow/forest land use types with 2.40, 1.68 and 0.94 cmol kg^{-1} respectively but are not significantly different from the 1.95, 1.19 and 0.91 cmol kg^{-1} of Ca, exchangeable acidity and Mg obtained at the old rubber plantations. Whereas Arable farm had the lowest values of 1.77, and 0.55 cmol kg^{-1} of Ca and Mg respectively, the juvenile rubber had the lowest exchangeable acidity with 0.6 cmol kg^{-1}.

Plate 4.5: A young rubber plantations aged three (4) years old at Iyanomo

Plate 4.6: Middle aged rubber plantations aged 12 years old at Iyanomo

Plate 4.7: Old rubber plantation aged 32 years.

Plate 4.8: Reference forest at Block M9 Iyanomo depicting the fallow/ forest land use type

Plate 4.9: Arable cropping land use type with yam, cassava, plantain and cowpea mixed cropping system

Table 4.29: Effects of different landuse types associated with rubber cultivation on the chemical properties of the surface soils

Landuse/ rubber age	pH	Avail P	Org C	Exch acidity	Ca	Mg	Na	K	ECEC	B sat	Fe	Cu	Mn	Zn
	(H_2O)	(mg kg^{-1})	g kg^{-1}	←		cmol kg^{-1}			→	(%)	←	Mg kg^{-1}		→
Young rubber (3-10 yrs)	4.7^{a}	13.3	18.5^{bc}	0.6^{bc}	2.00	0.80^{ab}	0.29	0.40	4.29^{b}	86.6^{ab}	98.0^{bc}	7.86	204.80	29.6
Middle aged rubber (12-20 yrs)	4.5^{abc}	15.6	29.4^{a}	0.42^{c}	1.95	0.81^{ab}	0.26	0.59	3.83^{b}	90.4^{a}	91.5^{c}	7.77	165.6	25.6
old rubber (>25 yrs)	4.41^{abc}	18.5	29.7^{a}	1.19^{ab}	2.02	0.91^{a}	0.20	0.26	5.34^{ab}	95.0^{a}	105.4^{abc}	7.80	168.0	31.9
Fallow/Forest	4.48^{abc}	16.5	33.4^{a}	1.46^{a}	2.40	0.97^{a}	0.20	0.61	5.99^{a}	75.7^{bc}	118.9^{ab}	8.37	175.8	32.5
Arable Farm	4.30^{c}	7.1	27.2^{ab}	1.16^{ab}	1.77	0.55^{b}	0.25	0.38	4.46^{b}	73.7^{c}	111.0^{abc}	7.13	188.7	30.2
SE of Mean	0.12	5.72	4.04	0.30	0.26	0.14	0.12	0.24	0.64	5.19	10.06	0.68	22.05	5.15

Means bearing similar alphabets are not significantly different by DMRT (p = 0.05).

Table 4.30: Effects of different landuse types associated with rubber cultivation on selected physical and biological characteristics of the surface soils

Landuse/rubber age	Sand	Silt	Clay	Bulk density	Total Porosity	bacterial count	fungal count
		g kg^{-1}		g cm^{-3}	(%)		
Young rubber (3-10 yrs)	853.0	8.50	138.8	1.16^{ab}	55.41^{ab}	3.8^{c}	6.0
Middle aged rubber (12-20 yrs)	814.0	5.60	180.3	1.09^{ab}	58.74^{a}	10.0^{c}	9.8
Old rubber (>25 yrs)	824.0	9.90	166.1	1.14^{b}	56.85^{ab}	41.3^{b}	6.0
Fallow/Forest	799.0	7.30	193.6	1.10^{b}	58.49^{a}	84.1^{a}	5.7
Arable Farm	799.0	10.60	190.3	1.13^{a}	57.31^{b}	6.0^{c}	10.7
SE of Mean	35.0	6.15	34.17	0.43	1.65	0.013	0.064

Means bearing similar alphabets are not significantly different by DMRT (p = 0.05).

The physical and microbial characteristics (Table 4.30) showed that the land use types did not bring any significant change in soil textural properties (sand silt and clay). The variation were however higher in sand and silt with standard error values of ±35.0 and ±34.17 respectively. Also, the lowest bulk density (BD) and by implication the highest total porosity was obtained in middle aged rubber with 1.09 kg m^{-3} and 58.74 % for BD and total porosity respectively.

Microbial counts in the Iyanomo study area showed that the forest soils are more favourable for bacterial growth with a highly significant 84.1 x 10^3 count**.**

4.15 Indigenous Knowledge of land evaluation for rubber

The characteristics of the rubber farmers in the three farm settlements namely: Mbiri, Utagbuno and Iguoriakhi are shown in Table 4.31

4.15.1 Demographic characteristics of rubber farmers

Analysis of the personal characteristics of the rubber farmers reveals that rubber production in this part of the country is almost exclusively for men; with 100 % male recorded at Mbiri, Utagbuno and Iguoriakhi farm settlements. This is probably a cultural issue that deprives women of direct land ownership in this part of Nigeria.

Table 4.31: Characteristics of the rubber farmers in three farm settlements

Characteristics	Number of respondents (%)			
	Mbiri	Itagbuno	Iguoriakhi	Combined
Gender				
Male	100	100	100	100
Female	0	0	0	0
Age				
24-35	9.6	0.0	0.0	2.9
36-45	19.1	3.6	30.0	15.7
46-55	32.9	14.3	30.0	24.4
56-65	33.4	42.9	25.0	34.6
65 and above	4.8	21.4	15.0	14.3
No response	0.0	17.9	0.0	7.2
Marital Status				
Single	0.0	0.0	0.0	0.0
Married	98.6	96.4	100.0	97.1
divorced	0.0	0.0	0.0	0.0
Widowed	4.8	0.0	0.0	1.4
No response	0.0	3.6	0.0	1.4
Education				
No formal ducation	4.8	3.6	5.0	2.9
Adult Education	0.0	7.1	5.0	4.3
Vocational training	19.0	28.6	15.0	1.4
Primary	71.4	57.1	45.0	58.0
Secondary	19.0	28.6	25.0	24.6
Post Secondary	4.8	3.6	15.0	7.2
Primary Occupation				
Rubber farming	72.4	90.8	69.5	80.63
Others	27.6	7.2	15.0	

In terms of age distribution, more than half of the rubber farmers in the three farm settlements are well above 50 years with 34.60 % between the ages of 55-65 while 14.30 % are above 65 years. At Utagbuno, more than 60 % of the farmers are 55 years and above. Most (97.1 %) of the rubber farmers are married. Apart from a farmer who did not respond to the marital status question at Utagbuno and one respondent who is a widower, at Mbiri, all other respondents from the three farm settlements reported that they are married. The educational level showed that only 2.90 % of respondents have no formal education, signifying that the farmers are mostly literate. Though only 7.2 % overall had post secondary education (some of which are actually retired Civil Servants or Teachers), it is commendable that the rubber farmers are over 90% literate having one form of training or the other. About 80.63 % of the total respondents have rubber farming as their primary occupation. At Utagbuno, about 90 % of the respondents primarily engage in rubber cultivation, meaning that many households in the study areas make their likelihood through rubber cultivation.

4.15.2 Indigenous land evaluation methods

Land suitability determination among rubber farmers and the perceived effect of soil and land systems on rubber yield is presented in Table 4.32. This classification is not limited to rubber alone as many of the farmers also practice arable farming inside and outside their rubber plantations. Many of the percentage responses may not add up to 100 because some of the respondents employed more than two methods to classify the suitability of their lands for rubber. About 48.50 % of the farmers rely on visual appraisal to determine the suitability of their lands for rubber and other agricultural uses. The highest number of respondents (57.10 %) relying on visual appraisal is from Utagbuno while 42.90% and 40 % use this method at Mbiri and Iguoriakhi respectively.

Table 4.32: Methods of determining land suitability and perceived effects of soil on rubber yield among rubber farmers

	Number of respondents (%)			
Methods	Mbiri	Itagbuno	Iguoriakhi	Combined
Visual appraisal	42.9	57.1	40.0	48.5
Indicator plants	19.0	39.3	20.0	28.4
Vegetation vigour	28.6	50.0	80.0	52.2
Cropping history	9.5	17.9	0.0	10.1
Recommendation from agencies	0.0	3.6	25.0	13.9
Others	6.9	7.1	10.0	6.81
Soil type				
Sandy	9.5	0.0	5.0	4.3
Loamy	76.2	89.3	90.0	85.5
Clayey	14.3	3.6	0.0	5.8
Gravelly	0.0	0.0	0.0	0.0
Swampy	0.0	7.1	0.0	2.9
Others	0.0		5.0	1.4
Perceived effect of soil on rubber yield				
Positive effect	47.6	50.0	55.0	50.7
No effect	47.6	46.4	45.0	46.4
No response	4.8	3.6	0.0	2.9

Use of indicator plants is also higher at Utagbuno (39.30%) compared with the 19 % and 20 % at Mbiri and Iguoriakhi respectively. The use of indicator plants and visual appraisal require some experience. During the follow-up interview it was discovered that some of the indicator plants that may indicate a good soil are *Chromolaena odorata* and *Andropogon gayanus* (which they refer to as elephant grass), while *Imperata cylindrical* (spear grass) is indicative of a poor soil. Majority of the farmers at Iguoriakhi (80 %) estimate the suitability of land for rubber through the vigour of the native vegetation. According to one of the farmers, it is logical to believe that where other trees that look like rubber are growing well, the land will be able to support rubber. Very few farmers rely on cropping history (17.9 % at Utagbuno). It was only in Iguoriakhi that an appreciable number of the farmers obtain advice from some agricultural agencies. While many of the farmers categorized their soils (surface soils) as loamy, spot checks on field texture by hand feel method at Mbiri and Iguoriakhi showed that the surface soils range from loamy sand to sandy loam. However, about half of the farmers believe that rubber yield (latex and coagula) is not related to the nature of the land. Table 4.33 shows some selected laboratory analysis of soil samples collected from the catenary positions in the farmers' farms.

Table 4.33: Selected physical and chemical properties (0-20cm) of some soils at Mbiri and Iguoriakhi with the fertility indication by farmers.

Farm settlement	Catenary position	Farmers description	Fertility* class	sand	Silt	clay	Texture	pH	Org C	Total N	Available P
					g kg^{-1}			(H_20)	g kg^{-1}		mg kg^{-1}
Mbiri	Upper slope	Red soil/ loamy	Good	828.4	21.2	150.4	SL	4.7	2.2	0.57	6.2
	Middle slope	Red soil/ loamy	Fair	836.2	2.2	156.0	SL	4.5	7.9	1.25	5.6
	Lower slope	Brown soil / sandy	Fair	846.2	2.2	146.0	LS	5.2	1.1	0.44	5.6
Iguoriakhi	Upper slope	Black soil/ loamy	Very good	810.2	3.4	186.4	SL	4.7	20.4	2.40	18.18
	Middle slope	Black soil/ loamy	Good	840.8	40.6	118.6	LS	4.8	7.9	1.25	4.4
	Lower slope	White sand	good	862.4	12.8	124.8	LS	4.8	11.3	1.00	12.51

***** Fertility class as described by farmers

4.15.3 Soil fertility management

Majority of the local rubber farmers rely predominantly on the recycling process of natural fallow to rejuvenate their soil fertility. In the three locations studied, 72.5 % have applied fertilizers at one stage or the other in their rubber farms (Table 4.34). This comprised of 38 % at Mbiri, 92.9 % at Utagbuno and 80 % at Iguoriakhi. Almost all the respondents that applied fertilizer applied NPK in the three study sites. While the awareness and availability of chemical fertilizers were identified as major constraints to fertilizer application practices by many farmers, the interview showed that many of them actually applied other forms of manure such as household wastes, wood ash and poultry droppings as soil amendments which they did not regard as fertilizers at the time of filling the questionnaires. Interview revealed that those who are educated and seemed to have more access to fertilizer supply, apply too much chemical (NPK) fertilizer relative to the nutrient demand of the rubber and accompanying subsistence crops. Consequently, some practices in subsistence plots may result in excessive macronutrient levels without consideration of the possibility of nitrate and phosphate pollution. In all the farm settlements, 73.9 % of rubber farmers agreed that there was an improvement on their rubber yield as a result of fertilizer application. The highest was at Utagbuno (96.4 %). On rate of improvement in the yield of rubber due to fertilizer application, 58% of the rubber farmers showed no response (Consisting mostly of those who have never applied Chemical fertilizer in the past), majority of the farmers (24.60 %) observed a range of 15-30 % increase in their rubber yield as a result of fertilizer application.

