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Land use change and carbon stock dynamics in Sub-Saharan Africa

Case study of Western Africa – Ghana

Cambiamenti di uso del suolo e dinamiche degli stock di carbonio nell'Africa Sub-Sahariana

SETTORE SCIENTIFICO-DISCIPLINARE
AGR05

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Only when the last tree has died, the last river has been poisoned and the last fish has been caught will we realize that we cannot eat money.

Cree proverb

Summary

1 List of Acronyms

AGB	Aboveground biomass
AFOLU	Agriculture, Forestry and Other Land Use
ANOVA	Analysis of variance
BGB	Belowground biomass
C	Carbon
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
DBH	Diameter at Breast Height
FAO	The Food and Agriculture Organization of the United Nations
FCPF	Forestry Carbon Partnership Facility
FLEGT	Forest Law, Enforcement and Trade
GPG	Good Practice Guidance
GPG-LULUCF	Good Practice Guidance for Land Use, Land-Use Change and Forestry
GPS	Global Positioning System
GREL	Ghana Rubber Estates Limited
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
NREG	Natural Resources and Environmental Governance Program
REDD:	Reducing Emissions from Deforestation And forest Degradation
REDD+	Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
R-PIN	Readiness Plan Idea Note
R-PP	Readiness Preparation Proposal
SD	Standard deviation
UNFCCC	United Nations Framework on Climate Change

2 Foreword

Climate change is perhaps the greatest environmental challenge emerged in the twenty-first century. It can be considered a source of the major global threats, such as hunger, poverty, armed conflict, displacement, air pollution, soil degradation, desertification and deforestation. These global issues are intricately intertwined and all contribute to climate change, necessitating a comprehensive approach to a solution (Stone and Chacón León, 2010).

The role of the African continent in the global carbon cycle, and therefore in climate change, is increasingly recognized (Houghton and Hackler, 2006; Williams et al., 2007). Of all the region in the world, Africa has contributed less than any other region to the greenhouse gas emissions, which are widely held responsible for global warming and consequently for climate change. But the continent is also the most vulnerable to the consequences and sub-Saharan Africa (SSA) is the least well equipped to face the issues related to climate change (Justice et al., 2005). In Sub-Saharan Africa the role of land use change in controlling CO_2 emissions and annual C budgets at regional and global scale may be more critical than in any other regions (Houghton and Hackler, 2006).

According to the IPCC in its Fourth Assessment Report, reducing and/or preventing deforestation is the mitigation option with the largest and most immediate carbon stock impact in the short term (UNFCCC, 2010). International community decided to face climate change problems related to deforestation, through specific policies to *Reducing Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks* (referred as REDD+). Deforestation and other land-cover changes typically release carbon from the terrestrial biosphere to the atmosphere as CO_2 (carbon dioxide), while recovering vegetation in abandoned agricultural or logged land removes CO_2 from the atmosphere and sequesters it in vegetation biomass and soil carbon. Emissions from land-use and land-cover change are perhaps the most uncertain component of the global carbon cycle, with enormous implications for balancing the present-day carbon budget and predicting the future evolution of climate change (Ramankutty et al., 2007).

A common paradigm about the reduction of emissions from deforestations estimated for the purpose of promoting it as a mitigation option in the context of the United Nations Framework Convention on Climate Change (UNFCCC) is the high uncertainties in input data - i.e., area change and C stock change/area - that may seriously undermine the credibility of the estimates and therefore of reduced deforestation as a mitigation option. It is likely that the most typical and important example of incomplete estimates will arise from the lack of reliable data for a carbon pool (Grassi et al., 2008). Uncertain rates of tropical deforestation, account for more than half of the range in estimates of the global carbon flux. Three other factors account for much of the rest of the uncertainty: (1) the initial stocks of carbon in ecosystems affected by land-use change, (2) per hectare changes in carbon stocks in response to different types of land-use change, and (3) legacy effects; that is, the time it takes for carbon stocks to equilibrate following a change in land use (Houghton and Goodale, 2004).

Considering the source of uncertainty and the lack of field data for sub-Saharan Africa, it has been decided to place the study in the Ghana (Jomoro district, Western Region) where for more than 20 million Ghanaians, particularly people living in the rural areas, the forest is the only source of wood that is used locally as fuel wood, and for construction and furniture (Blay et al., 2007) and where deforestation annual rate reaches 2.19% for the period 2005-2010 (FAO, 2010).

The study will analyze the above mentioned gaps related to deforestation and land use change, by assessing: 1) initial carbon stocks (tropical rain forest), 2) per hectare changes in carbon stocks as consequence of deforestation followed by six different main land uses [tree plantations (rubber, coconut, cocoa, oil palm, mixed) and secondary forest], 3) dynamics of soil carbon stocks through the time considering chronosequences.

Moreover some specific carbon pool issue has been taken into consideration. When accounting changes in carbon stocks in the UNFCCC framework, it is required to consider 5 carbon pools that are: aboveground biomass, belowground biomass, litter, dead wood and soil. Within REDD+ mechanism there are not official methodologies but some guidelines developed for the voluntary standards (e.g. BioCarbon Fund- *Methodology for Estimating Reduction of GHG Emission from Mosaic Deforestation*, Voluntary Carbon Standard (VCS) - *Tool for AFOLU Methodological Issues*, etc.) and it is clear that only aboveground pool has to be always considered, belowground biomass is recommended and the others are facultative.

Evidence from official reports (e.g., UNFCCC 2005a, UNFCCC 2005b, FAO 2006) suggests that only a very small fraction of developing countries currently reports data on soil carbon, even though emissions from soils following deforestation are likely to be significant in many cases (Grassi et al., 2008).

Despite the common understanding about the effects of deforestation on different compartment in terms of carbon variation - an increase or disappearance of biomass relatively visible, variations in soil carbon much less perceptible, even after a radical change in land use (Calmel et al., 2010) - this study brings in the spotlight the soil reaction to radical land use change in the long run demonstrating that it is not so trifle as commonly believed. Importance of considering soil carbon stock for accounting the land use change dynamics is not properly recognize in the international deforestation policies and its influence and role in mitigating climate change is nowadays neglected but it is really not negligible.

3 Sommario

I cambiamenti climatici sono forse la più grande sfida che il genere umano si trova a dover affrontare nel ventunesimo secolo e la risoluzione delle complesse conseguenze che questi cambiamenti hanno sulla vita di tutti noi, necessita un approccio globale e uno sforzo unanime (Stone and Chacón León, 2010). Di tutte le regioni del mondo, il continente africano è quello che contribuisce meno alle emissioni di gas serra ma allo stesso tempo è il più vulnerabile alle loro conseguenze. E' infatti ormani ampiamente riconosciuto il ruolo delle emissioni di gas serra nel riscaldamento globale e quinid dei cambiamenti climatici (Houghton and Hackler, 2006; Williams et al., 2007). In particolare l'Africa Sub-Sahariana è la regione meno preparata ad affrontare le problematiche legate ai cambiamenti climatici (Justice et al., 2005) e soprattutto è la regione in cui i cambiamenti di uso del suolo possono avere implicazioni particolarmente negative nel controllo delle emissioni di CO_2 e sul bilancio annuale di carbonio (Houghton and Hackler, 2006). In base a quanto riportato ne *Fourth Assessment Report* dell'IPCC, ridurre e prevenire la deforestazione è l'opzione migliore per la mitigazione dei cambiamenti climatici dato il suo immediato impatto sugli stock di carbonio nel breve periodo (UNFCCC, 2010). La comunità internazionale ha deciso quindi di affrontare il problema della deforestazione attraverso specifiche politiche per ridurre le emissioni dovute alla deforestazione e alla degradazione delle foreste valorizzando il ruolo dellla conservazione, della gestione sostenibile e aumentando gli stock di carbonio delle foreste, tale meccanismo è conosciuto come REDD+ dal suo acronimo inglese (*Reducing Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks*). Le emissioni legate ai cambiamenti di uso e copertura del suolo sono forse la componente più incerta all'interno del ciclo globale del carbonio, con enormi implicazioni per il bilancio attuale e per le previsioni di evoluzioni future dei cambiamenti climatici (Ramankutty et al., 2007). Questo condiziona perciò la credibilità delle stime che attestano la valità della riduzione della deforestazione come miglior opzione per la mitigazione dei cambiamenti climatici. La mancanza di dati affidabili sulle stime dei pool di carbonio ne è l'esempio più tipico (Grassi et al., 2008). I tassi incerti della deforestazione tropicale rappresentano più della metà delle stime globali del flusso di carbonio. Tre altri fattori rappresentano più della restante parte di incertezza e questi sono: 1) gli stock iniziali di carbonio nell'ecosistema soggetto al cambiamento di uso del suolo, 2) cambiamenti ad ettaro degli stock di carbonio come risposta a differenti tipi di cambiamento di uso del suolo e 3) gli effetti a lungo termine considerati come il tempo necessario agli stock di carbonio per tornare ad una situazione di equilibrio dopo il cambiamento di uso del suolo (Houghton and Goodale, 2004). Considerando le fonti di incertezza e la mancanza di dati per l'Africa sub-Sahariana, il presente studio è stato ha avuto come oggetto la realtà del Ghana (Jomoro district, Western Region) dove una popolazione di più di 20 milioni di persone e in particolar modo nelle aree rurali, dipende dalla foresta come unica fonte di legno usato come legna da ardere, per costruzioni e mobili (Blay et al., 2007) e dove il tasso annuo di deforestazione ha raggiunto il 2.19% nel periodo 2005-2010 (FAO, 2010). Il presente studio analizzerà quindi gli aspetti legati alla deforestazione e al cambiamento di uso del suolo stimando: 1) lo stock iniziale di carbonio della foresta pluviale, 2) i cambiamenti ad ettaro degli stock di carbonio come conseguenza della deforestazione seguita da sei diversi usi del suolo in particolare piantagioni di gomme, cocco, palma da olio, piantagioni miste e infine la foresta secondaria generata dall'abbandono di terre prima destinate all'agricoltura, 3) la dinamica degli stock di carbonio nel tempo tramite l'analisi di cronosequenze. Alcuni specifici pool di carbonio sono stati presi in esame. Stimado i cambiamenti di stock di carbonio nel contesto dell'UNFCCC vengono richiesti 5 pools che sono: la biomassa epigea, la biomassa ipogea, la lettiera, la necromassa e il suolo. All'interno del meccanismo REDD+ non sono ancora state previste metodologie specifiche per la stima di questi pools ma sono state sviluppate alcune linee guida di carattere insicativo a cui poter far riferimento (es. BioCarbon Fund- *Methodology for Estimating Reduction of GHG Emission from Mosaic Deforestation*, Voluntary Carbon Standard (VCS)- *Tool for AFOLU Methodological Issues*, etc.) ed è chiaro che il pool che deve sempre incluso nelle stime rimanga la biomassa epigea mentre quella ipogea è raccomandata e gli altri pool sono facoltativi e discrezionali. Da report ufficiali (es., UNFCCC 2005a, UNFCCC 2005b, FAO 2006) emerge che solo una piccola parte dei paesi in via di sviluppo ad oggi include il pool del suolo nelle stime anche se le emissioni dal suolo a seguito di un processo di deforestazione risultano essere in molti casi significative (Grassi et al., 2008). A dispetto di quanto comunemente si crede riguardo gli effetti della deforestaizone sui differenti comparti in termini di variazione di carbonio, (un aumento o scomparsa della biomassa risultano relativamente visibili, mentre variazioni del suolo molto meno percettibili anche dopo cambi radicali nell'uso del suolo (Calmel et al., 2010), questo studio porta alla luce la reazione del comparto suolo a cambi radicali legati a processo di deforestazione nel lungo periodo dimostrando che il cambiamento non è così irrilevante come comunemente creduto. L'importanza del considerare il suolo nelle dinamiche post deforestazione, non è adeguatamente riconosciuta nelle politiche internazionali e questo influenza il ruolo che il comparto suolo può avere nella mitigazione dei cambiamenti climatici oggi forse trascurato ma non certo trascurabile.