Table 4.34: Soil fertility management practices among the rubber farmers, effects on rubber yield in the three farm settlements

	Mbiri	Itagbuno	Iguoriakhi	Combined
	Number of respondents (%)			
Fertilizer application				
Applied fertilizer	38.1	92.9	80.0	72.5
No Fertilizer	61.9	3.6	20.0	26.1
Fertilizer Type				
NPK	38.1	92.9	80.0	72.5
Rock Phosphate	-	-	-	-
Organic Manure	-	-	-	-
Urea	-	-	-	-
MOP	-	-	-	-
SSP	-	-	-	-
Others	-	-	-	-
Effect of fertilizer on yield				
Improved	38.1	96.4	80.0	73.9
No improvement	4.8	-	-	1.4
No response	57.1	3.6	20.0	24.6
Rate of improvement due to fertilizer				
0-5 %	-	-	-	-
5-15%	-	14.3	5.0	7.2
15-30 %	28.6	25.0	20.0	24.6
30-50%	-	10.7	20.0	10.1
Above 50%	-	-	-	-
No response	71.4	50.0	55.0	58.0
Other fertility management practises				
Animal dung	-	7.1	5.0	4.4
Liming	-	-	-	-
Household waste	-	7.1	-	2.9
Intercropping	33.3	64.3	15.8	41.2
Cover cropping	4.8	17.9	63.2	17.6

The impact of some recommending agencies on the soil fertility management decision of the farmers in the three farm settlements are shown in Fig. 4.29. Few farmers at Utagbuno and Iguoriakhi felt a minimal impact of the ADP in their soil fertility management. Majority of the farmers relied on the recommendations of the Tree Crops Unit (TCU) of the Federal Ministry of Agriculture and Natural Resources to source for advice on fertilizer application. Other sources of advice listed by farmers are friends, radio jingles and some Non Governmental Organisations (NGOs) around their vicinity. Many of the farmers are not aware of fertilizer recommendations for rubber.

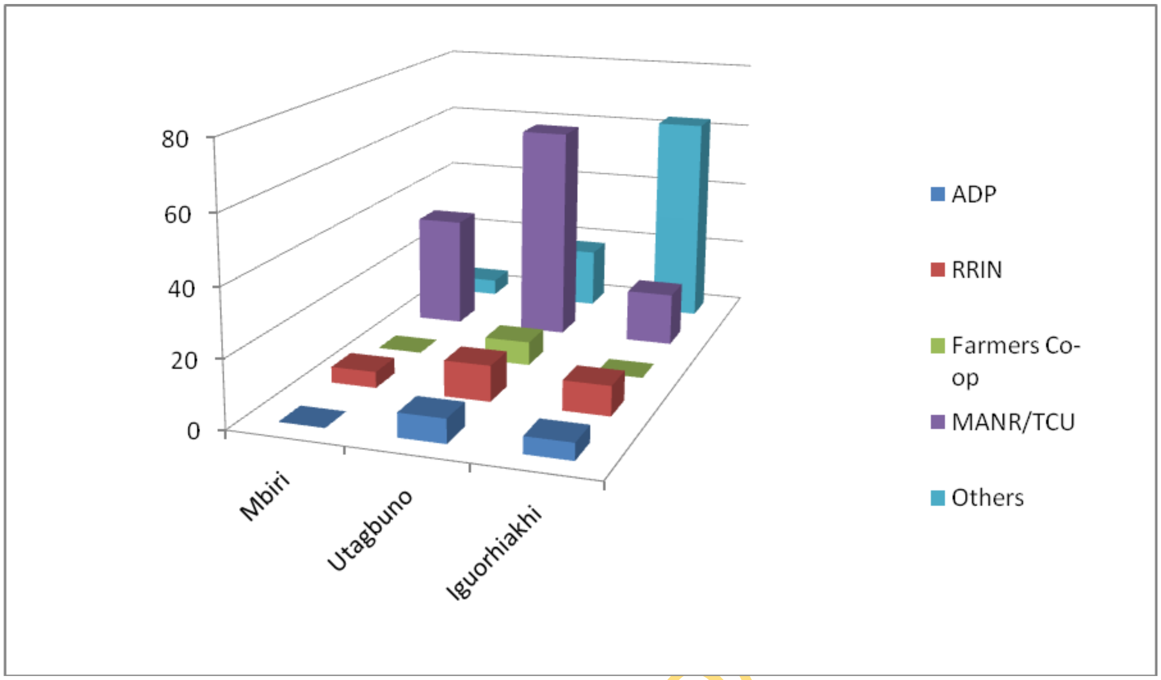


Fig. 4.25: Relative influence of various recommending agencies on rubber farmers' soil fertility management practices.

CHAPTER 5

DISCUSSION

The soil type distribution of the study areas were observed to have been influenced by the physiographic position. The spatial distribution of soils is widely agreed to be a function of the five soil forming factors with topography being the principal controlling factor at the local level. McBratney *et al.*, (2003) and Rezaei and Gilkes, (2005), belief that the existence of a spatial correlation between the occurrence of soil types and landform position in the physiography is a basic premise of applied pedology. In most humid tropical soils, there tends to be a soil-slope association occurring both on gently sloping and rolling landscapes as a result of the influence of topography on pedogenesis. This characteristic and predictable relationship has been used successfully to map and characterise soils especially at Series level in Western Nigeria (Smyth and Montgomery, 1962). Younger soils (Inceptisols) occur at valley bottoms while the older more developed Ultisols occur at the hillcrests and middle-slope positions at both Iyanomo and Akwete sites. Fasina, (1997) noted that the valley pedons of most toposequences of the coastal plain sand derived soils tend to have younger soils (Entisols and Inceptisols) with no major diagnostic horizons and evidences of recent or continuous deposition compared with soils of the upper slope which are usually Alfisols, Ultisols or Oxisols. This trend was also highlighted in the works of Smyth and Montgomery (1962), Modrock *et al.* (1976) in Western Nigeria; Lekwa (1979) in Eastern Nigeria as well as Moss (1957) and Kamalu *et al.* (2002) on the soils of the Niger Delta.

The soils are of sedimentary origin and referred to as the Coastal Plain Sands parent material. The Iyanomo soils belong to the 'Benin Fasc' while Akwete soils belong to the 'Calabar Fasc' parent materials (Ojanuga, 2006). Ahiara and Kulfo Series were so classified according to their lower slope physiographic positions in the non mottled and non concretionary toposequence of 'red' soils in the Benin Fasc with Ahiara occurring below Kulfo along the catena (Moss 1957). The two soil series are closely related in texture but were differentiated by colour. Alagba and Orlu series are located at the upper and middle slope positions of the same toposequence. The two soil series are closely related in colour and texture but the major difference is the depth at which the clayey texture (usually sandy clay) occurs. While the sandy clay texture is encountered at about 40 cm depth or less in Alagba series, it usually occurs at about 60 cm in Orlu series. Though, Moss (1957), suggested the discontinuation of the Orlu Series and instead be classified as the clayey subseries of the Kulfo series, Ogunkunle (1983), argued that the Orlu Series as earlier identified by Vine (1954), be upheld since the distinguishing characteristics are very relevant to soil management.

In the higher category, the soils at Iyanomo belong to two orders of the USDA soil taxonomy namely Ultisol and Inceptisol. Ahiara and Kulfo series are of the Inceptisol order of the USDA soil taxonomy since there are no diagnostic horizons other than structural and colour Cambic B horizons. At Iyanomo, the temperature regime inferred from the climatic data is Isohyperthemic while the moisture regime is udic, therefore they are Udepts. Base saturation of less than 50 % placed them in the Dystrudept suborder. Ahiara Series has organic matter greater than 0.2 % at a depth below 40 cm which decreases irregularly between 25 – 125 cm. This placed Ahiara Series in the Fluventic Dystrudept great group while Kulfo has ECEC values that are less than 24 cmol kg^{-1} and is therefore classified as Oxic Dystrudept. Alagba and Orlu Series have argillic B horizons with epipedons that have sandy to sandy-loam texture and therefore of the Ultisol order. Both are of the udic moisture regime thus belonging to the Udult suborder. The clay content did not decrease with depth by as much as 20 % from the maximum while it has Hue less than 3.5 in the Bt horizon and are therefore placed in the Rhodic great group. Other properties are Haplic for this great group and are therefore classified as Rhodic Haplaudult.

At Akwete, Uyo series has a kandic B horizon with low ECEC and base saturation, with Udic moisture regime. It was classified as Kadiudult. It has a sandy particle size throughout the horizons extending from the soil surface to the top of the kandic horizon which is less than 75cm thick. This placed the soil in the Arenic Kandiudult great group. The Calabar and Etinan series belong to the Inceptisol order and Udept suborder as explained above. Base saturation is less than 50 % and both have horizons that show evidence of water logging for some time of the year with redox depletion of the chroma to 2 or less. Etinan series was placed in the Aquic Dystrudept great group. Calabar series has organic carbon of 0.2 % below 50 cm depth with irregular decrease down the profile; it was classified as Fluvaquentic Dystrudept. In the work of Kamalu *et al.* (1991), Uyo series was classified as Tropudult while the Calabar and Etinan Series were classified as Tropaquents with an earlier ascension of the Soil Taxonomy (Soil Survey Staff, 1975).

However, the ‘Tropudult’ and ‘Tropaquent’ great groups have ceased to exist since the 2003 (ninth) edition of the Soil Taxonomy.

There exist some basic differences in the morphological and chemical properties of the soils of the two study sites. While the two sites are on gently sloping free draining landscape, differences were observed in colour and texture. While the soils at Iyanomo are reddish in colour, those of Akwete are lighter, with a majority of them more or less brownish in colouration. It was noted that most (about 75 %) of the soils of the two areas are Ultisols. Pai *et al.* (2003), observed that the appearance of many Ultisols is dominated by the morphological expression of altering oxidation and processes affecting Fe-oxides either inherited from parent materials (lithogenic) or formed in-situ (pedogenic). Most of the upper horizons of the soils in both Akwete and Iyanomo are characterised by loamy sand or sandy texture (Figs. 4.9 and 4.15). The Akwete soils are however more sandy than those of Iyanomo. This could be due to the geological formation which is inherently sandier. Usman (2008), had observed that soils on the sedimentary formations of south eastern Nigeria are very sandy and are susceptible to soil erosion.

All the soils at Iyanomo and Akwete are acidic (with pH values <5.0 at almost all depths) reflecting strong acid reactions mainly due to leaching. Chandran *et al.* (2005), attributed such strong acidity to high rainfall (> 2500 mm annually) and the subsequent leaching of basic cations. Low pH values could also be due to Al saturation in soil solution (Soil Survey Staff, 2003). This low pH characterises most of the soils of the Coastal Plain Sands which led to the popular ‘Acid sands’ nomenclature of the soils of this region (Ojanuga *et al.*, 1981).

Generally Effective Cation Exchange Capacity (ECEC) is very low ranging from 1.97 to 5.28 cmol kg^{-1} at Iyanomo and from 2.34 – 6.80 cmol kg^{-1} at Akwete. This values fall within the range reported by previous workers in these areas (Ataga *et al*., 1981; Onuwaje and Uzu, 1982, Esekhade and Ugwa, 2001 and Ugwa *et al*., 2006). However, these values did not meet the optimum requirements of rubber especially at the 0-20cm depth where most feeder roots of rubber are located according to Van-Ranst *et al*., (1999). The ECEC according to Karthikakuttyamm *et al.* (2000), depends on the amount and type of clay, organic matter content and soil pH. Ojanuga (2006) and Usman (2008), did pointed out that soils of the coastal plain sands consist of low activity 1:1 lattice clays which are inherently low in their capacity to hold nutrient elements (especially bases) in exchangeable form for plant nutrition. Since the sum of exchangeable bases and exchangeable acidity (Al^{3+} and H^{+}) is involved, the higher values obtained at Akwete and at lower depths are due to higher amounts of Al^{3+} and this is attested to by lower base saturations (less than 45%) where such is obtained. Where low activity clays are involved, FAO (2006), suggests that the exchange capacity due to organic matter be deducted through graphical method or by analysing the CEC/ECEC of the organic matter or mineral colloids separately before CEC/ECEC could be used as diagnostic criteria in soil classification. Most of the soils of Akwete and Iyanomo have base saturations that are lower than 50 %. This shows that more reserved acidity (Al^{3+} and H^{+}) occupy the exchange sites of the soil colloids than the exchangeable bases and this is a reflection of the degree of weathering (Soil survey Staff 1998). This also confirms the observation of Usman (2008), that Nigerian soils in general, especially those of the high humid areas of

Southern Nigeria, is highly weathered and has limited capacities to supply nutrient elements needed by plants.

The soils show a higher amount of extractable micronutrients (Fe, Mn, Zn and Cu) at Iyanomo than Akwete with Mn and Fe being higher in value at Iyanomo than Akwete. The content and form of micronutrients are usually affected by soil pH. Fageria *et al.* (2002), opined that the availability of micronutrients and their degree of effectiveness in soils are controlled by many factors, out of which pH is about the most important. The availability of Mn is strongly affected by soil reaction while other factors are of limited influence. Cu, Mn and Zn are predominantly organically bound in soils but are also associated with Mn oxides and amorphous forms in Alfisols, Entisols and Ultisols. Though there are not much differences in the soil reaction between Iyanomo and Akwete, there are obviously higher oxides of Al, Mn and Fe which are mostly responsible for the chemistry of the soils at Iyanomo (Onuwaje and Uzu, 1982) and many other parts of southern Nigeria (Eshett, 1991).

The point interpolation diagrams showed the spatial distribution of some of the field observed parameters involved in soil mapping. The parameters used and displayed: soil matrix colour (Hue, value and Chroma), field texture and soil consistency are prominent because they are the major parameters used in soil mapping by which differences can be identified in soils (Moss, 1957; Ogunkunle, 1983). Other parameters by which soils are classified at series level such as mottling, iron/hard pans, gravel concentration were not considered because they are either non-existent in the study sites or are so infinitesimal in space and intensity to constitute a soil mapping unit or influence the soil classes. For instance, at Iyanomo, only three out of the over 350 augering points showed very faint mottling and five showed few gravels. The points are so wide apart that other factors (such as hydrology) could have accounted for this rather than pedogenesis. Also, such observations are so discontinuous and wide apart that they could not be grouped together. The absence of gravels in the soils of the Coastal Plain Sands parent materials was observed long ago by Vine (1953), who described the soils as *'stoneless' latosols* (Ojanuga *et al.*, 1981). Variations in colour and texture form the basis for recognizing and differentiating soil series on the non-mottled and non-concretionary toposequences of the Benin and Calabar Fascs by Moss (1957). The distribution of the soil characteristics at the various depths could be well appreciated in the figures 4.6 to 4.12 mentioned above as a result of the ability of GIS to interpolate and display the phenomena. While there remains some differences in the shape and coverage areas of the various soil mapping units both at Akwete and Iyanomo with conventional and GIS soil mapping techniques, there was a significant agreement between the two methods. Considering the position of Dent and Young (1981), who believed that conventional mapping methods even at detailed scales are considered excellent at 80-85 % accuracy. The conventional soil map may have some errors which are actually being corrected by the krigging method. In this study, an error of orientation on the soil map of Kamalu *et al*, (1991; Fig. 4.3) was corrected when actual points in the field were transferred into the GIS environment. Also, a generalized spherical semi-variogram model was adopted as advocated by Weindorf and Zhu (2010) in order to reduce errors and noise from sampling and measuring processes as the shape of a model can be strongly affected by the extreme measurement of one variable. The GIS based approaches to soil survey and land evaluation have gained prominence as a result of the ability to overlay various layers of spatially referenced maps with various themes to produce a desired map. Collins *et al.* (2001), traced this to the application of hand-drawn overlay techniques used by American landscape architects in the late nineteenth century and early 20th century where hand drawn maps on transparencies were overlaid on each other to bring out a final map relating to the desired purpose.

The parametric and non parametric suitability ratings of the pedons at Iyanomo and Akwete agreed very strongly (r = .964**). However, actual yield in both 2005/2006 and 2006/2007 cropping seasons were not significantly related to the ranking of the pedons. When yield index which takes into account the potential yield of the rubber clones were involved, there were significant correlations (r = .964** and .929 ** for Non-parametric and parametric evaluation methods respectively) between the rankings of the soils and yield index in 2006/2007 season. This implies that, in evaluating the yield of rubber, it should be considered that each rubber clone has different yield abilities even when all other variables are held constant. The flaw with the LSE in crop yield prediction can be attributed to the high class limit set for the characteristics used for evaluation (Oluwatosin and Ogunkunle 1991). The class limit set for rubber, especially on surface and subsurface texture and fertility put all the soils into low or medium classes. For instance, a soil that has pH less than 5.0 is considered too strongly acidic for rubber whereas, optimal rubber performance at pH of between 4 and 4.5 have been reported (Watson, 1989; VanRanst *et al.*, 1996). Also, in most of the soils of Peninsular Thailand, Malaysia and Sumanthra province in Indonesia where rubber is grown, many of the soils have very sandy surface (Ahn, 1993 and Werner, 2001). Watson (1989) and Saraswathyama *et al.* (2000), reported that most farmers believe that rubber is one of the least fertility demanding crops. Ahn (1993), also reported that much of the early planting of rubber in Southeast Asia was on soils exhausted by the production of other crops. Though, the nutrient needs of the crop is less than for most other tropical tree crops like cocoa or oil palm; yields are never the less, higher in richer soils than on very poor ones. While Tananka *et al.* (2009), is of the opinion that rubber is a high nutrient demanding crop as a result of significant nutrient export through latex exploitation, Ahn (1993), believed that the amount of nutrient exported in the latex is very low. However, Agboola (personal communication) explained that rubber like some other crops in the euphobeacea family (e.g cassava), have an unusual ability to mine nutrients from the soil that are ordinarily not available to other crops. This probably accounted for the seemingly less nutrient demands of rubber. The suitability class of a pedon is determined by the lowest or least characteristic/quality rating for any suitability criterion. A combination of two or more limitations may effect a downgrading in the suitability classification of soil series as the system is based on the Leibig's law of the minimum. Where cases of varying tolerance to certain parameters such as mentioned above exist, Chukwu (2007) opined that the law of the minima cannot be established in practice for all conditions and interpretive judgment has to be exercised to maintain a balance between the varying criteria.

In choosing LSE as the land evaluation method for soils of the study areas, the test crop, rubber, being a perennial tree crop and LSE being crop specific were considered. While most early land evaluation methods adopted the Land Capability Classification of

Klingiebel and Montgomery (1961) or its modifications, the application in many parts of the country has been faulted (Oluwatosin, 1991). Though it has subsoil characteristics such as soil depth and textural properties as part of the rating criteria, the fertility rating demands a CEC of 15 cmol kg^{-1} for a land to qualify as class I which is very hard to come by in the low activity clay soils that characterize most Nigerian soils. Kamalu *et al.* (1991), actually employed the LCC system and assessed about 75 % of the Akwete area as class III soils while about 20 % were classified as class IV, non-arable land.

Whereas, LSE placed the soils at Iyanomo at S2 and S3 categories and those of Akwete at S3 and NS, with weighted overlay analysis in the GIS, using the modified criteria of Van Ranst *et al.* (1996), 88.01 % and 11.98 % of the land area were highly suitable (S1) and moderately suitable (S2) respectively at Iyanomo. At Akwete, 52.76 % and 47. 33% were S1 and S2 classes respectively. This is possibly so because all the criteria were allocated equal weight in the overlay analysis. The fertility criteria though contributed but did not affect the classification as it did in the parametric and non parametric LSE methods. One peculiar feature of the GIS overlay analysis is that each point was rated on its own merit; therefore suitability class did not follow pedogenic classes. For instance, part of Ahiara series was in class S1 while some were in S2 at Iyanomo. At Akwete also, Uyo series was divided between S1 and S2. For this reason comparison of soil mapping units by correlation or ranking is not feasible.

Despite the high correlation between rubber yield index and the land evaluation classes in the 2006/2007 season, the agreement exist only in the ranking of the yield index and the suitability classes assigned to the soils. However, when the yield indices were compared with the indices expected of the suitability classes, larger proportions of the soils both at Akwete and Iyanomo produced yield indices that are expected of S1 soils. The implication of this is threefold. First, yield index is a better assessment of yield in evaluating land suitability; secondly, land quality ratings as it is, cannot be relied upon for consistent evaluation of land for rubber except, possibly, localized interpretative judgment as advocated by Chukwu (2007), is allowed and thirdly, weighted overlay analysis gives a better interpretative evaluation for rubber when dry rubber yield is the object of interest.