4 Introduction

4.1 Tropical forests and climate change

The rapid increase in atmospheric concentration of CO_2 and other greenhouse gases (CH_4, N_2O, NO_x) since about 1850 has raised numerous questions of global significance. Several are important: What is the role of tropical ecosystems as sources or sinks for atmospheric CO_2, and how does the potential change in climate alter ecological processes and basic function of such ecosystems? How do anthropogenic perturbations of tropical ecosystems affect atmospheric CO_2 concentrations, and how would these ecosystems function under raised levels of atmospheric CO_2? What is the role of soils of tropical ecosystems in the global carbon cycle, and what soil management options can exploit the full potential of these soils as major sinks for atmospheric CO_2?

Forests are important carbon pools which continuously exchange CO_2 with the atmosphere, due to both natural processes and human action. Understanding forests' participation in the greenhouse effect requires a better understanding of the carbon cycle at the forest level. Organic matter contains carbon susceptible to be oxidized and returned to the atmosphere in the form of CO_2. Carbon is found in several pools in the forest:

- the vegetation: living plant biomass consisting of wood and non-wood materials. Although the exposed part of the plant is the most visible, the below-ground biomass (the root system) must also be considered. The amount of carbon in the biomass varies from between 35 to 65 percent of the dry weight (50 percent is often taken as a default value).
- dead wood and litter: dead plant biomass, made up of plant debris. Litter in particular is an important source of nutrients for plant growth.
- soil organic matter, the humus. Humus originates from litter decomposition. Organic soil carbon represents an extremely important pool.

African tropical rainforest (TRF) areas have been geologically stable for long periods of time and the soils have undergone intense weathering. In forest environments the nutrients are largely locked in the living vegetation. Once the forest is removed, the soil degrades rapidly as a result of microclimatic changes, and quickly loses its nutrient supply through leaching under the abundant rainfall (FAO, 2003). In the contest of the global C balance, land use practices are closely linked with C stock (Hairiah et al. 2001).

The impacts of the ongoing processes of land use change need to be assessed and efforts to store more C in terrestrial ecosystems need to be evaluated, in terms of their ability to slow down the rate of increase of atmospheric CO_2. Data on soil C stocks are particularly needed to stimulate C storage in the process of development. A reduction in organic inputs to the soil and/or accelerated losses after forest conversion to agricoltural land, lead to a decline in the more active ('labile') C fractions in the soil with a depletion of 20-50 % of the original conditions for repeated cropping periods. These changes mainly caused by agricultural management i.e. residue removal via harvesting or burning, and soil tillage, influence crop productivity at a localised scale as well as the global C budget. So, to some extent, the interests of the farmer in maintaining soil fertility may coincide with interests at the global level in reducing the rate of increase of atmospheric CO_2 (Hairiah et al. 2001). Soil degradation, and in particular the decline of soil chemical fertility, is a major concern in relation to food production and the sustainable management of land resources. It also affects land use but the spatial and temporal effects of soil fertility change and its interaction with land cover change has to be investigated. Conservation and improvement of the natural resources on which agricultural production depends is essential (Hartemink et al. 2008).

At the global level, 19 percent of the carbon in the earth's biosphere is stored in plants, and 81 percent in the soil. In all forests, tropical, temperate and boreal together, approximately 31 percent of the carbon is stored in the biomass and 69 percent in the soil. In tropical forests, approximately 50 percent of the carbon is stored in the biomass and 50 percent in the soil (IPCC 2000).

Wood products derived from harvested timber are also significant carbon pools. Their longevity depends upon their use: lifetimes may range from less than one year for fuelwood, to several decades or centuries for lumber.

The oxidation of carbon found in organic matter and the subsequent emissions of CO_2 result from the following processes:

- respiration of living biomass,
- decomposition of organic matter by other living organisms (also called heterotrophic respiration),
- combustion (fires).

The process of photosynthesis explains why forests function as CO_2 sinks, removing CO_2 from the atmosphere. Atmospheric CO_2 is fixed in the plant's chlorophyll parts and the carbon is integrated to complex organic molecules which are then used by the whole plant.

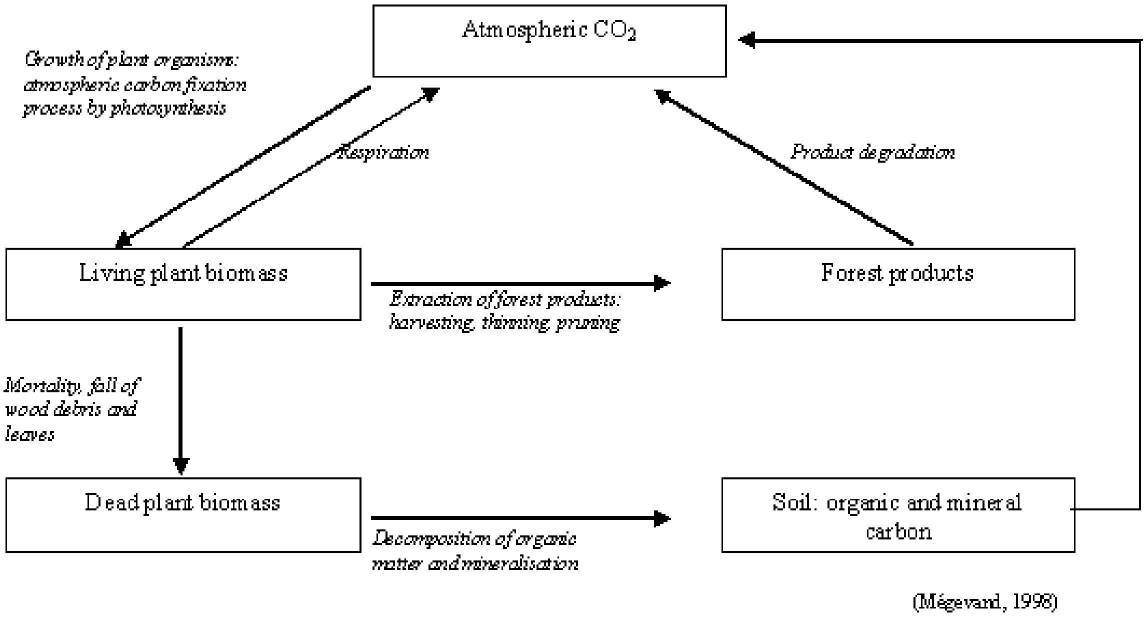

Figure 1: The carbon cycle in the forest (source: Mégevand 1998)

The participation of forests in climate change is thus three-fold:

• they are carbon pools

• they become sources of CO_2 when they burn, or, in general, when they are disturbed by natural or human action

• they are CO_2 sinks when they grow biomass or extend their area.

The earth's biosphere constitutes a carbon sink that absorbs approximately 2.3 Gt C annually. This represents nearly 30 percent of all fossil fuel emissions (totaling from 6.3 to 6.5 Gt C yr^{-1}) and is comparable to the CO_2 emissions resulting from deforestation, 1.6 to 2 Gt C yr^{-1}.

The carbon cycle (photosynthesis, plant respiration and the degradation of organic matter) in a given forest is influenced by climatic conditions and atmospheric concentrations of CO_2. The distinction between natural and human factors influencing plant growth is thus sometimes very difficult to make. The increase of CO_2 in the atmosphere has a "fertilizing effect" on photosynthesis and thus, plant growth. There are varying estimates of this effect: + 33%, + 25%, and + 60% for trees, + 14% for pastures and crops (IPCC, 2001). This explains present regional tendencies of enhanced forest growth and causes an increase in carbon absorption by plants. This also influences the potential size of the forests carbon pool. There are still questions regarding the long-term future of the biospheric carbon pool. Several bio-climatic models indicate that the ecosystems' absorption capacity is approaching its upper limit and should diminish in the future, possibly even reversing direction within 50 to 150 years, with forests becoming a net source of CO_2. Indeed, global warming could cause an increase in heterotrophic respiration and the decomposition of organic matter, and a simultaneous decrease of the sink effectiveness, thereby transforming the forestry ecosystems into a net source of CO_2 (Scholes, 1999).

4.2 Tropical deforestation and land use change

By virtue of their size and biomass contained in them, tropical ecosystems are important to the global C cycle. Tropical rainforest ecosystems consist of approximately one-sixth of the deciduous forests of the world and occur between 6 to 10° north and south of the equator in South America, Africa, Southeast Asia and the Pacific. Primeval TRF covered more than 90% of the biome’s land surface before the advent of humankind. Bruenig (1996) estimated that cumulative area of all TRF was 5.5 x 10^6 km^2 in 1975 and 4.4 in 1985. The area of TRF is projected to be 4.0 x 10^6 km^2 in 2000 and 3 x 10^6 km^2 in 2050. Bruenig (1996) estimated temporal changes in TRF (million ha) in tropical America from 1850 to 1985 as follow:

	1850	1985
Evergreen	226	212
Seasonal	616	445
Open	380	211
Total	1222	868

The distribution of land area of the TRF in three continents and the rate of deforestation are shown in Tables 1 and 2. The types of vegetation in three ecoregions of Asia, Africa and tropical America are quite different from one another, highly variable or diverse (Jordan, 1983; Almeda and Pringle, 1988), and are characterized with a large quantity of above and below ground biomass. The annual addition of biomass in TRF (e.g. litter, branches and dead roots) in the mature forest is about 5 Mg ha^{-1} yr^{-1} compared with about 1 Mg ha^{-1} yr^{-1} in temperate forest. The range of organic matter return to the soil is 3 to 15 Mg ha^{-1} yr^{-1} in TRF compared to 1 to 8 Mg ha^{-1} yr^{-1} in temperate forests.

Table 1: Estimates of forest cover and deforestation in the humid tropics (1000 ha). Modified from NRG (1993).

Continent	Forest 1980	Forest 1990	Annual rate of deforestation 1981-1990	Rate of change 1981-1990 (% yr^{-1})
Africa	289,700	241,800	4,800	-1.7
Latin America	825,900	753,000	7,300	-0.9
Asia	334,500	287,500	4,700	-1.4
Total	1,450,100	1,282,300	16,800	-1.2

Table 2: Tropical rainforests and the rate of deforestation. Modified from WRI, 1993; Soughate, 1998; and Faminow, 1998; Faminow estimated total TRF at 1756.5 M ha and the rate of deforestation at 15.4 M ha^{-1} yr^{-1}

Region	Area (10^6)	Rate of deforestation
Central Africa	204,10	1.08
Tropical southern Africa	100,46	0.84
West Africa	55,60	0.53
South Asia	63,90	0.5
Southest Asia	210,60	2.8
Mexico	48,60	0.59
Central America	19,50	0.36
Brazil	561,10	3.42
Andean region and Paraguay	241,80	2.25
Total	1,505,70	12.37

Estimates made for *Forest Resource Assessment* (FRA 2010), show that the world's forests store more than 650 billion tons of carbon, 44% in the biomass, 11% in dead wood and litter, and 45% in the soil. While sustainable management, planting and rehabilitation of forests can conserve or increase forest carbon stocks, deforestation, degradation and poor forest management reduce them. Deforestation and other land-cover changes as well as logging and intensive cultivation of cropland soils, typically release carbon from the terrestrial biosphere to the atmosphere as CO_2 (carbon dioxide), while recovering vegetation in abandoned agricultural or logged land removes CO_2 from the atmosphere and sequesters it in vegetation biomass and soil carbon (Ramankutty et al., 2007; IPCC, 2007). Emissions from land use change (LUC) are the second-largest anthropogenic source of CO_2. These emissions are partly compensated by CO_2 uptake from the regrowth of secondary vegetation and the rebuilding of soil carbon pools following afforestation, abandonment of agriculture (including the fallow phase of shifting cultivation), fire exclusion and the shift to agricultural practices that conserve soil carbon. Unlike fossil fuel emissions, which reflect instantaneous economic activity, LUC emissions are due to both current deforestation and the carry-over effects of CO_2 losses from areas deforested in previous years (Le Quéré et al., 2009). A central role has been taken by tropical deforestation and forest degradation which have dramatically increased in the last 100 years, and have accelerated since the 1960s as a result of mechanization, improved transport, the globalization of markets and other factors. Emissions from deforestation since 1850 have contributed to 90% of the emissions from land use change, resulting from a 20% decrease in forest area (Houghton JT et al., 2001). Emissions from land-use and land-cover change in terms of CO_2 are estimated to be 5.9 Gt CO_2 per year over the 1990s, although these estimates are perhaps the most uncertain component of the global carbon cycle, with enormous implications for balancing the present-day carbon budget and predicting the future evolution of climate change (Ramankutty et al., 2007; IPCC, 2007; UNFCCC, 2010). Deforestation and forest degradation may have released between 0.8 and 2.2 Gt C per year during the period 1990–2000, corresponding to 10–25% of the global human-induced GHG emissions in that decade (Houghton, 2003; DeFries et al., 2002). In addition, forest fires contribute to the release of GHG; for example, forest and peat fires in Indonesia in 1997/1998 may have released the equivalent of one-third of the aggregated annual anthropogenic carbon emissions in that period (World Bank, 1999; Page et al., 2002). Table 3 lists the countries with the highest total and relative deforestation.

Table 3: The ten countries with the highest absolute and relative deforestation rates in the world

Country	Deforestation (ha) (average per annum 1990–2005)	Country	Deforestation (% of 1990 forest cover)
Brazil	2,821,900	Burundi*	6.0
Indonesia	1,871,500	Togo*	5.2
Sudan*	589,000	Honduras*	3.9
Myanmar*	466,500	Nigeria	3.7
DR Congo*	461,400	Niger*	3.6
Zambia*	444,800	Philippines	3.2
Tanzania*	412,300	Benin*	2.8
Nigeria	409,700	Uganda*	2.4
Zimbabwe	312,900	Ghana	2.3
Venezuela	287,500	Indonesia	2.1
Other 68 countries	3,257,400		
Total	11,334,900	Average 78 tropical countries	0.65

*LDC countries in the UNFCCC. Source: (Forner et al., 2006)

Table 3 shows that the four countries with the highest annual deforestation together accounted for 51% of total tropical deforestation between 1990 and 2005. Estimates using data from 78 tropical developing countries indicate that the highest average deforestation between 1990 and 2005 occurred in Tropical South America[1], (4.44 M ha yr^{-1}) followed by Africa[2] (4.1 M ha yr^{-1}), and Tropical Asia and the Pacific[3] (2.8 M ha yr^{-1}). In relative terms, the highest annual deforestation rate is observed in Tropical Asia (0.88%), followed by Africa (0.69%) and Tropical America (0.53%). Sub-regions with the highest annual relative loss of forests between 1990 and 2005 were West Africa (1.65%) and Central America (1.05%). It is worthy to note that between 1990 and 2005, tropical deforestation progressed at an average rate of 11.3 million ha yr^{-1}, a rate of 0.65% (Forner et al., 2006). For the world as a whole, carbon stocks in forest biomass decreased by an estimated 0.5 Gt annually during the period 2005–2010, mainly because of a reduction in the global forest area. The net change in forest area in the period 2000–2010 is estimated at -5.2 million hectares per year at the global level. Around 13 million hectares of forest were converted to other uses – largely agriculture – or lost through natural causes each year in the last decade (FAO, 2010). According to the IPCC in its Fourth Assessment Report, reducing and/or preventing deforestation is the mitigation option with the largest and most immediate carbon stock impact in the short term (UNFCCC, 2010). The conversion of forested land to uses such as agriculture represents in fact a radical change

[1] Data from 10 countries
[2] Data from 36 countries
[3] Data from 18 countries

in the ecology of an area but knowledge of the longer-term implications of large-scale changes in the forest landscape – at national and global levels – is limited (Grainger, 1993; Kaimowitz et al., 1998). To worsen this situation there is the gap in deforestation and forest degradation assessment (Van der Werf et al., 2009). In detail, deforestation is the long-term reduction of tree canopy cover (Penman et al., 2003) to below 10–30%. In practice, deforestation is associated with the conversion of forest to other types of land use, such as cropland or pasture. Forest degradation is typically considered partial deforestation, with more than 10–30% of forest cover remaining (for example, through selective logging). Land degradation that does not involve changes in tree cover density, such as oxidation and combustion of deforested and drained tropical peatlands, may also involve substantial carbon emissions. However, losses of these non-forest carbon stocks are not generally included in deforestation and forest degradation assessments (Van der Werf et al. 2009). Tropical deforestation and forest degradation patterns are heterogeneous due to a wide array of drivers, where socio-economic factors play the greatest role in shaping local deforestation. Due to social, environmental and political complexities, the indirect nature of many of the causal relations and the wide diversity of situations, any attempt to generalize the causes of deforestation and forest degradation is difficult and ‘invites criticism’ (Kaimowitz and Angelsen, 1999). However, there is evidence that deforestation and poverty are linked (Grainger, 1993; Kaimowitz et al., 1998) and that deforestation causes changes in local site conditions that can exacerbate natural disasters (Blaser and Husain, 2001). The essential role of forests in supporting life on Earth is highlighted by possibility of mitigating climate change by reducing carbon emissions caused by deforestation and forest degradation, and by increasing carbon uptake through afforestation and sustainable forest management. But forests are more than just carbon. At local to global scales, forests provide essential ecosystem services beyond carbon storage – such as watershed protection, water flow regulation, nutrient recycling, rainfall generation and disease regulation (GCP, 2008). In a time of economic crisis, it should be reminded that forests provide employment and livelihoods for a large proportion of the population – especially in developing countries – and often act as an economic safety net in times of need (FAO, 2010). Sustainably managed forests have multiple environmental and socio-economic functions important at the global, national and local scales, and play a vital part in sustainable development. Reliable and update information on the state of forest resources - not only on area and area change, but also on such variables as growing stock, wood and non-wood products, carbon, protected areas, use of forests for recreation and other services, biological diversity and forests' contribution to national economies - is crucial to support decision - making for policies and programs in forestry and sustainable development at all levels (FAO, 2010). The future role of forests and particularly tropical forests in the global carbon cycle and the climate system is a function of future deforestation rates and the degree to which remaining forests will be sustainable or even increase their carbon stock. Deforestation rates are strongly influenced by economic development and international agreements about the protection of forest resources (Cramer et al., 2004). In developing countries, deforestation is the largest source of emissions from the forestry sector and it has remained at high levels since 1990 (FAO, 2005). The causes of tropical deforestation are complex, varying across countries and over time in response to different social, cultural, and macroeconomic conditions (Geist and Lambin, 2002). Broadly, three major barriers to enacting effective policies to reduce forest loss are: (i) profitability incentives often run counter to forest conservation and sustainable forest management (Tacconi et al., 2003); (ii) many direct and indirect drivers of deforestation lie outside of the forest sector, especially in agricultural policies and markets (Wunder, 2004); and (iii) limited regulatory and institutional capacity and insufficient resources constrain the ability of many governments to implement forest and related sectorial policies on the ground (Tacconi et al., 2003). Globally, land use has changed considerably in the past decades – mostly reflecting the enormous growth in human population and their need for food. The world's population has doubled since 1960. The developing world accounts for about 95% of the population growth with Africa as the world's fastest growing region. The growing population has many implications but most of all it requires an increase in agricultural production to meet food demand. This demand can be met by expansion of agricultural land or by intensification of existing systems. Conservation and improvement of the natural resources on which agricultural production depends is essential (Hartemink et al., 2008). Land use has generally been considered a local environmental issue, but it is becoming a force of global importance. Worldwide changes to forests, farmlands, waterways, and air are being driven by the need to provide food, fiber, water, and shelter to more than six billion people. Global croplands, pastures, plantations, and urban areas have expanded in recent decades, accompanied by large increases in energy, water, and fertilizer consumption, along with considerable losses of biodiversity. Such changes in land use have enabled humans to appropriate an increasing share of the planet's resources, but they also potentially undermine the capacity of ecosystems to sustain food production, maintain freshwater and forest resources, regulate climate and air quality, and ameliorate infectious diseases. Human race faces the challenge of managing trade-offs between immediate human needs and maintaining the capacity of the biosphere to provide goods and services in the long term (Foley et al., 2005).

4.3 Africa

Africa has the world's lowest CO_2 emissions. Climate change is now recognized as an equity issue because the world's poorest people, those who contributed least to the atmospheric buildup of greenhouse gases, are the least equipped to deal with the negative impacts of climate change. Wealthier nations that have historically contributed the most to global warming are better able to adapt to the impacts. Addressing disparities between developed and developing countries is integral to the success of global climate change mitigation and adaptation (Osman-Elasha, 2009). Tropical terrestrial ecosystems across the African continent may play an increasing role in the global carbon (C) cycle with potentially significant climate change implications (Stephens et al., 2007), especially in sub-Saharan Africa where the role of land use change in controlling CO_2 emissions and annual C budgets at regional and global scale may be more critical than in other regions (Houghton and Hackler, 2006). New studies confirm that Africa is one of the most vulnerable continents to climate variability and change because of the range of projected impacts, multiple stresses and low adaptive capacity (IPCC AR4). The Intergovernmental Panel on Climate Change (IPCC, 2007a) has reported a warming of approximately 0.7 °C over most of the African region during the twentieth century. This warming occurred at the rate of about 0.05 °C per decade, with slightly more warming in the season from June to November than from December to May. A temperature rise of about 0.1 °C per decade is expected for the next two decades, even if greenhouse gas and aerosol concentrations are kept at year 2000 levels. IPCC has reported that extreme events, including floods and droughts, are becoming increasingly frequent and severe. Certain regions of Africa are more prone to such extreme events than others. It is probable that the increased frequency of recorded disasters is a result of a combination of climatic change and socio-economic and demographic changes. Habitats and ecosystems in Africa are currently under threat from a variety of stresses such as deforestation, land degradation and heavy dependence on biomass for energy (United Nations, 2007). Furthermore Africa's vulnerability to climate change is exacerbated by a number of non-climatic factors, including endemic poverty, hunger, high prevalence of disease, chronic conflicts, low levels of development and low adaptive capacity. The average income per capita in most African countries is lower now than it was 30 years ago. Of the 25 countries in Africa that faced food emergencies in 2003, ten are currently experiencing civil strife and four are emerging from conflicts. Conflicts often divert scarce resources into military budgets and away from development needs, and result in high numbers of internally displaced persons and refugees. Other non-climatic factors adding to Africa's vulnerability include heavy dependence on primary products; poor governance and weak institutions; low capital investment; lack of access to foreign markets; poor infrastructure; inadequate technology transfer; and continuing high levels of external debt, fast-growing population, leading to pressure on already degraded landscapes above all on forest resources, deforestation and forest degradation (Osman-Elasha, 2009). African forests contain large carbon stocks in biomass, up to 255 Mg C ha^{-1} in tropical rainforests (Palm et al., 2000), that appear to be particularly vulnerable, mainly due to the impact of climate change, land use change, population increase and political instability. Africa's land use pressures will undoubtedly increase in the next years and the forecasted increase in drought and temperature can lead to a significant decrease in ecosystem carbon stocks in tropical forests and savanna, at least without human countermeasures (Tan et al. 2009). Previous studies on the African continent C budget focused only on either forests or conversion of forest to cropland (Houghton and Hackler, 2001, 2006). In fact, human activities such as cutting, fuelwood harvest, fertilization, and other factors affecting net primary productivity also play a critical role in regional and global C budgets (Tan, 2009). Despite the increasingly acknowledged importance of Africa in the global carbon cycle and its high vulnerability to climate change due to both ecological and socio-economic factors, there is still a lack of studies on the carbon cycle in representative African ecosystems, in particular tropical forests (Bombelli et al., 2009). Sustainable development in Africa cannot be addressed effectively without accounting for the impacts of climate change on agriculture, conflicts and disease patterns, all of which have particular impact on the poor. Sustainable development and adaptation are mutually reinforcing; an important conclusion of IPCC is that adaptation measures, if taken up in the sustainable development framework, can diminish negative impacts from future climate change (Osman-Elasha, 2009).