Rubber latex yield (dry rubber content) is associated with a number of edaphic and environmental characters, some of which in turn are interrelated. Such interdependence of contributing factors often affects their direct relationship with latex and dry rubber content. Thus, in selecting indices for the relevant parameters, correlation and regression has been the conventional statistical tools (Wheater and Cook 2003). Usually, stepwise regression is employed and the validity (lack of bias) requires the inclusion of all independent variables that affect the dependent variable, while the reliability (small standard error) of the regression parameters may worsen if some of the independent variables are highly correlated (Wittink, 1988). If the primary interest is in the regression coefficients per se, or if the purpose is to identify "important" variables, the impact of co-linearity on ordinary linear regression is very serious. Stepwise procedures are useful if regression analysis involves a large set of variables and the purpose is prediction. On the other hand, if the purpose is explanation, then adopting some other more logical model-building techniques might be more useful (Howell 1997). As more variables are included in the correlation and regression analysis studies, the inherent association becomes complex, hence, the role of path co-efficient analysis becomes important. In such situations, the path coefficient helps to measure the direct influence of one variable upon another and permits the separation of relative contribution of different parameters to the trend of measured interest. Correlation and path analysis, though frequently used in agricultural crops, has been restricted to selection of desirable characters for breeding of field crops. In recent times it has been successfully applied to tree crops (Gera *et al.*, 1999; Omokhafe, 2001). It was applied in this study to select the contributing factors to the yield of rubber. It was discovered that K and bulk density influenced the latex yield at Iyanomo site, while the weather parameters especially rainfall exerts a negative influence on dry rubber yield. This might have been a result of the many tapping days that are usually lost during heavy rains and the high moisture content of latex during the raining months. Vijayakumar *et al.* (2000), observed that high dry rubber yields are obtained around October and November when the dry season has just set in. Other weather factors such as relative humidity are directly dependent on rainfall. As observed by Mokwunye *et al.* (2007), rainstorms can also bring about a lot of wind damage in rubber plantations.

From Tables 4.29 and 4.30, it is obvious that the various land use types exerted profound influence on the surface soil properties. Surface soils are the zone of plant nutrition and are of much interest to farming. The influence of landuse on soil properties and formation led to the suggestion of Agbede (2009), that man's influence should be considered a separate factor of soil formation. Despite the reported export of nutrients through latex exploitation (Karthikakuttyamma, 1997), the soils under middle aged and old rubber plantations showed a lot stability, resilience and soil health as defined by Van Bruggen and Semenov (2000) possibly due to high biological diversity and high levels of internal nutrient cycling. Under the tropical conditions of rubber cultivation in Nigeria, litter additions are rapidly decomposed under high soil temperatures and increased activities of soil microorganisms occasioned by the moist conditions. Organic matter therefore accumulates on the soil surface. The extensive canopy cover in the rubber plantations helps to minimise erosion and run off losses thus the system eventually attains a nearly closed nutrient cycle in which the nutrient additions from the leave litter replaces to a large extent, nutrient uptake by the plantation. With rubber plantations exhibiting major indicators of sustainability pointed out by Walter and Stutzel (2009), rubber cultivation may be employed low cost and economically viable mitigation strategy to prevent degradation of soils within the rubber growing belt.

In studying indigenous knowledge on land evaluation, direct and indirect interview methods in the three rubber growing communities were employed. Interviewing methods is increasingly being employed in the field of environmental management to document local knowledge (Di Mauro, 2003). It has proved especially valuable in regard to local inhabitants' knowledge of local soils, their potential and their management (Cools et al., 2003). It was observed that all (100 %) of the respondents in this study are men (Table 4.8.) This does not mean that the womenfolk are totally excluded from rubber farming but rather, is a reflection of the cultural believes and custom prevalent in this part of the country that lands (and by implication, permanent crops) are rarely owned by women.

Inheritance by custom is patri-lineal and every land is bequeathed to the first son of the family even if the land has been bought by a woman. However, oral interview results revealed that 88 % of the women's work occurs in both the home, homestead gardens and nearby subsistence plots, compared to less than 11% for men.

It was also noted that that over 60 % of the rubber farmers are well above 50 years in age while less than 20% are 45 years and below. This has been observed by Abolagba *et al.* (2004). The implications of this is that the rate of adoption of new techniques will be very low (Omokhafe and Abolagba, 2002). Replanting of ageing rubber farms will be at a very low rate especially in the midst of other competing land use that promise earlier return on investment than rubber. This portends a great danger for the rubber industry in Nigeria unless younger generations are encouraged. Rubber production may go into extinct in a few decades.

It was observed that the fertility classification by rubber farmers agrees to a large extent with laboratory analysis. Though the basis for their allocation may not be 'scientific', the near accuracy borne out of vast experience is worth studying. According to Winklerpins and Sandor (2003), the study of indigenous knowledge of local farmers with regard to soils help us to understand how they perceive different soils and on what basis they divide soils into different categories. Unlike in the past, efforts in this direction should be focused not only to identify the number of soil classes in a local soil classification, but also to examine the criteria of classification, understand the basis of categorization and determine how all the criteria considered in local soil classification may affect soil management (Talawar and Rhoades 1998). Therefore, Sikana (1993), stated that it would be easier for researchers and extension workers to communicate with farmers if local soil categories could be related to the scientific classification. Additionally, an understanding of traditional knowledge by extension workers increases the effectiveness of communication through allowing for a proper use of vernacular terms in relation to explanations rooted in the formal knowledge sector (Warren, 1991).

According to Barrera-Bassols *et al.* (2003), many 'rules of thumb' developed by traditional resource managers and enforced by social and cultural means are in many ways as good as scientific prescriptions. The increased acceptance of ethnopedology and local soil knowledge within soil science reflects the acknowledgement of the important contributions that the farmer can make. It is important to investigate local soil knowledge for several reasons. The first is that it offers a different set of temporal and spatial scales with regard to land use, which has important implications for sustainable agriculture (Sandor and Furbee, 1996). Local or indigenous cultures and people hold significant knowledge of soils and environments, attained by experience and testing through many generations of living close to the land. The environmental knowledge embedded in local cultures provides a long-term perspective on land use and management not otherwise available. The long-term nature of local people's land use strategies, commonly on the order of many centuries to millennia, contrasts with the rapid changes, on the order of a century or less, of land use characteristics of many areas of industrial and globalized agriculture.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

This study was carried out to identify the soil types and the suitability of the soils of Iyanomo in Edo State, and Akwete in Abia State on the Coastal Plain Sands derived soils in Southern Nigeria for rubber cultivation. It also seek to explore the application of Geographic Information System (GIS) to soil mapping, examine the influence of rubber cultivation on the soil and traditional knowledge of evaluation of land and soil fertility. The soils were identified and the potentials for continuous and sustainable rubber cultivation evaluated. The practical relevance of the qualitative land evaluation was evaluated by field yield of rubber for two growing seasons.

Four soil series (Alagba, Orlu, Kulfo and Ahiara) were identified at Iyanomo namely while at Akwete, three soil types (Uyo, Calabar and Etinan series) were found. The soils encountered in the two study locations fall generally into the Ultisol and Inceptisol soil orders of the Soil Taxonomy. The Ultisols covered 73.07 % of the study area at Iyanomo and 71.03 % at Akwete while Inceptisols covered 26.93 % and 29.12 % at Iyanomo and Akwete respectively. Geographic Information System (GIS) point interpolation methods were also used to do the soil mapping. The difference between GIS and conventional soil mapping was statistically not significant ($t = 0.118$, $p < 0.05$).

The soils were evaluated for rubber cultivation using both parametric and non parametric methods. The study sites ranged between moderate (S2) and marginal (S3) suitability at Iyanomo and S3 and (not suitable) NS at Akwete. Generally, 63.66 % of the total studied area were rated moderately suitable (S2), 32.89 % were rated marginally suitable (S3) while 3.88 % were rated Non Suitable (NS) for rubber cultivation. The major limitations are low fertility status and textural (sandy) properties of the soils. Rankings of actual and potential ratings by parametric and non parametric methods strongly agreed by ranked correlation co-efficient. GIS overlay analysis however, rated 83.35 % of the total land area as S1 while 16.65 % were rated S2.

The accuracy or practical application of the evaluation was tested with dry rubber yield obtained in the 2005/2006 and 2006/2007 cropping seasons. There was no significant correlation between the conventional parametric and non parametric soil classes and the rubber yields in both years. However, when yield index which considered the inherent yield potential of the rubber was used, the rankings of soil classes correlated with yield in the 2006/2007 season. It was observed that the expected yield index of the soil classes were very much below the obtained yield index, thereby making the GIS suitability classification by overlay analysis superior to the conventional suitability evaluation methods.

Correlation and path analysis revealed that high rainfall negatively affected rubber yield while soil K though directly influenced rubber yield positively, but the aggregate effect of K was negative as a result of the indirect effect of other soil factors.

The study also reveals that rubber plantations compared favourably with the forest or fallow landuse type with respect to soil quality indices such as soil porosity, basic cations, soil organic matter content and microbial populations (Bacteria and fungi).

Rubber farmers in the three farm settlements of Mbiri, Iguoriakhi and Utagbuno are ageing men who rely mostly on physical observations such as indicator plants and vegetation vigour to rate suitability of land for rubber cultivation and other agricultural enterprises and also, to manage their soil fertility rather than recommendations from government and non-government agencies.

From this study therefore, the following conclusions are drawn:

(a) Yield index rather than actual yields of rubber is a better indicator of land classification when varying rubber clones are involved

(b) The GIS technology can be used to carry out soil mapping to a high degree of accuracy. Considering the speed, flexibility and ability to handle large volumes of data, GIS could be adopted for soil mapping in Nigeria at larger scales.

(c) GIS overlay analysis is a better instrument than both parametric and non parametric land evaluation methods in predicting the yield of rubber.

(d) Rubber cultivation over time has almost the same effect on soil qualities as a forest or fallow land use. Therefore, rubber cultivation may be suggested as an economically viable land reclamation strategy for nutrient degraded soils within the rubber growing belt

(e) While farmers' perception of fertility agrees with scientific data, the impact of government and non-government agencies on the soil fertility management of rubber farmers is very poor. There is a need to integrate scientific knowledge with the farmers experience to bring out the best in our agricultural productivity, especially with respect to rubber farming.

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Appendix I: Soil morphological characteristics of Iyanomo study area

Profile No	Location	Soil series	Pysiography	Horizon	Depth	Colour (moist)	structure	Consistency (moist)	Texture (field)	Boundary	roots
L12	6° 9'23.51"N 5°35'56.05"E	Ahiara	Lower slope	Ap	0-18	10YR 5/4	1, vf, cr	l	S	ds	mx, ma
				AB	18-42	10YR 6/8	1, f, cr	fr	S	ds	co, ma
				B	42-71	10YR 6/8	1, m, sbk	fr	LS	cw	f, ma
				B1g	71-104	10YR 7/8	1, m, sbk	fr	LS	cw	co, fe
				B2g	104-133	7.5YR 6/8	1, m, sbk	s, fm	LS	cw	me, vfe
				B3gt	133-158	7.5YR 7/8	1, m, sbk	mo, fm	SL	gw	f, vfe
				B4gt	158-180	7.5YR 5/8	2, m, sbk	mo. fm	SL		f, vfe
K12	6° 9'25.72"N 5°35'56.15"E	Kulfo	Middle slope	A	0-13	5YR 3/2	1, vf, cr	fr	LS	gs	f, ma
				AB	13-32	5YR 4/4	1, vf, sbk	mo, fm	SL	gs	co, ma
				B1	32-74	5YR 4/6	1, vf, sbk	mo, fm	SL	gs	f, fe
				B2	74-108	5YR 4/6	2, f, sbk	mo, fm	SL	ds	f, vfe
				Bt1	108-165	2.5YR 4/6	2, m, sbk	fm	SCL		co, vf
N13	6° 9'36.74"N 5°35'59.05"E	Orlu	middle slope	A	0-18	5YR 3/4	1, vf, cr	fr,	LS	gs	mx, ma
				AB	18-47	5YR 4/6	1, f, cr	fr	SL	gs	wo, ma
				Bt1	47-85	2.5YR 4/6	1, m, sbk	mo, fm	SCL	gs	co, fe
				Bt2	85-116	2.5YR 4/8	2, m, sbk	v, fm	SCL	gs	co, vfe
				Bt3	116-180	2.5YR 5/8	2, m, sbk	v, fm	SC		co, vfe
S 16	6°10'17.13"N 5°36'3.90"E	Alagba	Hill crest/ upper slope	Ap	0-9	5YR 4/4	1, vf, cr	fr	LS	gs	mx, ma
				AB	9-29	5YR 3/4	1, m, sbk	mo, fm	SCL	gs	mx, ma
				Bt1	29-63	2.5YR 4/6	1, m, sbk	v, fm	SC	ds	co, fe
				Bt2	63-101	2.5YR 4/6	2, m, sbk	v, fm	SC	ds	me vfe
				Bt3	101-132	2.5YR 4/8	2, m, sbk	v, fm	SC	ds	f, vfe
				Bt4	132-180	2.5YR 5/6	2, m, sbk	v, fm	SC		f, vfe
N1	6° 9'38.45"N 5°34'40.22"E	Orlu	upper slope	Ap	0-16	7.5YR 4/4	1, vf, cr	fr,	LS	gs	mx, ma
				AB	16-43	7.5YR 5/6	1, f, cr	mo,fm	SL	gs	co, ma
				B	43-67	7.5YR 6/8	1, m, sbk	mo, fm	SCL	gw	me, fe
				Bt1	67-93	5YR 5/8	2, m, sbk	v, fm	SCL	gs	f, vfe
				Bt2	93-125	5YR 6/8	2, m, sbk	v, fm	SC	ds	f, vfe
				2Bt3	125-151	2.5YR 5/8	2, m, sbk	v, fm	SCL		f, vfe