4.4 Ghana context

Ghana lies between longitudes 3° 15’ W and 1° 12’ E, and latitude 4° 44’and 11° 15’ N. The country is bordered on the East by the Republic of Togo, the West by Cote d’Ivoire, the North by Burkina Faso and the South by the Gulf of Guinea. The total land area of Ghana is 238,533 km^2 with an Exclusive Economic Zone (EEZ) of 110,000 km^2 of the sea, forming the territorial area of Ghana. Ghana has a coastline of 550 km^2. The country is under the influence of the tropical humid climatic conditions and experiences two major seasons, namely the rainy season and dry season, brought about by the harmattan, a dry dusty wind that blows along the northwest coast of Africa. The mean minimum rainfall is 900 mm yr^{-1} occurring around the Southeastern part of Ghana (Accra-Aflao) while the mean maximum rainfall is about 2000 mm yr^{-1}, occurring in the southwestern portions (Axim). Mean minimum temperature ranges from 21 °C to 23 °C and mean maximum temperature is from 30 °C to 35 °C. The mean annual evapotranspiration rate is low in southern Ghana (80 mm) and higher in the north (190 mm). There are six vegetation zones in Ghana. These are the Savannah (Sudan, Guinea and Coastal), Forest-Savannah Transitional Zone, The Semi-Deciduous Forest Zone, and the Rain Forest Zone. Human activities and natural pressures have considerably changed the natural vegetation (Tamakloe, 2000).

Surface Area: **239, thousand sq km**
Capital: **Accra**
Population**: 23,350,927 (2008 estimate)**
Official Language: **English**
Nationalities**: multi ethnic with 45 languages**
Chief earners**: Cocoa, gold, timber, diamonds, bauxite and manganese**
GDP per capita (US$)**: 671.33 (2009)1**

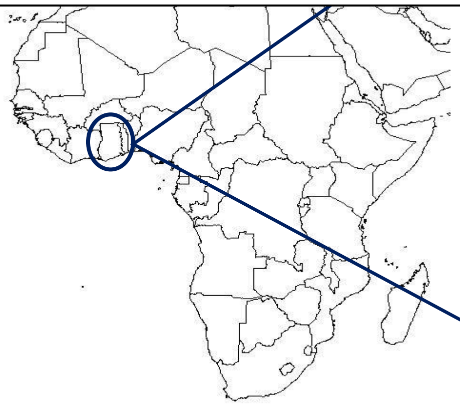

Figure 3 – Map of Ghana (right) and its location within the African continent (left).

4.4.1 *Historical evolution of forest policy in Ghana and its impact on deforestation and forest degradation*

Forest resources have played a central part in Ghana's historical development, and continue to do so to this day. However, with few exceptions, Ghana's high forest areas are now in a severely degraded condition, and it is recognized that without urgent and radical remedial action, this could lead to a major knock-on effects for agriculture and the environment (volume and incidence of rainfall, atmospheric humidity, watersheds, soil and water conservation, etc.) and for the country's ability to adapt to the predicted levels of climate change (FC, 2010).

Ecologically, Ghana is dominated by dry savannas in the north and east and a "high forest zone[4]" in the southwest. The remnant high forests are part of West Africa's Guinean forests, one of 25 biodiversity hotspots worldwide (Hall and Swaine, 1981; Kotey et al., 1998). About one-fifth of the estimated remaining forests in Ghana's high forest zone are officially gazette as forest and wildlife reserve. Forests play a crucial socioeconomic role in Ghana, providing employment and subsistence resources for many of the country's 24 million people; the forest sector is the country's fourth-largest earner of foreign exchange (Mayers et al., 2010). Many of the early colonial legal enactments (e.g. the 1894 Crown Land Bill and the 1897 Lands Bill) were aimed at securing wholesale control over "waste and uncultivated" forestlands. These were resisted successfully by local activist groups and ultimately overturned. In 1911, however, the colonial government enacted the Forest Ordinance, which established procedures for gazetting forest reserves and set out a long list of prohibitions and restrictions on forest use by local communities (Mayers et al., 2010). After much opposition from traditional landowners, a new ordinance was enacted in 1927 that maintained the rights of local chieftaincies over forest reserves but clearly established the role of the colonial government'sagent - the Gold Coast Forest Department - in supervising and managing the forest reserves (Amanor, 1999).

The upshot of colonial policy was that it established the conditions for large-scale deforestation in Ghana, which commenced in the first half of the 20th century with the state-sanctioned conversion of forested land to farmland. Inside the forest reserves the emphasis was on forest management by the state, but beyond their boundaries the main

[4] The high forest zone is a high-rainfall zone that makes up about one-third of the country and was once largely covered by forest.

focus was on maximizing the exploitation of forest in the expectation that it would be converted to farmland. Since then, the production of palm oil, rubber and especially cocoa has been the major driver of land-use change in the high forest zone. Deforestation accelerated in the second half of the 20th century and the stock of trees outside forest reserves declined rapidly (FC, 2010).

At least part of the reason for this was a change in the way that tree ownership was defined and revenues were shared. Prior to 1962, landowning communities were entitled to no less than two-thirds of the gross revenue generated in forest reserves. Under the 1962 Concessions Act, however, that entitlement was cancelled and revenue was used to first pay the running costs of the Forestry Department, with a proportion of any remaining money returned to local authorities and communities (Treue, 2001). Even more significant, perhaps, was a provision in the Concessions Act to "vest of all timber resources in the Office of the President." As Amanor (1999) pointed out, this effectively institutionalized the myth that farmers had no rights over naturally occurring timber trees growing on their own land. Deforestation and forest degradation were exacerbated in the 1980s by a push from Ghana's donors for economic "structural adjustment" that supported the acceleration and expansion of timber exports to increase revenue (Benhin and Barbier, 2000; Kotey et al., 1998).

More recently, deforestation has resulted from the expansion of food crops, tree crops such as cocoa, and logging, underpinned by drivers such as over-capacity in the forest industry, market and policy failures, and burgeoning urban and rural populations. In addition, the relatively recent introduction of full-sun cocoa varieties, which perform well without the shade trees required by traditional cocoa production systems, combined with other factors such as the lack of clear tree-ownership rights, has significantly reduced the presence of on-farm trees (Mayers et al., 2010). Despite reforestation and afforestation projects and participatory forest management practices, deforestation occurred at an annual rate of 1.8% between 1990 and 2005, and Ghana currently loses about 65,000 hectares of forest per year (Marfo, 2010). A recent IUCN analysis (IUCNb, Förster 2008) showed that most of the substantive blocks of forestland outside forest reserves that existed in Ghana's Western Region in 1990 had been converted to other land uses by 2007 (Figure 2).

Figure 2: Land-use cover change in the Western Region, Ghana, 1990-2007 (source: Förster, 2008)

Estimates of the total annual timber off-take in Ghana range from 3.3 to 4 million m^3. Some 70% of this off-take is unrecorded (and by implication illegal) and it is uncertain what proportion is derived from reserve forests (only 600,000 m3 according to official figures although the real figure is likely to be substantially higher). This estimated off-take is 3–4 times greater than the volume considered by the Forestry Commission to be sustainable (Parren et al., 2007; Nketiah et al. 2009).

In drier areas and transition zones, wildfire is a major problem, with charcoal production and fuelwood collection also contributing to deforestation in off-reserve areas (Katoomba, 2009). Degradation in the off-reserve areas of the high forest zone is proceeding at an even greater pace. The timber industry is close to crisis point, with off take more than three times the sustainable harvest level, and the supply declining rapidly in both quantity and quality. A number of influences account for this situation, both forest sector and extra-sector. Major influences include (a) population growth and increasing demand for timber and agricultural products, both nationally and internationally; (b) the poor governance of the forest sector, which has led to massive over-capacity, to an industry structure unconducive to high value added, and to a thriving market for 'illegal' chainsaw lumber; (c) conversion to agriculture, particularly for production of cocoa, the main crop in the high forest zone; (d) bush fires, especially in the transition and savannah zones; (e) minerals extraction. Agro-industries and large scale commercial productions have not been major causes hitherto. However, demand is growing for oil palm and other oils and biofuels, and for export crops such as pineapple but sill the most pressing requirement, and the factor likely to have the greatest impact on forest cover, is yet to be addressed (FC, 2010). The demand for agricultural and wood products is growing locally as well as internationally; farming systems have undergone only limited technological development, however, and there remains a high dependency on swidden agriculture (FC, 2010). This is the need for incentives for tree conservation and planting in the high forest zone. A radical reform of tree tenure in the off-reserve areas could well be required, to increase the tenurial rights of farmers and land owners. Implementing the reform would also be challenging, as land markets have a long history in the forest areas, and conflicts already exist over land claims in many areas (FC, 2010).

As far back as 1995, Hawthorne and Abu-Juam indicated that less than 16% of Ghana's high forests remained in good condition mostly in the wetter southwestern corner of the country (Figure 3). It is reasonable to assume that this percentage may have further declined in the intervening years (Mayers et al., 2010).

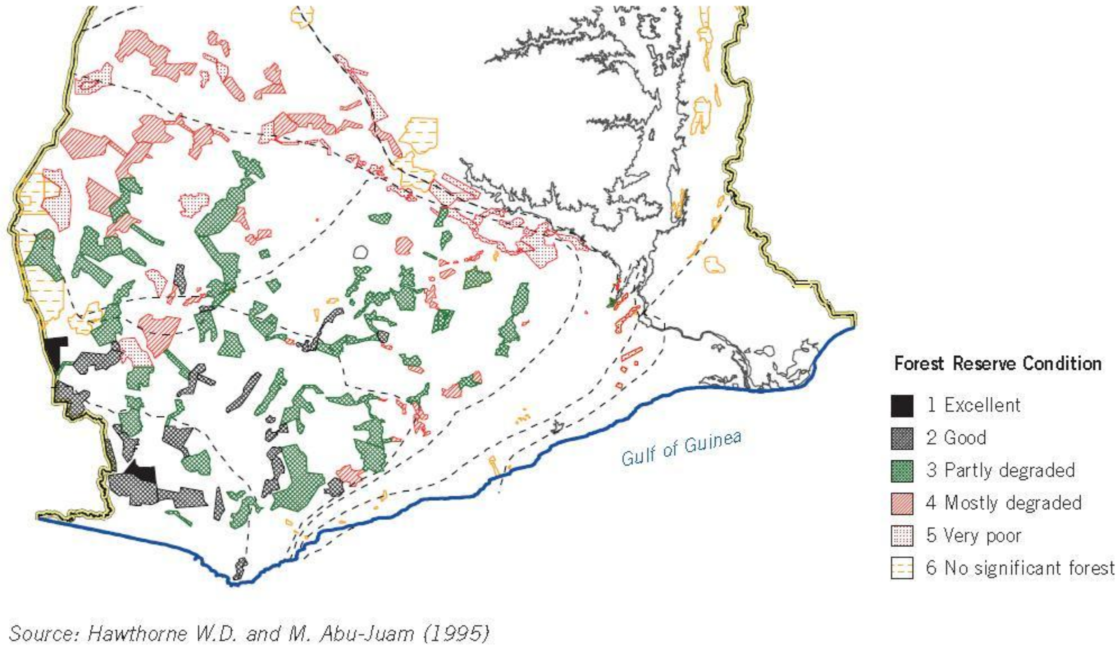

Figure 3 : Forest reserve conditions map of Ghana's high forest zone.