Q1	6° 9'59.76"N 5°34'40.53"E	Ahiara	Lower slope	A	0-18	10YR 5/4	c, gr	l	S	cs	mx, ma
				AB	18-42	10YR 6/8	1, vf, cr	fr	S	gs	mx, ma
				B1	42-71	10YR 6/8	1, vf, abk	fr	LS	gs	co, fe
				B2	71-104	10YR 7/8	2, f, sbk	fr	LS	ds	me vfe
				B3	104-133	7.5YR 6/8	2, m, sbk	fr	LS	ds	f, vfe
				B4t	133-158	7.5YR 7/8	1, vf, sbk	fr	S	ds	f, vfe
				B5t	158-180	7.5YR 5/8	1, vf, sbk	mo, fm	SL		f, vfe
CD1	6° 8'51.38"N 5°34'47.69"E	Kulfo	Middle slope	A1	0-16	7.5YR 3/2	1, vf, gr	fr	LS	cs	mx, ma
				A12	16-43	7.5YR 4/4	1, f, cr	fr	LS	gs	co, ma
				B	43-67	7.5YR 5/6	1, m, sbk	fr	LS	gs	me, fe
				Bt1	67-93	5YR 6/8	1, m, sbk	s, fm	SL	ds	f, vfe
				Bt2	93-125	5YR 5/8	1, m, sbk	s, fm	SL	ds	f, vfe
				Bt3g	125-151	5YR 6/8	1, m, sbk	mo, fm	SCL	ds	f, vfe
				Bt4g	151-180	2.5YR 6/8	2, m, sbk	mo, fm	SCL		-
OP 8	6° 9'42.03"N 5°35'34.61"E	Orlu	Upper Slope	Ap	0-12	2.5YR 3/4	1, vf, cr	fr	SL	cs	co, ma
				AB	12-32	2.5YR 4/8	1, f, cr	fr	SL	cw	co, fe
				Bt	32-70	2.5YR 5/8	1, m, sbk	mo, fm	SCL	gs	co, vfe
				Bt2	70-112	2.5YR 5/8	2, m, sbk	v fm	SCL	gs	co, vfe
				Bt3	112-144	2.5YR 5/8	2, m, sbk	v fm	SC	gs	f, vfe
				Bt4	144-170	2.5YR 4/8	2, m, sbk	v fm	SC		f, vfe
D6	6° 8'50.21"N 5°35'7.05"E	Orlu	Middle slope	Ap	0-11	2.5YR 3/4	1, vf, cr	fr	SL	cs	co, fe
				AB	11-30	10R 4/6	1, f, cr	fr	SL	gs	wo vfe
				Bt	30-69	10R 4/6	1, m, sbk	mo, fm	SCL	ds	co, vfe
				Bt2	69-108	10R 4/8	2, m, sbk	v fm	SCL	ds	f, vfe
				Bt3	108-157	10R 5/8	2, m, sbk	v fm	SCL	ds	f, vfe
				Bt4	157-182	10R 5/8	2, m, sbk	v fm	SC		f, vfe

Structure: gr= granular, cr = crumb, abk = angular blocky, sbk = sub angular blocky, vf = very fine f = fine, m = medium,
Consistency: l = loose, fr = friable, fm = firm, s = slight, vfm = very firm, mo= moderate
Texture: S = sandy, LS = loamy sand, SL = sandy loam, SCL = Sandy clay loam, SC = sandy clay
Boundary: cs = clear smooth, gs = gradual smooth, ds = diffuse smooth, cw = clear wavy, gw = gradual wavy
Roots: f = fine, co = coarse, wo = woody mx = mixed, ma = many, vfe = very few, fe = few,

Appendix 1I: Physical properties of soils of Iyanomo study area

Profile No/ Location	Soil Type	Horizon	Depth	Colour	Sand	silt	Clay	Texture	Bulk density	Total porosity	Hydraulic conductivity
L12	**Ahiara Series**	Ap	0-16	10YR 5/8	803.40	11.20	195.40	SL	1.34	49.43	0.49
		AB	16-42	10YR 5/6	783.40	11.20	215.40	SCL	1.51	43.02	0.42
		B	42-75	10YR 6/6	833.40	21.20	145.40	SL	1.53	42.26	0.40
		B1g	75-109	10YR 6/8	818.40	1.20	180.40	SL	1.55	41.51	0.64
		B2g	109-140	10YR 7/8	784.60	8.80	215.40	SCL	1.58	40.38	0.17
		B3gt	140-180	10YR 7/8	779.60	13.80	220.40	SCL	1.76	33.58	0.13
K12	**Kulfo Series**	B4gt	0-13	7.5YR 4/4	856.20	7.80	136.00	LS	1.44	45.66	0.80
		A	13-32	5YR 4/4	846.20	2.20	146.00	LS	1.55	41.51	0.55
		AB	32-74	5YR 4/6	836.20	2.20	156.00	SL	1.67	36.98	0.31
		B1	74-108	5YR 4/6	826.20	17.80	156.00	SL	1.66	37.36	0.23
		B2	108-165	2.5YR 4/6	896.20	2.80	101.00	LS	1.77	33.21	0.30
N13	**Orlu Series**	Bt1	0-18	5YR 3/4	862.40	12.80	124.80	LS	1.48	44.15	0.38
		A	18-47	5YR 4/6	782.40	12.80	204.80	SCL	1.55	41.51	0.54
		AB	47-85	2.5YR 4/6	787.40	12.80	204.80	SCL	1.59	40.00	0.27
		Bt1	85-116	2.5YR 4/8	777.40	7.80	214.80	SCL	1.79	32.45	0.60
		Bt2	116-178	2.5YR 5/8	777.40	12.80	209.80	SCL	1.82	31.32	0.55
S16	**Alagba Series**	Bt3	0-9	7.5YR 4/4	755.20	32.80	212.00	SL	1.47	44.52	0.28
		Ap	9-29	5YR 3/4	775.20	32.80	192.00	SCL	1.50	43.39	0.28
		AB	29-63	5YR 4/6	731.20	12.80	252.00	SC	1.49	43.77	0.31
		Bt1	63-101	2.5YR 4/6	675.20	12.80	312.00	SC	1.57	40.75	0.18
		Bt2	101-132	2.5YR 4/8	615.20	32.80	352.00	SC	1.62	38.87	0.09
		Bt3	132-180	2.5YR 5/6	615.20	32.80	352.00	SC	1.67	36.98	0.10
N1	Orlu	Bt4	0-16	7.5YR 4/4	828.40	21.20	150.40	SL	1.43	46.04	0.24
		Ap	16-43	7.5YR 5/6	798.40	1.20	200.40	SCL	1.64	38.11	0.20
		AB	43-67	7.5YR 6/8	768.40	1.20	230.40	SCL	1.67	36.98	0.29
		B	67-93	5YR 5/8	708.40	16.20	275.40	SCL	1.76	33.58	0.18
		Bt1	93-125	5YR 6/8	718.40	11.20	270.40	SCL	1.78	32.83	0.10
		Bt2	125-151	2.5YR 5/8	728.40	11.20	260.40	SCL	1.77	33.21	0.08

Appendix 1I (cont): Physical properties of soils of Iyanomo study area

Profile No/ Location	Soil Type	Horizon	Depth cm	Colour	Sand g kg-1	silt g kg-1	Clay g kg-1	Texture	Bulk density g cm^{-3}	Total porosity %	Hydraulic conductivity Cm min^{-1}
Q 1	**Ahiara Series**	A	0-18	10YR 5/4	880.80	5.60	113.60	LS	1.25	52.83	0.75
		AB	18-42	10YR 6/8	850.80	15.60	133.60	LS	1.51	43.02	0.49
		B1	42-71	10YR 6/8	826.40	4.40	169.20	SL	1.34	49.43	0.41
		B2	71-104	10YR 7/8	810.80	5.60	183.60	SL	1.58	40.38	0.40
		B3	104-133	7.5YR 6/8	820.80	5.60	173.60	SL	1.53	42.26	0.64
		B4t	133-158	7.5YR 7/8	810.80	5.60	183.60	SL	1.45	40.38	0.07
		B5t	158-180	7.5YR 5/8	800.80	5.60	193.60	SL	1.76	33.58	0.03
CD1	**Kulfo Series**	A1	0-16	7.5YR 3/2	830.30	20.60	148.60	LS	1.32	50.19	0.37
		A12	16-43	7.5YR 4/4	840.80	40.60	118.60	LS	1.33	49.81	0.54
		B	43-67	7.5YR 5/6	800.80	15.60	183.60	SL	1.54	41.89	0.07
		Bt1	67-93	5YR 6/8	780.80	5.60	213.60	SCL	1.57	40.75	0.80
		Bt2	93-125	5YR 5/8	815.80	0.60	183.60	SL	1.64	38.11	0.55
		Bt3g	125-151	5YR 6/8	770.80	25.60	203.60	SCL	1.62	38.87	0.31
		Bt4g	151-180	2.5YR 6/8	750.80	5.60	243.60	SCL	1.67	36.98	0.23
OP 8	**Orlu Series**	Ap	0-12	2.5YR 3/4	875.80	0.60	123.60	LS	1.35	49.06	0.22
		AB	12-32	2.5YR 4/8	860.80	5.60	133.60	LS	1.41	46.79	0.18
		Bt	32-70	2.5YR 5/8	770.80	0.60	228.60	SCL	1.55	41.51	0.15
		Bt2	70-112	2.5YR 5/8	740.80	5.60	253.60	SCL	1.67	36.98	0.06
		Bt3	112-144	2.5YR 5/8	750.80	5.60	243.60	SCL	1.64	38.11	0.04
		Bt4	144-170	2.5YR 4/8	745.80	0.60	253.60	SCL	1.67	36.98	0.03
D6	**Orlu Series**	Ap	0-11	2.5YR 3/4	885.80	0.60	113.60	LS	1.51	43.02	0.23
		AB	11-30	10R 4/6	810.20	3.40	186.40	SL	1.55	41.51	0.23
		Bt	30-69	10R 4/6	778.40	1.20	220.40	SCL	1.48	44.15	0.31
		Bt2	69-108	10R 4/8	798.40	1.20	200.40	SCL	1.59	40.00	0.18
		Bt3	108-157	10R 5/8	718.40	26.20	255.40	SCL	1.67	36.98	0.08
		Bt4	157-182	10R 5/8	768.40	1.20	224.60	SCL	1.69	35.23	0.09
G22	**Orlu Series**	A	0-15	2.5YR 3/4	828.40	11.20	171.60	SL	1.26	52.45	0.22
		BA	15-39	2.5YR 4/8	838.40	1.20	161.00	SL	1.44	45.66	0.18
		Bt	39-70	2.5YR 5/8	768.40	1.20	230.40	SCL	1.45	45.28	0.12
		Bt2	70-110	2.5YR 5/8	773.40	1.20	225.40	SCL	1.67	36.98	0.06
		Bt3	110-139	10R 5/8	778.40	15.60	206.00	SCL	1.64	38.11	0.06
		Bt4	139-171	2.5YR 4/8	768.40	6.20	228.80	SCL	1.67	36.98	0.04
		Bt5	171-190	2.5YR 4/8	763.40	16.20	220.40	SCL	1.71	34.70	0.03