Deforestation and forest degradation are 'slow drip' phenomena in Ghana. This process is largely one of long-term and progressive degradation, without any dominant deforestation drivers, though forest loss is nevertheless occurring at a significant rate (FC, 2010). This may be because most of the accessible rainforests are still shrinking due to the combined

effect of forest fires, logging, agricultural colonization, mining activities and wild land fires and. It is believed that at the start of the 1900's, one-third of Ghana's 238,500 km2 land area was covered by natural tropical forest (Wagner and Cobbinah, 1993). By 1989, Hawthorne (1989) estimated that only about 22 % (18,000 km^2) of the original tropical forest remained or that 78 % of Ghana's tropical forest had disappeared (Repetto, 1990).
In more recent times the trend is not changed, since 1990, when forests cover an area of 7,448,000 ha, there is been a gradually disappearance of forested areas up to reach 4.940.000 hectares in 2010 (FAO 2010a). Nevertheless, this suggests that tropical forests in Ghana face an ever-increasing set of pressures resulting in the loss of forest and associated biodiversity throughout most of Ghana. Unfortunately, these forests support vital economic and ecological functions, providing commercial trade and employment opportunities (Wagner and Cobbinah, 1993). For more than 20 million Ghanaians, particularly people living in the rural areas, the forest is the only source of wood that is used locally as fuel wood, and for construction and furniture. The forests also provide a suitable environment for farming practices such as cocoa cultivation (Blay et al., 2007). Although Ghana is the second world's leading producer of cocoa, Ivory Coast now accounts for 38% of global production with Ghana second at 21% (UNCTAD, 2005), the crop remains the bedrock of the agricultural economy in the High Forest Zone (HFZ).
The overall production trend is rising (Vigneri, 2007). For over a century, cocoa has been the major driver of land use change in the HFZ. The area under cocoa is now about 1.270.000 ha, comparable to the total area of forest under protection. Cocoa production in Ghana uses low-technology methods, with the heaviest inputs being labor for clearing and weeding, and chemicals for spraying against disease. Cocoa farm holdings are typically small, about 2-8 ha, though the range is wide, and some holdings are substantial (FC, 2010). For this reasons Cocoa can be considered a synonymous with the economy of the high forest zone but its production inevitably implies some loss of forest cover, but degradation has been much increased in recent years by the introduction of new full-sun hybrid varieties. Reversion to the shade-dependent traditional varieties would have much to commend it, as it would not only improve tree cover on the farm but might also revive support within the farming community for the policy of forest reservation, with attendant atmospheric benefits. Unfortunately the declining area available for food crops is pushing farmers to favor open-field varieties, in part because of their inter-cropping potential, despite long-term sustainability concerns (FC, 2010). Other causes of degradation

associated with rural livelihoods, such as shifting cultivation and fire in the agricultural and pastoral cycles, have long exercised the authorities. However, without viable alternatives well adapted to the low purchasing power of the rural majority, little headway has been made on finding substitute livelihoods. There is also strong hostility to charcoal and fuelwood production though, again, the high demand from consumers cannot easily be ignored. Neither should it be assumed that charcoal production systems are universally destructive of forest cover, for some systems could well be sustainable, and may represent optimal use of marginal scrub lands (FC, 2010). This view that the rural household is dependent on forest resources is a well-shared one among researchers and development practitioners (Appiah et al., 2007). In recent years, there has been increasing interests to understand the contribution that forest resources make to local employment, income and the wellbeing of rural communities (Arnold and Townson, 1998; Mamo et al., 2007). With few exceptions (Mamo et al., 2007), however, the level of rural dependence on forest resources have often been overlooked in poverty surveys (Cavendish, 2000). There is very little investigation on the level of dependence across different socioeconomic groups. Empirical information on dependency of forest resources may help to improve macro-level poverty estimates and serve as an input into conservation policy, particularly the establishment of protected areas by determining the potential loss to rural dwellers that would have reduced access to forest resources (Mamo et al. 2007). Since forest is the source of many products on which the local people depend, complete protection of remaining natural forests, although highly desirable, faces socio-economic constraints, which makes such a goal difficult or impossible to achieve. Therefore, to manage the existing level of forest cover or increase it, efforts of the government of Ghana to curb deforestation have revolved around the promotion of economic development through the promotion of reforestation and sustainable utilization of natural forest resources with local involvement (Blay et al., 2007). Their approach essentially puts local people in the centre of forest resources management with the understanding that local communities are significant players in forest management and are believed to have a significant understanding of their local environmental problems (Hares et al., 2006). Thus, their perceptions in deforestation discussions cannot be ignored (Lawrence, 2000). However, collaborative management faces problems of differing views in terms of forest management goals, methods, utilization, and preferences, particularly between different stakeholders such as the government and local people. This has often resulted in the failure of many community- based forest management projects that had good chances of success (Appiah, 2007).

4.5 The role of forests in the international policies

Land use and land cover changes, including legal and illegal deforestation, are amongst the most important factors that contribute to the social and environmental challenges facing mankind in the 21st century (Goez, 2010). Deforestation alone is responsible for about 12-15% of the world's anthropogenic greenhouse gas (GHG) emissions, whereas another 6% stems from peat oxidation and fires on degraded peatland areas (Van der Werf et al., 2009). The combined effects of logging and forest regrowth on abandoned land are responsible for 10-25% of global human-induced emissions (Achard et al., 2002; Gullison et al., 2007).

Since project activities to reduce emissions from deforestation were excluded from the Kyoto Protocol's Clean Development Mechanism (CDM), obtaining support to address this source of emissions has been among the top priorities of developing countries in discussions about a future climate regime (Goez, 2010; Ghazoul et al., 2010). Kyoto Protocol sets out the rules for "Land use, land-use change and forestry" (LULUCF) activities in Articles 3.3 and 3.4 and in decision 16/CMP.1. According to Article 3.3 Annex I countries (developed countries) must count afforestation, reforestation and deforestation since 1990 towards their emission reduction targets for the period 2008-2012 (first commitment period). Under Article 3.4 Annex I countries can choose to include revegetation, forest management, cropland management and/or grazing land management (UN, 1998)[5]. The international community through the United Nations Framework Convention on Climate Change (UNFCCC), now recognizes reducing emissions from deforestation and forest degradation and carbon stock enhancement (REDD+)[6] as a critical component of national and international strategies for mitigating global climate change and for providing financial incentives to conserve rather than exploit forests, but this premise was reached through a long path. The expression REDD was used for the first time in its shortened form RED (Reducing Emissions from Deforestation) during the 11th UN Conference of Parties (COP 11) in Montreal (2005) by

[5] Available at: http://unfccc.int/resource/docs/convkp/kpeng.pdf

[6] REDD+ (Decision 1/CP.13; UNFCCC 2007).

the Coalition for Rainforest Nations led by Papua New Guinea (FGCC, 2010). This reference was part of an advocacy strategy aimed at promoting compensation payments for developing countries that reduce their national rates of deforestation. Well received at COP 11, the concept was further elaborated, expanded and officially adopted during COP 13 in Bali, Indonesia in 2007 in the form of REDD. The addition of Degradation to this acronym was due to the observation that forest degradation in some developing countries was as threatening as deforestation (if not more) to the forest ecosystems. Following the debates during the 14th COP in Poznan, Poland in 2008, it was decided that REDD should evolve to REDD+ to encompass all the initiatives that can increase the carbon absorption potential of forests. The insertion of '+' on the acronym REDD is aimed at broadening its scope to include all operations associated with preservation, restoration and sustainable management of forest ecosystems. The official definition of REDD+ as set by UNFCCC is as follows: "*reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries*" (UNFCCC Decision 2/CP.13–11). Following the clarification of its identity and mission, REDD+ won greater importance and since 2008 it has become one key tool for tropical forest countries in the negotiations on climate change under the United Nations (FGCC, 2010). Natural forest protection (and specifically REDD+ which additionally recognizes reforestation and sustainable management of forests) was recognized as key to reducing global carbon emissions with the '*Copenhagen Accord*' during the COP 15 held in Copenhagen in 2009[7] (Ghazoul et al., 2010). Afterwards with the COP 16 held in Cancun in 2010, the UNFCCC agreed to consider REDD+ as an instrument able to alter the situation for developing countries including the implementation of the following mitigation actions:

(a) Reducing emissions from deforestation;

(b) Reducing emissions from forest degradation;

(c) Conservation of forest carbon stocks;

(d) Sustainable management of forest; and

(e) Enhancement of forest carbon stocks.

This means that, potentially, all forest resources in developing countries are subject to accountable mitigation actions. The issues addressed at Cancun focused on forests in

[7] http://unfccc.int/resource/docs/2009/cop15/eng/l07.pdf

particular were REDD+, forest management accounting rules for Annex 1 countries under the Kyoto Protocol, and discussions of including “forests in exhaustion” under the CDM (FAO, 2010b).

The long-awaited decision on REDD+, under discussion for the past five years, confirms the scope of REDD+ and outlines principles as well as safeguards against negative social and environmental impacts of REDD+ actions. Countries are requested to develop national strategies and action plans for REDD+, a national/sub-national forest (emissions) reference level(s), a national forest monitoring system for the monitoring and reporting on REDD+ activities, and a system for providing information on how the safeguards are being addressed and respected. A phased approach, from strategy development to pilot activities, is adopted. SBSTA (*Subsidiary Body for Scientific and Technological Advice*) is requested to work on methodological issues on REDD+, including on methods to estimate emissions and removals from REDD+ activities and modalities for developing forest reference (emission) levels and a national forest monitoring system for monitoring and reporting on REDD+ activities and to report to COP17.

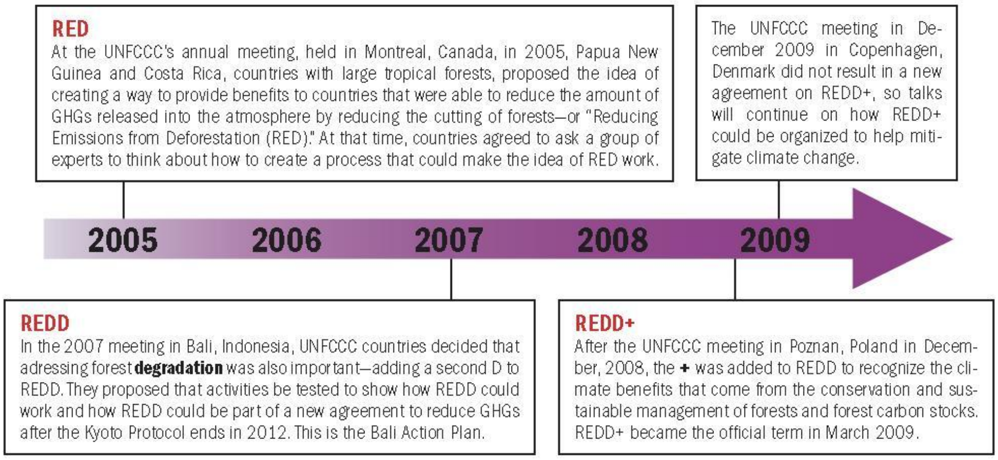

Figure 4 : Timeline of the development of REDD+ (Stone and Chacon Leon, 2010)

4.5.1 Economic instruments for developing countries and a potential for African forestry

The climate change negotiations, have produced different economic instruments for developing countries. Some of them are already operational, some are still being developed, and others depend on the ratification of the Kyoto Protocol. REDD+'s main goal is thus to reduce the carbon emissions from deforestation in developing countries and increase their carbon storage capabilities through sustainable forest management programs. Two major principles underlie the REDD+ mechanisms:

1. Adequate financial compensation should be provided to developing countries in exchange for their efforts to preserve their natural forests, or to participate in sustainable forest management (SFM) initiatives.
2. Financial compensation should be attractive enough to developing countries that, when given the option to preserve or clear forestland, they opt for conservation.