Appendix 1II: Chemical properties of soils of Iyanomo study centre

Profile no	Horizon	Depth	pH	pH $CaCl_2$	Org C	T/ N	Av P	Ex Ac Cmol/ kg		Ca	Mg	Na	K	ECEC	ECEC /Clay	B Sat %	Fe mg/kg	Zn mg/kg	Mn mg/kg	Cu mg/kg
		cm	H_2O		g/ kg		mg/ kg	Al^{3+}	H^+	Cmol/ kg					%					
Ahiara L12	Ap	0-16	4.48	3.94	10.80	3.90	49.27	0.99	0.99	1.60	0.50	0.11	0.06	4.25	21.75	58.11	94.50	20.50	175.90	6.90
	AB	16-42	4.33	3.88	10.80	1.40	62.17	1.16	1.99	1.80	0.30	0.11	0.14	5.50	25.53	42.72	101.10	31.40	187.40	8.40
	B	42-75	4.67	3.96	4.00	1.10	63.93	1.16	1.49	0.80	0.30	0.12	0.07	3.94	27.10	32.74	115.60	29.70	210.60	8.10
	B1g	75-109	4.45	3.86	12.50	1.00	9.38	0.99	2.16	0.80	0.30	0.17	0.35	4.77	26.44	33.96	103.90	31.40	211.30	8.60
	B2g	109-140	4.89	3.93	7.00	0.60	11.14	0.66	1.99	1.10	0.70	0.15	0.21	4.81	22.33	44.90	98.60	23.30	217.90	7.30
	B3gt	140-180	4.35	3.97	14.40	3.50	24.05	0.83	1.49	0.70	0.50	0.13	0.09	3.74	16.97	37.96	102.60	27.80	165.10	8.10
Kulfo K12	B4gt	0-13	4.13	3.83	14.6	2.00	26.39	1.33	0.66	1.30	0.10	0.13	0.16	3.68	27.06	45.92	105.70	27.90	187.30	7.70
	A	13-32	4.35	3.76	23.0	1.20	28.74	1.16	1.04	1.00	0.10	0.14	0.07	3.51	24.04	37.32	98.10	25.40	175.40	7.20
	AB	32-74	4.56	3.96	10.3	1.00	15.25	1.33	0.66	1.30	0.40	0.13	0.11	3.93	25.19	49.36	103.30	30.40	190.60	8.60
	B1	74-108	4.65	3.94	13.0	1.00	9.97	0.83	0.16	0.90	0.20	0.11	0.01	2.21	14.17	55.20	130.50	32.60	213.80	8.70
	B2	108-165	4.50	4.01	24.0	0.60	8.21	0.61	1.16	0.80	0.10	0.15	0.03	2.85	28.22	37.89	125.90	31.70	205.80	8.50
Orlu N13	Bt1	0-18	4.02	3.86	23.3	1.50	22.29	0.83	1.66	1.10	0.80	0.12	0.06	4.57	36.62	45.52	125.90	34.30	203.80	8.60
	A	18-47	4.59	3.93	21.6	1.40	17.00	0.83	1.69	0.90	0.30	0.17	0.12	4.01	19.58	37.16	97.50	19.30	174.90	6.90
	AB	47-85	4.24	3.87	20.3	0.60	10.56	0.83	1.66	0.80	0.40	0.16	0.09	3.94	19.24	36.80	114.80	24.40	198.60	7.30
	Bt1	85-116	4.54	3.89	14.4	0.70	10.56	0.83	1.09	0.90	0.60	0.14	0.06	3.62	16.85	46.96	103.60	20.60	220.60	6.80
	Bt2	116-178	4.46	3.90	08.4	0.80	14.66	0.66	0.99	0.90	0.50	0.15	0.10	3.30	15.73	50.00	98.60	19.10	175.90	6.50
Alagba S16	Bt3	0-9	5.65	5.01	30.00	3.90	24.05	0.67	1.67	1.40	0.92	0.67	0.25	5.58	26.32	58.06	110.50	33.90	181.50	8.40
	Ap	9-29	5.67	5.22	24.00	1.40	16.24	0.42	1.27	1.20	0.64	0.12	0.21	3.56	18.54	56.17	96.60	28.90	211.70	7.20
	AB	29-63	5.15	4.65	13.00	1.10	9.74	0.57	1.33	0.80	0.56	0.07	0.25	3.58	14.21	46.93	105.90	20.50	183.90	8.20
	Bt1	63-101	5.05	4.58	11.00	1.00	5.05	0.61	1.03	0.80	0.40	0.15	0.21	3.20	10.26	48.75	97.50	31.40	165.50	8.70
	Bt2	101-132	5.13	4.47	6.00	0.60	4.97	0.46	1.08	0.60	0.32	0.06	0.25	2.77	17.87	44.40	90.40	29.70	140.90	8.50
	Bt3	132-180	5.08	4.51	3.00	0.40	4.21	0.46	1.08	0.50	0.12	0.05	0.25	2.46	16.99	37.39	85.80	31.40	179.40	8.10
Orlu N1	Bt4	0-16	5.06	3.91	20.50	1.00	31.67	0.67	1.16	1.10	0.40	0.11	0.07	3.51	23.34	47.86	97.50	22.10	183.90	6.70
	Ap	16-43	4.86	3.90	10.60	3.10	52.20	0.99	1.25	0.70	0.20	0.11	0.12	3.37	16.82	33.53	90.40	21.10	165.50	6.40
	AB	43-67	4.93	3.82	7.40	1.40	112.61	0.99	1.08	0.80	0.60	0.11	0.09	3.67	15.93	43.60	85.80	24.30	140.90	7.10
	B	67-93	4.83	3.81	4.80	1.50	45.16	0.75	1.42	1.40	0.60	0.12	0.11	4.40	15.98	50.68	101.50	38.10	179.40	8.50
	Bt1	93-125	4.47	3.89	11.70	1.30	2.35	0.67	1.33	1.30	0.40	0.15	0.09	3.94	14.57	49.24	110.70	33.90	185.60	8.30
	Bt2	125-151	4.25	3.77	9.10	0.70	18.19	1.08	1.25	0.90	0.50	0.11	0.20	4.04	15.51	42.33	105.90	28.90	174.80	7.50

Appendix 1II (Cont): Chemical properties of soils of Iyanomo study centre

Ahiara Series (Q1)	A	0-18	4.73	4.08	18.00	2.40	18.77	0.16	0.25	1.30	0.50	0.65	0.89	3.75	33.01	37.89	85.50	24.90	114.30	7.70
	AB	18-42	4.60	3.93	7.60	1.40	28.74	0.08	0.16	1.10	0.70	0.10	0.62	2.76	20.66	52.72	100.90	30.40	170.80	8.30
	B1	42-71	4.97	4.08	10.60	1.30	12.86	0.08	0.16	0.90	0.20	0.09	0.54	1.97	11.64	45.51	135.80	35.30	208.10	8.70
	B2	71-104	5.22	4.36	14.10	1.00	16.98	0.08	0.08	1.60	0.80	0.15	0.95	3.66	19.93	37.16	117.40	28.90	185.60	7.40
	B3	104-133	5.16	4.27	6.70	0.60	13.31	0.08	0.16	1.00	0.30	0.13	0.82	2.49	14.34	36.80	143.30	34.40	201.60	8.80
	B4t	133-158	5.05	4.44	4.80	0.60	12.68	0.08	0.16	1.50	0.80	0.11	0.66	3.31	18.03	46.96	103.60	32.10	190.50	8.40
	B5t	158-180	5.35	4.19	4.30	0.40	24.63	0.16	0.08	1.60	0.30	0.10	0.16	2.40	12.40	50.00	96.70	29.80	168.80	8.10
Kulfo Series (CD1)	A1	0-16	5.51	5.04	19.40	3.80	21.11	0.16	0.25	1.90	0.80	0.04	0.10	3.08	20.73	41.86	90.50	30.30	153.60	8.60
	A12	16-43	5.31	4.59	19.00	1.40	23.46	0.16	0.25	1.10	0.50	0.12	0.39	2.52	21.25	50.33	85.70	26.80	140.90	7.40
	B	43-67	5.45	4.59	8.40	1.10	36.95	0.08	0.25	1.20	0.40	0.05	0.03	2.01	10.95	40.38	100.70	34.40	211.10	8.30
	Bt1	67-93	5.38	4.12	5.30	1.00	17.00	0.16	0.25	2.40	0.70	0.10	0.12	3.73	17.46	47.86	105.90	34.60	220.60	8.50
	Bt2	93-125	5.28	4.23	3.10	0.60	18.77	0.16	0.25	1.00	0.40	0.09	0.19	2.09	11.38	33.53	87.50	19.80	182.60	6.80
	Bt3g	125-151	5.16	4.38	7.00	0.70	7.04	0.08	0.42	2.10	0.40	0.09	0.17	3.26	16.01	43.60	89.80	20.30	170.50	7.20
	Bt4g	151-180	4.95	4.08	2.20	0.40	11.73	0.08	0.49	0.80	0.30	0.08	0.22	1.97	8.09	50.68	83.40	21.60	150.90	7.40
Orlu Series (OP8)	Ap	0-12	5.44	4.50	16.50	2.80	26.98	0.08	0.16	1.80	0.50	0.12	0.21	2.87	23.22	49.24	101.40	34.80	175.50	8.70
	AB	12-42	5.53	4.43	7.40	1.00	44.57	0.08	0.49	0.60	0.40	0.21	1.57	3.35	25.07	42.33	91.70	18.90	144.90	6.50
	Bt	42-70	4.80	3.76	8.90	0.10	56.30	0.08	0.33	1.10	0.80	0.10	0.09	2.50	10.94	53.41	110.50	33.30	163.90	8.50
	Bt2	70-112	4.93	3.95	8.20	1.00	56.30	0.16	0.16	2.70	0.40	0.16	0.67	4.25	16.76	42.73	113.90	34.80	195.10	8.40
	Bt3	112-144	4.92	4.07	8.20	0.60	8.21	0.16	0.33	1.00	0.60	0.15	0.46	2.70	11.08	32.74	94.30	31.10	130.80	8.40
	Bt4	144-170	4.85	3.88	8.90	0.30	1.74	0.16	0.16	1.10	0.60	0.71	3.13	5.86	23.11	33.96	120.80	32.90	185.90	8.20
Orlu Series (D6)	Ap	0-11	5.32	4.32	20.40	2.40	18.18	0.08	0.25	1.40	0.90	0.18	0.97	3.78	33.27	44.91	141.50	33.60	210.70	8.50
	AB	11-30	5.22	3.84	7.00	1.50	49.85	0.08	0.42	1.10	0.40	1.27	0.54	3.81	20.44	37.97	103.10	28.50	178.90	6.60
	Bt	30-69	5.73	4.26	8.60	1.10	13.49	0.08	0.42	0.70	0.20	0.27	1.30	2.97	13.48	25.75	99.40	27.90	176.50	6.40
	Bt2	69-108	5.58	4.06	9.60	1.80	6.45	0.67	0.67	1.20	0.60	0.23	0.85	4.22	21.06	37.32	130.50	34.10	210.70	8.40
	Bt3	108-157	5.67	4.02	5.20	1.40	1.17	0.58	0.67	1.10	0.70	0.17	0.49	3.71	14.53	49.36	115.90	29.60	162.50	7.20
	Bt4	157-182	5.10	4.11	2.10	0.60	1.76	0.83	0.58	1.40	0.60	0.14	0.27	3.82	17.01	55.20	116.30	30.70	120.80	8.20
Orlu Series G22	A	0-15	4.48	3.62	10.60	4.10	9.17	0.75	1.99	0.90	0.10	0.11	0.11	3.96	23.08	30.80	142.80	35.30	215.50	8.70
	BA	15-39	4.82	3.98	8.90	1.40	34.02	0.67	1.33	0.80	0.70	0.11	0.19	3.80	23.60	47.37	137.40	36.60	210.70	8.50
	Bt	39-70	4.70	3.87	11.30	1.00	12.51	1.08	1.49	1.20	0.60	0.15	0.27	4.79	20.79	46.34	139.80	36.90	231.50	8.10
	Bt2	70-110	4.89	3.87	6.90	1.40	95.60	0.92	1.58	0.70	0.10	0.23	0.77	4.30	19.08	41.86	110.50	29.80	202.50	7.20
	Bt3	110-139	4.98	3.99	6.50	1.10	8.80	0.83	0.66	0.90	0.40	0.12	0.09	3.00	14.56	50.33	96.60	28.10	181.50	6.90
	Bt4	139-171	4.01	3.98	7.70	1.00	0.59	0.75	1.42	0.90	0.40	0.14	0.03	3.64	15.91	40.38	105.90	31.60	211.70	8.30
	Bt5	171-190	3.97	3.65	17.80	3.50	26.39	0.50	1.15	0.90	0.70	0.18	0.06	3.49	15.83	52.72	100.70	28.90	186.60	7.40.