There is an overall agreement in the ongoing negotiations on a three phase approach to REDD+ initiatives:

<u>Phase 1</u> is characterized as the 'readiness' phase. Countries prepare their national REDD+ strategy by organizing multi-stakeholder consultations, building capacity for monitoring, reporting and verification (MRV) and undertaking demonstration activities.

<u>Phase 2</u> is characterized as the 'more advanced readiness' phase. Countries focus on the development of implementing policies and measures to reduce emissions as outlined in the national strategy.

<u>Phase 3</u> is referred to as the full UNFCCC 'compliance' phase. In this phase, tropical forest countries are compensated exclusively for quantified reduced carbon emissions and removals, resulting from enhanced carbon stocks, based on agreed reference levels. Although the mechanism has been recently defined by a COP decision, REDD+ activities are already implemented around the world. REDD + financial resources comes from five major institutional arrangements and mechanisms:

1. The **global multilateral donors**. This group is dominated by the UN-REDD Programme and two World Bank institutions: the Forest Carbon Partnership Facility (FCPF) and the Forest Investment Program (FIP). The Interim REDD+ Partnership created in Paris during the May 2010 conference on forests and climate change could also

be mentioned here. This entity made up of an initial group of six developed nations has pledged to provide US$4.5 billion to assist developing countries jumpstart REDD+ activities.

2. The **regional multilateral funding institutions** like the Amazon Fund which promotes REDD+ projects in the Amazon basin and the Congo Basin Forest Fund (CBFF) that sponsors REDD+ initiatives in the central African countries. The latter focuses predominantly on projects oriented on payments for ecosystems services (PES), community forests initiatives and capacity building.

3. **Bilateral cooperation** finance, with the governments of Norway and Australia as key players in the bilateral funding. A study piloted by CIFOR in 2009 has recorded a total of 109 REDD+ projects (44 demonstration activities, 65 readiness initiatives) with 40 in Asia, 35 in Africa and 34 in Latin America. They were funded by bilateral, multilateral and government sources (Wertz-Kanounnikoff and Kongphan-apirak, 2009).

4. **The private sector and NGOs** are increasingly becoming key players in financing REDD+ projects. These entities can operate in partnership or individually.

5. **Market mechanisms** are also seen as an important financial source. The carbon credit is the main commodity or key exchange value in this market. There are multiple avenues of exchange for example: between developed and developing countries, an industry in North and an industry in the South, two firms or two industrialized countries. A carbon credit is earned when a developing country is engaged in green carbon sequestering activities. One carbon credit corresponds to one ton of carbon and 1 ton of CO_2 can cost over US$30. An industrialized country can also earn carbon credits by engaging in low-carbon activities, or if its annual GHG emissions are below the rate set by the Kyoto Protocol. Those with reduced GHG emissions or those who engage in carbon capture activities are the sellers of carbon credit. The buyers are the countries or companies that are net emitters of carbon. The carbon market is thus a trade in which both buyers and sellers can be either from developed or developing countries. It is hoped that cash resulting from the carbon markets can support conservation efforts. So far, avoided deforestation initiatives (REDD+) have contributed marginally to the voluntary carbon market (3% market share and average per-ton price of $2.90 in 2010). The main reason why market demand for REDD+ credits remains insignificant at the moment is because countries are not legally obligated to offset their emissions since there has been no agreement on limiting global emissions. The major critics against this finance sourcing is

that it offers industrialized countries a leeway to buy cheap carbon credit in other countries, in a sense a right to continue polluting instead of reducing their GHG emissions (FGCC, 2010).

4.5.2 Critical issues

Formal discussions at the international level initially focused primarily on technical and methodological issues. There are not official methodologies to undertake in REDD+ framework. The COP in the decision CP/16[8] which refers to Decision 4 CP/15 requests developing countries "*to use the most recent Intergovernmental Panel on Climate Change guidance and guidelines, as adopted or encouraged by the Conference of the Parties, as appropriate, as a basis for estimating anthropogenic forest-related greenhouse gas emissions by sources and removals by sinks, forest carbon stocks and forest area changes*[9]". Unfortunately many issues remain unsettled including:

• **Financial mechanisms:** funding sources and delivery mechanisms (different international funds vs. carbon market integration vs. hybrid solutions, such as auctioning Assigned Amounts Units) able to support and provide sufficient economic incentives to stop deforestation.

• **Monitoring:** The ability to accurately quantify tropical deforestation is critically important for the generation of carbon credits from reduced deforestation. Key elements of a possible monitoring system include its ability to measure changes throughout all forested area within a country, use consistent methodologies at repeated intervals to obtain accurate results, and verify results with ground-based or very high-resolution observations (Herold et al. 2006). The lack of accuracy (due to high costs of monitoring) could, in any case, have important implications for including national approaches in the carbon market. Monitoring deforestation at national level is often assumed to be less uncertain than at the project level, yet many developing countries lack data on

[8] Available at: http://unfccc.int/files/meetings/cop_16/application/pdf/cop16_lca.pdf

[9] Main existing guidance: **IPCC (www.ipcc.ch):** Revised 1996 GL for National GHG Inventories; 2003 GPG for Land Use, Land Use-Change, and Forestry; 2006 GL for National GHG Inventories, Vol. 4, Agriculture, Forestry and Other land Uses (AFOLU). **Winrock International (www.winrock.org):** Reducing GHG Emissions from Deforestation and Degradation in Developing Countries: a Sourcebook of Methods and Procedures for Monitoring, Measuring and Reporting; Land Use, Land Use Change and Forestry Projects. **Voluntary Carbon Standard (www.v-c-s.org):** Guidance for Agriculture, Forestry and Other Land Use Projects.

deforestation and corresponding carbon stocks. In these cases, it probably makes more sense to develop regional baselines at sub-national administrative levels (DeFries et al. 2005).

• **Scale**: level of accounting and crediting to be recognized in an international agreement; scale of implementation, including the debate over "national" versus "sub-national" scale project. These issue has been faced during the COP 16 and in draft decision [-/CP.16] [10] as Outcome of the work of the Ad Hoc Working Group on long-term Cooperative Action under the Convention it has been recognized that developing countries has to develop "*A national forest reference emission level and/or forest reference level or, if appropriate, as an interim measure, sub-national forest reference emission levels and/or forest reference levels, in accordance with national circumstances, and with provisions contained in decision 4/CP.15, and with any further elaboration of those provisions adopted by the Conference of the Parties*";

The implementation of national approaches as an exclusive instrument to provide incentives to reduce emissions from deforestation in developing countries could have negative equity implications. These would arise primarily from the general lack of capacity in most developing countries to successfully implement REDD in the near future. Likewise, under an exclusive national approach, countries with large forest areas (see Figure 5) and those currently suffering mostly from degradation would be in a disadvantageous situation, since they would require more expensive monitoring methods. Moreover, even though—as argued by countries supporting national approaches—the use of the IPCC Good Practice Guidance and Guidelines for National Inventories could facilitate the estimation of emissions from deforestation at the national level, those countries with less capacities would have to rely on default values, by definition conservative (Corbera et al., 2010).

[10] Available at: http://unfccc.int/files/meetings/cop_16/application/pdf/cop16_lca.pdf

	Low deforestation rates (<0.5%)	High deforestation rates (>0.5%)
High forest cover (>40%)	Belize, Colombia, Costa Rica, DR Congo, Guyana, Panama, Peru, Republic of Congo, Suriname	Bolivia, Brazil, Cambodia, Cameroon, Equatorial Guinea, Honduras, Indonesia, Lao PDR, Nicaragua, Paraguay, Papua New Guinea, Zambia
Low forest cover (<40%)	Argentina, Chile, Central African Republic, Kenya, Madagascar, Mexico, Mozambique, Thailand, Vanuatu, Vietnam	Ecuador, El Salvador, Ethiopia, Ghana, Guatemala, Guinea, Liberia, Nepal, Tanzania, Uganda

Figure 5: Countries classified by forest cover (source: Wertz-Kanounnikoff, S. and Kongphan-apirak, M. 2009)

Under a carbon market scenario, this might imply that these countries could receive fewer incentives (carbon credits) for the same reduction effort than a country with available data and country-specific carbon content values. Nevertheless, a more flexible REDD approach, allowing for sub-national initiatives, may potentially benefit a higher number of countries, putting in place projects that ensure poverty and pro-poor development benefits, with the use of simplified methodologies for small scale activities, and the creation of niche markets for ethically motivated projects where sustainable development is prioritized (Brown et al., 2004). Regardless of the approach taken, selecting REDD pilot areas under a national scheme and defining a framework to transfer REDD incentives across scales, both for national/regional approaches and project activities, will be challenging processes. They are likely to generate tensions within countries and REDD participants and impact directly on the efficiency, effectiveness, equity and legitimacy of REDD schemes (Corbera et al., 2010).

• **Reference levels:** 'rewarding high deforestation' by using historical baselines[11;] interpretation of 'national circumstances'; interpretation of the principle of 'common but differentiated responsibilities'; criteria for establishing deforestation baselines and procedures to use for establishing reference levels. These are the key core of REDD issue and thus are here deepen. Deforestation dynamics and the timing of deforestation differ greatly amongst countries and even within countries. It will make a great difference

[11] The term 'baseline' in the REDD+ debate refers to three concepts. 1) A historical baseline is the rate of deforestation and forest degradation (DD) and the resulting greenhouse gas emissions over a specific number of years, e.g., the last 10 years. 2) A business as usual (BAU) baseline is the projected DD and associated emissions without any REDD+ interventions. It is used to assess the impact of REDD+ measures and ensure additionality. 3) A crediting baseline or reference level is a benchmark below which emissions must fall before a country or project is rewarded for reductions, e.g., before it can sell REDD+ credits (Angelsen et al., 2009).

which reference period is chosen in order to estimate a baseline. If one particular base year or base year period was set for all countries wishing to conduct REDD activities, one group of countries will always be put at a disadvantage: those that had low deforestation rates in the base year or base period. These problems are further aggravated by the fact that land-use change and carbon stock data for most developing countries are very incomplete, which could undermine the expected environmental benefits of national approaches (Corbera et al., 2010). No standard methods currently exist to estimate avoided deforestation project baselines. Pilot projects that currently receive carbon credits have used a number of different approaches, amongst them: (a) extrapolation into the future of past trends; (b) hypothetical future scenarios; (c) prevailing technology or practice; and (d) simple logical arguments based on adjusting observed trends (De Jong et al. 2005). However, none of the methods allow an objective assessment of whether the baseline is appropriate to the area in question or provide a measure of how accurate the prediction is likely to be (Corbera et al., 2010). Thereby it is more evident that a key challenge for successfully implementing REDD+ and similar mechanisms is the reliable estimation of biomass carbon stocks in tropical forests. Uncertain estimates of biomass carbon stocks of tropical forests (resulting from difficult access, limited inventory and their enormous extent, Baker et al., 2004; Hansen et al., 2008; Malhi et al., 2004) prohibit the accurate assessment of carbon emissions as much as uncertainties in deforestation rates (Houghton, 2005).