Appendix IV: Physical properties of Akwete soils

Profile No	Location (co-ord	soil series	Physiographic Position	Horizon	Depth (cm)	Colour	Sand	silt	Clay	Texture	Bulk density g cm^{-3}	Total porosity %
							g kg^{-1}					
AK 1	4°54'24.28"N 7°20'1.41"E	Uyo	upper slope	Ap	0-5	10YR 4/2	950	28	22	S	1.18	55.47
				AB	5-18	10YR 3/3	951	08	42	S	1.22	53.96
				B1	18-40	10YR 3/8	910	18	72	S	1.19	55.09
				Bt1	40-86	10YR 4/6	870	08	122	LS	1.29	51.32
				Bt2	86-127	7.5YR 5/6	880	18	102	LS	1.30	50.94
				Bt3	127-200	7.5YR 5/8	860	28	112	LS	1.45	45.28
AK2	4°19'39.63"E 7°54'16.42"N	Calabar	Middle/ lower slope	AC	0-17	5Y 4/2	970	18	12	S	1.32	50.19
				Cg1	17-34	5Y 5/2	980	18	02	S	1.29	51.32
				Cg2	34-52	5Y 6/2	980	18	02	S	1.38	47.92
				Cg3	52-70	5Y 7/2	980	18	02	S	1.44	45.66
				2Cc1	70-108	10YR 4/4	930	18	52	S	1.48	44.15
				2Cc2	108-165	2.5Y 6/6	940	08	52	S	1.42	46.42
				2Cc3	165-200	5Y 6/6	940	08	52	S	1.67	36.98
AK3	4°53'23.64"N 7°20'36.60"E	Etinan	Valley bottom	A	0-28	10YR 3/2	930	28	32	S	1.09	58.87
				AB	28-51	2.5Y 4/4	940	08	52	S	1.26	52.45
				BC	51-71	2.5Y 5/4	930	08	62	S	1.25	52.83
				C1	71-105	2.5Y 6/6	940	08	52	S	1.56	41.13
				C2	105-154	5Y 6/6	940	08	52	S	1.67	36.98
				C3	154-200	5Y 6/8	900	08	92	S	1.79	32.45

Appendix V: Chemical properties of Akwete soils

Profile No/ soil series	Horizon	Depth	pH	Org C	Total N	Avail P	K	Na	Ca	Mg	Ex Ac	ECEC	ECEC Clay	Base Sat	Fe	Zn	Mn	Cu
		(cm)	(H_2O)	(g kg^{-1})		mg/ kg^{-1}	cmol kg^{-1}							%	mg/kg			
AK 1 Uyo Series	Ap	0-5	4.60	18.80	2.53	8.40	0.22	0.07	0.96	0.32	1.68	3.25	14.77	48.31	83.8	4.12	37.2	2.66
	AB	5-18	4.50	8.80	1.35	8.00	0.23	0.07	0.48	0.64	0.88	3.72	8.86	38.17	73.9	2.75	34.6	2.75
	B1	18-40	4.50	7.90	1.25	5.60	0.32	0.54	0.32	0.32	2.80	5.80	8.06	25.86	62.7	1.24	32.4	0.36
	Bt1	40-86	4.50	4.70	0.87	6.40	0.05	0.07	1.28	0.64	2.72	6.80	5.57	30.00	150	3.21	53.5	2.94
	Bt2	86-127	4.70	2.20	0.57	3.20	0.06	0.06	0.48	0.48	1.52	3.68	3.61	29.35	123	1.14	63.5	1.17
	Bt3	127-200	4.60	1.10	0.44	3.60	0.07	0.07	0.48	0.48	1.40	3.60	3.21	30.56	151	1.19	62.8	1.6
AK 2 Calabar Series	AC	0-17	4.90	14.50	2.02	7.40	0.02	0.04	0.48	1.92	0.56	5.48	45.67	44.89	68.6	6.75	36.8	3.72
	Cg1	17-34	4.80	3.40	0.71	4.00	2.89	0.10	0.64	4.16	0.68	6.26	313.00	47.91	140	5.74	28.1	1.88
	Cg2	34-52	5.00	1.60	0.50	5.60	0.03	0.05	0.64	0.64	0.52	3.24	162.00	41.98	132	3.88	35.5	0.74
	Cg3	52-70	5.20	1.10	0.44	5.60	0.02	0.03	0.48	0.32	0.64	2.34	117.00	36.32	118	5.72	39.7	1.04
	2Cc1	70-108	4.80	2.20	0.57	6.00	0.03	0.06	0.48	0.64	0.52	2.94	5.65	41.16	74	7.74	33.7	3.83
	2Cc2	108-165	5.00	3.40	0.71	4.80	1.33	0.32	0.48	0.80	0.40	6.26	12.04	46.81	59	5.81	26.8	1.34
	2Cc3	165-200	5.00	0.90	0.42	9.60	0.04	0.10	0.64	0.16	0.48	2.36	4.54	39.83	69.3	5.02	32.6	1.05
																		1.
AK 3 Etinan Series	A	0-28	4.70	23.90	3.13	10.00	0.09	0.12	0.96	0.48	1.44	4.74	14.81	34.81	85.6	3.20	52.5	
	AB	28-51	4.80	7.90	1.25	4.40	0.03	0.04	0.48	1.44	0.80	4.78	9.19	41.63	80.6	2.89	28.3	2.56
	BC	51-71	4.90	4.30	0.82	8.80	0.03	0.06	0.48	0.16	0.88	2.34	3.77	31.20	83.8	1.12	37.2	1.66
	C1	71-105	4.80	2.00	0.55	3.60	0.45	0.08	0.32	0.32	1.00	3.34	6.42	35.03	73.9	2.75	345	1.75
	C2	105-154	4.80	1.40	0.48	4.00	0.06	0.04	0.16	0.80	1.16	3.28	6.31	32.32	62.7	3.23	32.6	1.36
	C3	154-200	4.50	0.90	0.42	2.80	0.15	0.05	0.32	0.32	0.88	2.56	2.78	32.81	150	1.21	53.5	2.94

Appendix VI: Suitability evaluation of Iyanomo and Akwete soils using the modified criteria of VanRanst *et al*. (1996)

Land Qualities	Ahiara	Kulfo	Orlu	Alagba	Uyo	Calabar	Etinan
Effective soil depth	180 (S1)	165 (S1)	178 (S1)	180 (S1)	200 (S1)	180 (S1)	200 (S1)
Ca	1.60 (S1)	0.30 (S1)	1.10 (S1)	2.4 (S1)	0.72 (S1)	0.48 (S1)	0.96 (S1)
Mg	0.51 (S1)	0.1 (S1)	0.80 (S2)	0.82 (S2)	0.32 (S1)	1.92 (S3)	0.48 (S1)
K	0.06 (S2)	0.16 (S2)	0.06 (S2)	0.25 (S1)	0.22 (S1)	0.02 (S2)	0.09 (S2)
Org C (g kg^{-1})	10.80 (S1)	14.6 (S1)	23.3 (S1)	30.0 (S1)	13.8 (S1)	14.5 (S1)	23.9 (S1)
pH	4.48 (S1)	4.13 (S1)	4.02 (S1)	5.65 (S1)	4.60 (S1)	4.90 (S1)	4.70 (S1)
Drainage	Moderate (S2)	Well (S1)	Well (S1)	Well (S1)	Well (S1)	Moderate (S2)	Moderate (S2)
Relative Humidity	> 80 (S1)	> 80 (S1)	> 80 (S1)	> 80 (S1)	> 80 (S1)	> 80 (S1)	> 80 (S1)
Altitude	38 (S1)	42 (S1)	48 (S1)	51 (S1)	23 (S1)	19 (S1)	15 (S1)
Surface texture	SL (S1)	LS (S1)	LS (S1)	SCL (S2)	S (S2)	S (S2)	S (S2)
Stoniness	Nil (S1)	Nil (S1)	Nil (S1)	Nil (S1)	Nil (S1)	Nil (S1)	Nil (S1)
Slope	< 10 (S1)	< 10 (S1)	< 10 (S1)	< 10 (S1)	< 10 (S1)	< 10 (S1)	< 10 (S1)
suitability class	S2	S2	S2	S2	S2	S3	S2