4.5.3 REDD in Ghana

The condition of Ghana's forests has been in decline for many years, particularly since the 1970s. Many forest reserves are heavily encroached and degraded, and the off-reserve stocks are being rapidly depleted. By and large, the problem is one of gradual 'degradation' rather than 'deforestation', and is incremental rather than dramatic, with no single dominant driver. The underlying causes involve a complex of demographic, economic and policy influences. According to Forestry Commission (2010), the immediate drivers include: forest industry over-capacity; policy/market failures in the timber sector; burgeoning population in both rural and urban areas; increasing local demand for agricultural and wood products; high demand for wood and forest products on the international market; heavy dependence on charcoal and fuelwood for rural and urban energy; limited technology development in farming systems and continued reliance on cyclical 'slash and burn' methods to maintain soil fertility and fire as a tool in land management. Arresting deforestation and forest degradation is an important priority for the country, and Ghana has already embarked on a series of forest and natural resource governance initiatives to address these challenges (FC, 2010) although the provision in the Concessions Act to "vest of all timber resources in the Office of the President" has institutionalized the myth that farmers had no rights over naturally occurring timber trees growing on their own land building up in this way, challenges to the process of REDD-plus readiness in Ghana. To support the process of preparation to the mechanism of the REDD+, the Government of Ghana, through Ghana's Forestry Commission[12], has sought and received support from the World Bank's Forest Carbon Partnership Facility (FCPF). This support follows a three phase process (shown below in Figure 6) through which Ghana aims to build its capacity while developing its own strategy for engaging with future international and domestic mechanisms that will reward REDD+ actions (FCG, 2010; Mayers et al., 2010). The REDD Readiness Process beginning in 2007 when Ghana submitted the Readiness Plan Idea Note (R-PIN)[13] to the World Bank and

[12] Ghana's Forestry Commission is the national entity responsible for establishing a national strategy for REDD

[13] The R-PIN is the initial preparation document. It provides an outline of the current country context, the institutions involved in forest utilization and governance and provides an indication of what organizations,

subsequently, a US$200,000 grant from the FCPF enabled the development of a Readiness Preparation Proposal (R-PP). On the 21st of July 2008, Ghana was named among 14 countries to benefit from the FCPF.

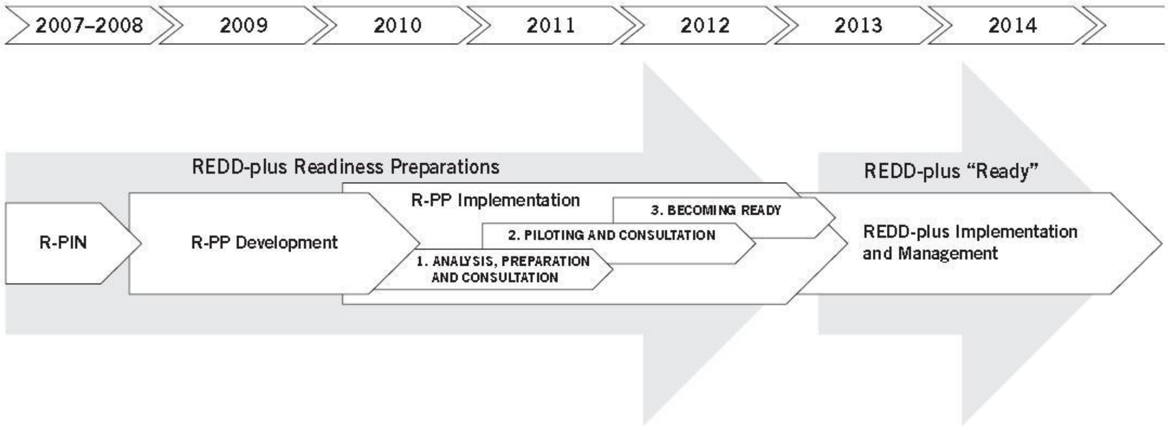

Figure 6: Phasing Ghana's progress towards REDD plus readiness (source: FCG, 2010)

Through a consultations process, in January 2010 Ghana, FCPF of the World Bank approved the Readiness Preparation Proposal (R-PP) document becoming one of the first African countries to fully develop a national REDD-plus strategy. Moreover, Ghana has been recommended as one of five countries to receive further support through the Forest Investment Program - a multi-donor trust fund designed to facilitate the transformational policy and institutional reform processes necessary to help countries address the underlying causes of deforestation and forest degradation.

institutions and sectors are most relevant to the development of a REDD mechanism within Ghana. Ghana submitted it is R-pin to the FCPF in 2007 after being developed in consultation with members of the FC, IUCN, MLNR, FORIG, CIFOR, University of Ghana (CERGIS). This document presents the current situation in Ghana and does not represent a decision by the government on how they are going to prepare for REDD+ (FCG, 2010).

5 Aims

The idea behind REDD may be simple, but in practice it conceals a host of challenges and issues related to estimating emissions from deforestation and degradation (Angelsen et al., 2009; De Fries et al., 2007). Further research is needed on quantifying forest carbon pools in the tropics where the uncertainty is very high and specifically it is primal to establish guidelines and protocols to determine historical estimates/measurements and develop agreed baselines or base intervals (Kanninen et al., 2007). This has strong implications for the distribution of benefits and costs across countries. The issue of baselines (reference levels) is a case in point. Baselines have a technical element, namely a realistic prediction of future DD in a business-as-usual scenario. But they also determine the level at which a country should start being credited for emissions reductions, based on the interpretation of principles such as 'common but differentiated responsibilities' and 'relevant national circumstances'. The reference levels will have a big impact on benefits and thus be a political issue (Angelsen, 2008). Thus it is nonetheless basic the need to estimate the carbon stocks of forests undergoing deforestation, and the subsequent carbon dynamics (Kanninen et al., 2007) in order to place a value on it. Therefore it is evident that as a consequence, for the implementation of REDD+ it is crucial to determine the spatio-temporal variation of carbon stocks (FGCC, 2010) and in this context this study has been conceived. The main focuses of the present work was to analyze the changes in terrestrial carbon stocks due to deforestation and to underline the dynamics of carbon stocks for different land uses by assessing: 1) initial carbon stocks (tropical rain forest), 2) per hectare changes in carbon stocks as consequence of deforestation followed by six different main land uses (tree plantations of rubber, coconut, cocoa, oil palm and mixed and secondary forest), 3) dynamics of soil carbon stocks through the time considering chronosequences. Moreover despite the common understanding about the effects of deforestation on different compartment in terms of carbon variation - an increase or disappearance of biomass relatively visible, variations in soil carbon much less perceptible, even after a radical change in land use (Calmel et al., 2010) - this study brings in the spotlight the soil reaction to radical land use change in the long run demonstrating that it is not so trifle as commonly believed. Importance of considering soil carbon stock for accounting the land use change dynamics is not properly recognize in the international deforestation policies and its influence and role in mitigating climate change is nowadays neglected but it is really not negligible.

6 Materials and methods

The study area of Jomoro District has been surveyed during three missions carried out in 2009 and 2010. The aim of the missions was to find out the eligible sites to assess the changes in C stocks in order to evaluate the effects of the forest clearing on the main C pools (soil, aboveground biomass, belowground biomass and litter). The first phase of the study was finalized to locate the main land uses following the original rainforest clearance, on the three different geological formations (Granite, Lower Birrimian and Tertiary sands). The sites were selected following specific characteristics to reconstruct chronosequences for each of the three substrates. Furthermore, to better understand what drives the deforestation process in the area and the importance of each land use for the livelihoods of local people, has been interviewed plantation's owners. Once found the eligible sites, has been started the field work for soil and aboveground sampling then followed by laboratory and data analysis.

6.1 Study areas

6.1.1 Ghana

The livelihoods of Ghanaians are highly dependent on natural resources that are being overexploited by non sustainable exploitation practices. This is the reason why Ghana was the first African country to initiate the development of a national strategy on REDD+ and also participates within negotiation on the development of international mechanisms on REDD+ (FCG, 2010). Forests are threatened by cocoa farming, mining activities, and an unregulated wood industry. Soil fertility is threatened by erosion resulting from deforestation and bad agricultural practices (Van Roosbroeck, 2006). Notwithstanding Ghana has the second richest rain forest in the world in terms of flora and fauna (JDA, 2009), the Ankasa Conservation Area, Western Region, which cover about the 30% of the Jomoro District. The Western Region has witnessed a massive increase in population and settlement in recent years. Unplanned and unregulated clearance of the forests, inappropriate agricultural practices and over-exploitation of natural resources has resulted in serious environmental degradation. Ankasa and the surrounding areas are the primary examples of this process. In the last thirty-five years they have become island forests in a sea of agriculture, with isolated faunae populations and increasing pressure on resources. (Symonds and Hurst, 2001).

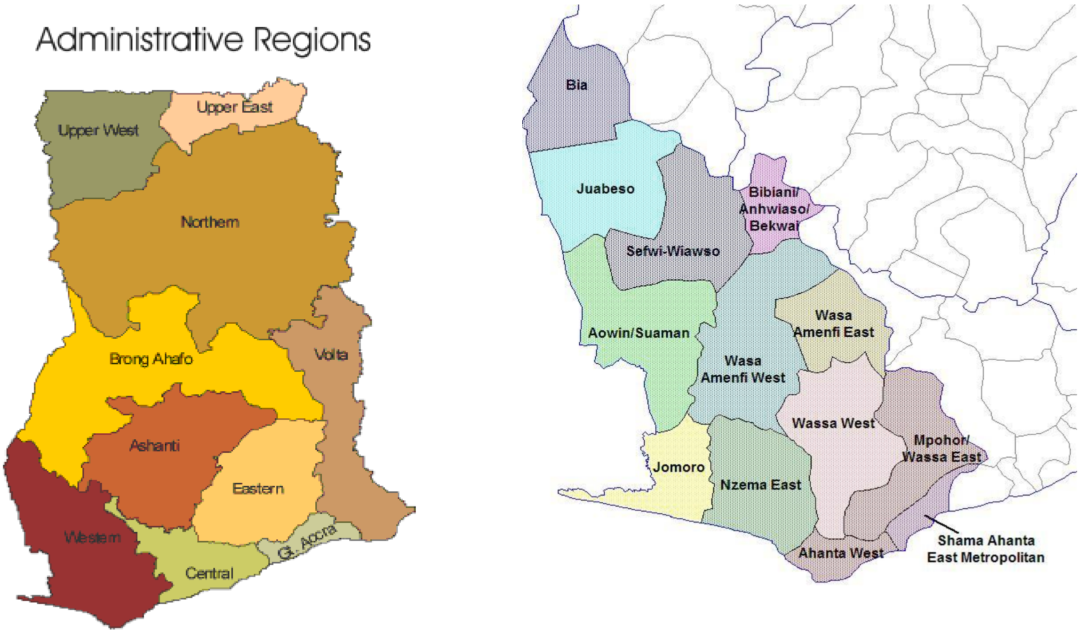

Figure 7: Maps of Ghana Administrative Regions and districts of the Western Region (FAO, 2004) [14]

6.1.2 Jomoro District

The Jomoro District, which used to be part of the Nzema District was created by Legislative Instrument 1394 in the year 1988. It is located in the Southwestern corner of the Western Region of Ghana. It is bounded on the South by Latitude 4.80° N and the Atlantic Ocean (Gulf of Guinea) and in the North it is bounded by Latitude 5.21° N and the Nini River. It also lies between Longitude 2.35° W to the East and 3.07° W to the West. The district covers an area of 1344 km^2 (JDA, 2009), representing about 5.6% of the total area of the Western Region. It shares boundaries with Wassa-Amenfi and Aowin-Suaman to the North, Nzema East District to the East and Ivory Coast to the West and the Gulf of Guinea at the South (JDA, 2009).