Appendix VII: Average dry rubber yield of various fields at Iyanomo in 2005/2006 and 2006/2007 seasons

Month	PB28-57	MN 4-7	LK 6,	OP6-9 MN7	Q6-12	Clonal garden	IJK	MN 9-12	RRI 6	RRI 15-16	Q12-13,	LK 13-17	MN 17-23	SG 2-6	Okun Zone	Ogbekpen
Jan	254.92	240.65	214.92	266.87	285.08	591.26	417.31	217.08	299.91	286.8	234.58	432.61	481.1	216.14	160.19	151.06
Feb	190.65	199.56	261.16	248.15	248.53	532.12	405.09	327.86	253.48	253.1	191.76	307.92	394.3	191.20	125.26	120.72
Mar	232.49	290.44	294.98	208.93	275.30	603.77	556.96	364.92	293.28	378.9	NA	417.54	383.0	235.62	110.20	101.18
Apr	182.69	202.82	193.29	179.21	232.65	314.21	378.42	260.38	203.94	249.7	268.37	229.02	195.0	150.17	113.99	137.99
May	145.86	160.86	143.39	144.22	281.68	193.59	294.31	211.65	152.92	174.4	NA	193.99	119.9	133.14	168.34	90.61
Jun	126.36	100.13	107.77	150.06	132.88	147.17	185.23	150.20	155.15	189.0	NA	172.87	124.6	93.11	151.57	93.51
Jul	159.11	153.10	151.43	180.78	233.34	305.18	349.85	207.73	181.86	264.9	NA	319.93	205.8	224.60	130.14	137.58
Aug	163.36	205.16	157.11	184.49	192.00	411.42	375.74	247.06	229.50	286.0	125.80	380.62	266.5	147.05	255.99	136.40
Sept	159.96	156.62	131.98	176.85	226.29	405.28	334.25	294.17	201.48	239.9	170.51	338.39	350.2	174.66	143.41	114.89
Oct	194.33	172.20	167.71	200.26	229.39	439.43	501.94	237.74	240.82	275.6	261.59	406.09	337.3	201.18	252.28	154.21
Nov	178.63	158.02	152.95	166.31	191.21	296.11	363.16	176.74	187.28	230.1	241.86	380.16	321.4	161.57	119.44	139.08
Dec	176.39	166.11	184.72	235.39	219.90	422.29	431.82	244.59	221.73	269.6	228.59	371.82	352.9	232.57	187.94	143.56
Total	2164.75	2205.6	2161.41	2341.5	2748.25	4661.8	4594.1	2940.12	2621.4	3098.0	1028.4	3951.0	3532.0	2161.0	1918.7	1520.79
#	187.62	187.64	182.98	207.19	228.13	426.51	400.96	250.70	229.76	261.35	215.38	355.82	337.33	184.31	169.81	137.238

Appendix VIII: Correlation matrix of soil properties with rubber yield at Iyanomo

	Sand	Silt	Clay	Surf BD	Sub BD	Sur Por	Sub Por	pH (H2O	Org C	Total N	Avail P	H	Al	Ca	Mg	Na	K	ECEC	B sat
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1																		
2	-.269	1																	
3	-.995	.106	1																
4	-.163	.028	.146	1															
5	-.001	.182	-.053	.882*	1														
6	-.15	.006	-.134	-.99**	-.884**	1													
7	-.012	-.181	.076	-‘88	-.994**	.884**	1												
8	-.019	.207	-.079	-.039	-.096	.052	.03	1											
9	.071	.726**	-.257	-.042	.203	.068	-.182	.141	1										
10	-.354	.233	.331	-.396	0.233	.428	.279	-.255	.308	1									
11	-.151	-.519*	.179	.448	.169	-.463	-.218	.382	-.530*	-.615*	1								
12	-.285	.246	-.319	.436	.472	-.454	-.477	-.341	.145	-.424	-.062	1							
13	.423	-.372	-.324	.042	.257	-.053	-.2	-.596*	-.596**	.078	-.17	.148	1						
14	-.26	.402	.262	-.182	-.34	.176	.345	.104	.104	-.19	-.221	.087	-.503*	1					
15	.059	-.25	.104	-.191	-.3	.175	.34	-.198	-.304	-.179	-.055	-.351	.082	.343	1				
16	.228	-.179	-.215	.118	.066	-.125	-.105	.225	-.333	-.301	.336	.078	-.137	-.367	-.016	1			
17	-.551*	-.093	.54*	.031	-.137	-.026	.14	.093	-.223	.359	.236	-.393	-.336	-.128	-.022	.167	1		
18	.081	-.173	-.04	.145	.142	-.172	-.078	-.728**	-.203	-.076	-.182	.259	.533*	.059	.519*	-.01	.113	1	
19	.324	.212	-.393	.127	-.019	.142	-.017	.756**	.346	-.179	.101	-.345	-.168	-.123	.068	.156	-.027	-.368	1
Yield	.303	-.062	-.291	-.680**	-.49	.683**	.500*	.078	.151	.142	-.274	-.268	.377	-.006	.033	-.2	.51*	-.203	.216

APPENDIX IX.

RUBBER RESEARCH INSTITUTE OF NIGERIA, IYANOMO, BENIN CITY

And

DEPARTMENT OF AGRONOMY, UNIVERSITY OF IBADAN, IBADAN

QUESTIONNAIRE

INDIGENOUS KNOWLEDGE ON LAND EVALUATION AND SOIL FERTILITY MANAGEMENT

SECTION A: IDENTIFICATION

State_____________ Local Government_____________ Village/Farm Settlement____________

SECTION B: PERSONAL CHARACTERISTICS

1. Sex (a) Male [ ] (b) female [ ]
2. Age_________________________ (in years)
3. Educational level
   (a) No formal education [ ]
   (b) Adult Education [ ]
   (c) Vocational training [ ]
   (d) Primary Education [ ]
   (e) Secondary Education [ ]
   (f) Post Secondary Education [ ]
4. Marital Status
   (a) Single [ ] (b) Married [ ] (c) Divorced [ ] (d) widowed
5. Number of wives if married ____________________________
6. Household size_____________________________________
7. Number of household members involved in farming on your farm (no)____________________
8. What is your primary occupation?

(i) Farming [ ] (ii) lumbering [ ] (iii) civil servant [ ] (iv) fishing [ ] (v) trading [ ] (iv) other (specify)___________________________

9. What other income generating activities do you engage in?

(a) Livestock farming [ ]

(b) Trading [ ]

(c) Hunting [ ]

(d) Gathering and selling non timber products [ ]

(e) Others (Specify)________________________________

10. Years of experience in rubber farming? _________________

SECTION C: SOCIO-ECONOMIC FACTORS

11. How many kg of coagula do you tap and sell per week

____

12 How many times do you tap per week_____________________________?

13. What is the total income (in Naira) that you realize from the sale of your coagula (in kg) per week? _______________________________________

14. At what current price do you sell your rubber per kg? __________________

15. What is the cost of labour per man day currently paid for labour in your locality ____

16. How much do you realize from other income generating activities/month.

(a) Livestock farming ____________________________________

(b) Trading ____

(c) Hunting ____

(d) Gathering and selling non timber products__________________

(e) Others specify _______________________________________

17. Indicate the source of your farm labour

(i) Family labour [ ] (ii) Cooperative labour [ ] (iii) Relatives [ ] (iv) Self labour [ ] (v) Hired labour [ ].

18. In what form do you sell your rubber? (i) Latex [ ] (ii) Coagula [ ] (iii) Sheet rubber [ ]

19. Which of the following best describe the availability of market to sell your latex/coagula

(a) Readily available [ ] (b) Available [ ] (c) Not available [ ] (d) Don't know [ ]

20. Did you receive any credit/loan for rubber production? Yes [ ] No [ ]

21. If yes what was the source of credit

(a) Agricultural Bank loan [ ]

(b) Cooperative Societies Loan [ ]

(c) Money Lenders [ ]

(d) Friend/relatives [ ]

(e) Others specify ____

22. What is the amount of credit received___________________________

23 Was the loan adequate Yes [ ] No [ ]

24. Do you belong to any organization/association? Yes [ ] No [ ]

25. Indicate as many organization/association you belong to

(a) Rubber farmers association [ ] (b) Cooperative society [ ] (c) village council of elders [ ]

(d) Age group [ ] (e) others specify____

26. What is your level of membership
(a) Ordinary member [ ] (b) committee member [ ] (c) Executive member [ ]

27. Indicate the number of urban centres you have traveled to and lived for a period of not less than 12 months._________________________

SECTION D: LAND/ FARM CHARACTERISTICS

28. What is the age of your mature rubber? _________________________

29. What is the land size of your mature rubber? ___________________

30. How did you acquire land for rubber farming?

(a) Land purchased and rubber plantation established by self [ ]

(b) Land inherited and rubber plantation established by self [ ]

(c) Established rubber plantation inherited from parents [ ]

(d) Established rubber plantation rented [ ]

31. How can you describe the soil in your rubber farmland?

(a) Sandy [ ]

(b) Loamy [ ]

(c) Clayey [ ]

(e) Gravelly [ ]

(f) Swampy [ ]

(g) Others (please specify)___________________________

32. Do you think the soil type in your rubber plantation affects your latex yield?

Yes [ ] No [ ]

33. How did you identify a good land for rubber?

(a) Visual appraisal [ ]

(b) Indicator plants [ ]

(c) Vigour of bush [ ]

(d) Cropping history [ ]

(e) Recommendation from ADP [ ] RRIN [ ] NTCDU [ ] Mitchellin [ ] Farmers co-operative [ ] Others (specify)_____________________

SECTION E: SOIL FERTILITY MANAGEMENT

34. Have you ever applied fertilizer to your rubber farm before? Yes [ ] No [ ]

35. If Yes, at what stage? Before tapping age [ ] during tapping age [ ] at old age [ ]

36. Which fertilizer did you apply?

(a) NPK [ ]

(b) Rock Phosphate [ ]

(c) Urea [ ]

(d) Single superphosphate (SSP) [ ]

(e) Murate of Potash (MOP) [ ]

(f) Organic Manure [ ]

(g) Others (Please specify) ____________

37. Was there any yield improvement as a result of the fertilizer applied

Yes [ ] No [ ]

38 If yes, what percentage increase did you observe 0-5% [ ] 5-15% [ ] 15-30% [ ] 30-50% [ ] Above 50% [ ]

39 What other soil management practises did you adopt?

Animal dung [ ]

Liming [ ]

Household waste [ ]

Intercropping [ ]

Cover cropping [ ]

Others (please specify)_____________

40. Have you ever applied latex stimulant before? Yes [ ] No [ ]

SECTION E: INFORMATION SOURCE

41. Please indicate the improved rubber production practices you have heard of and indicate through which of the under-listed sources of agricultural information you have heard about these improved practices.

a. NTCDU/TCU
b. RRIN
c. ADP
d. Rubber Rebirth, Michelin, Pamol (or other NGOs)
e. Farmers co-operative

S/N	Practices/Technologies	Heard about it		Source first heard about it
		Yes	No	
1	Land preparation for rubber cultivation			
2	Rubber plantation establishment			
3	Cultural practices and fertilizer application in rubber			
4	Cultural practices and intercropping in rubber			

5	Taping of rubber tree			
6	Weed management in rubber plantation			
7	Rubber plantation management			
8	Control of pest and diseases of rubber			
9	Lifting and handling of budded stumps			
10	Others specify______________________________			