The south-central part of the district, including the Ankasa Forest Reserve, is an area of rolling granite topography consisting of frequent steep-sided small round hills rising to 200-600 feet or no flat uplands and no broad valleys. Around the coastal area, the relief is lower consisting of flattish upland areas and steep valleys. A minor relief feature is the

[14] Map available on the website : www.ghanadistricts.com

one formed by a ridge of highland running northwest to southeast from the Tano to Bonyere that terminates on its northern side in the Nawulley scarp (JDA, 2009).

The district had extensive rainforest which has given rise to timber extraction. Lumbering activities can be found round Mpataba, Nuba, Ankasa, Tikobo No.1, Ellenda and Anwiafutu area. There is, however, no established timber processing companies except some illegal chainsaw operators. The activities of timber extractors in the district have had negative effect in depleting economic trees as a result of the neglect of afforestation and reforestation programs and the destruction of young trees all leading to micro climate change and ecological in balance (JDA, 2009).Besides, the forests are also used for crop farming. Major crops grown are cassava, coconut, maize, cocoa, and plantain (JDA, 2009). The use of traditional farming methods which include slash and burn and the extraction of wood fuel is gradually having a deleterious effect on the natural environment by degradation. Fuel wood is the main source of energy for domestic use (cooking) 36%, followed by electricity, kerosene, charcoal and liquefied petroleum gas 24%, 21%, 13% and 4%, respectively. A household survey conducted, indicates that 49% of the energy used in the district is supplied or exploited from the forest. This situation has contributed to the depletion of tree species (JDA, 2009).

6.1.2.1 Climate

Although gaps in climatic records on the district make them unreliable for planning purposes, the district is believed to be the wettest part of the country with a mean annual precipitation of 1732 mm. Temperature in the district is generally very high with a monthly mean of 26 °C (JDA, 2009). Relative humidity throughout the district is also very high about 90% during the night and falling to about 75% when temperature rises in the afternoon. The district is characterized by two rainy seasons from April to July and September to November. There is a short dry spell in August and longer dry period in December to January. Although February and March are relatively hot, a number of rains usually allow cropping to begin. The climate is classified as Equatorial Monsoon and owes its rains to low pressure areas over the Sahara attracting winds from the South of the Equator . The climate is favorable for plant growth and it is the climate rather than the soil, which is the greatest asset of the district. The harmattan air mass that brings dry conditions comes under the effects of the Monsoon and the Equatorial mass. The result is a variable weather, which includes moderate to very heavy rains. Mainly the Tano, Ankasa, Suhwen, Elloin and Amanzulle Rivers and their tributaries drain the district. The other water body of importance is the Dwenye Lagoon (JDA *ibid*).

6.1.2.2 Geology

The district lies in four main geological formations: the Lower Birrimian, the Granites, Tertiary Sands and the Coastal Sands (Ahn, 1961).

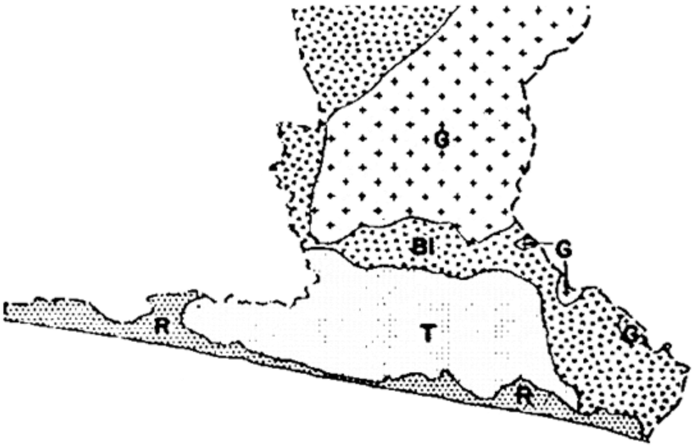

Figure 8: Main geological formations of the Lower Tano Basin according to Ahn (1961): B1- Lower Birrimian, G – Granite, T – Tertiary sands, R – Recent (coastal) sands.

The Lower Birrimian represents the oldest geological formation in the area and consists mostly of phyllites with injected quartz veins. The phyllite is the soil parent rock for this formation and it is clay sediment of Pre-Cambrian age hardened and foliated by heat and pressure. It is not usually seen in its original state since the high temperature and humidity of the region have weathered this rock to great depths. When seen in pits and road cuttings it is more or less soft, with its fine laminated structure very noticeable. Its color varies from black to blue, grey, brown, orange, and red. It breaks up easily, often crumbling into flattish fragments, and is sometimes soapy to the touch. Nevertheless, because of variations both in the nature of the original deposits and in their subsequent history, some phyllites are sandier than others and some, due to heat and pressure changes, more resistant. Phyllite occasionally grades into harder rocks such as slates and seriate schists, and odd patches of greywacke and tuffs occur, though within the basin these were not often found. The harder rocks usually stand up as hills. Veins and stringers of quartz injected into the phyllite break up during weathering to give stones and gravel.

Because of the uneven distribution of these veins the amount of quartz stones and gravel in the soil varies considerably, and may locally be very abundant.

According to Ahn (1961), the **Granite** was intruded mainly into the Lower Birrimian formation, where very large areas of granite are found. The heat, vapours and pressure associated with these intrusions also affected surrounding rocks, altering phyllite, in particular, to biotite schist. There is often a transition therefore from granite through biotite schist and other metamorphic rocks to phyllite, while in marginal areas both biotite schist and granite are frequently closely associated and the two rocks may be found in a single soil pit. Biotite schist weathers more easily than granite and the soft weathered rock is recognized by its typical purplish color and the included biotite (black mica). Aplites (fine-grained granites) and pegmatites also occur in relatively small quantities. The normal granites or granodiorites of the area sometimes weather rather slowly so that fresh hard granite may be found a foot or two below the surface arid can be quarried out for road foundations or for building. In other cases the granite may be weathered so that it is quite soft but still retains its original appearance and structure. The usual granite of the area is pale in color, medium-grained and speckled with black biotite: muscovite (white mica) granites are found occasionally. The feldspar in the granite softens relatively easily under the action of dilute acids to become kaolin, in which the very resistant quartz remains embedded. This quartz gives granite soils their characteristic grittiness, and varies in size according to the grain of the rock, which depends in turn on the rate of the original cooling. In certain areas books of white mica two to three inches across are found and these split up to give numerous mica flakes in the soil (Ahn *ibid*).

The **Tertiary sands** formations are located in the southwestern part of the district and represent a relatively recent addition to the Ancient African massif These deposits form a mantle of uniform sandy clays overlying a number of different geological formations below. From the soil point of view the material underlying the Tertiary sands is of little importance because no soils are developed. In the areas where the Tertiary sands are only 6.7-7.6 meters thick, several pits reached very pale coarse loose sands at this depth, presumably of cretaceous age, and though these do not affect the overlying soils directly, they no doubt accelerate still further the drainage of the deposits above them.

The **Recent or coastal sands** consist of very young sand and alluvial deposits along and behind the shore line of the district. They include raised beaches and other marine deposits, supplemented on the landward side by alluvial material from inland. The present coastline is remarkably straight and is the result of the cutting back of higher land and headlands, and the filling in of intervening bays. The sands here are sometimes similar to the Tertiary sand deposits, from which some of them may have been derived, but contain less clay and may be coarser, while the most recent deposits immediately behind-the present beach usually still contain shell fragments. These formations include small areas of very fine sands which are thought to occupy the sites of former lagoons (Ahn *ibid*).

6.1.2.3 Soils

Two main groups of soils are found in the Jomoro District: Ochrosols and Oxysols (Soil Taxonomy, 2010). The difference between the two groups is mainly in the topsoil with the Ochrosols showing a pH of 5.5 and the Oxisols of less than 5. The nature of the soil in the district can be sedentary, colluvial and alluvial (Ahn, 1961). Sedentary soils, the most extensive, are usually found on upland sites and are developed directly from the parent material below. Colluvial soils occur on the lower slopes of hills below the sedentary soils and are developed in slope-wash material derived from them. Alluvial soils are developed in Water-borne deposits of alluvium, either in recent alluvium in valley bottoms or in older material on river terraces. In each type of soil, two main processes are involved. The first process is the geomorphological sorting and transport of material, in particular the removal of fine material, the resultant concentration of residual gravel in upland soils, and the deposition by rivers and streams of alluvial sands and clays in lowland areas. The second process is the action of soil-forming factors themselves, including the work of soil animals and bacteria, which result in the development of soil horizons (Ahn 1961).

6.1.2.4 Potential vegetation of the Jomoro district

The original potential vegetation of the district is represented by the high forest (see Figure 9) and it is not uniform throughout but can be divided into a number of belts which differ in their floristic composition and general character. The distribution of these-belts is connected with rainfall and soil acidity

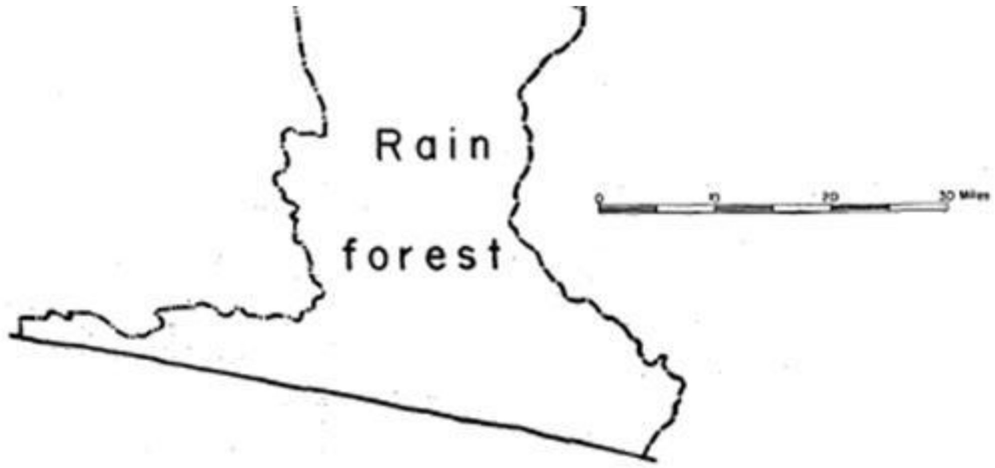

Figure 9: Potential vegetation (Ahn, 1961)

The evergreen rain forest in the extreme south of the forest area is found where the rainfall is 1800 mm per annum and the dry seasons are shorter than in the rest of the forest zone. The distribution of the rain forest is similar to the distribution of upland soils with a topsoil more acid than pH 5.0. The particular species which characterize this forest, referred to as indicator trees, are *Cynometra ananta* (ananta), *Lophira alata* (kaku) and *Tarrietia utilis* (nyahköm), and the forest is known as the *Cynometra-Lophira-Tarrietia* association. This association is characterized equally by the complete absence of two trees very common in the forests to the north, *Celtis mildbraedii* (esa) and *Triplochitoh scleroxylon* (wawa). In the lower part of the Jomoro district, the approximate boundary between the evergreen *Cynometra-Lophira-Tarrietiaassociation* and the moist semi-deciduous forest to the north of it is thought to pass through the latitude of Samreboi, and to continue west of Samreboi through the Tano-Nimri forest reserve to the southern part of the Boin River forest reserve. There is a fairly well defined and narrow zone where, going from south to north, *Tarrietia* disappears and *Celtis* and *Triplochiton* begin to occur. There are, however, considerable exceptions to even this simplified pattern of distribution since large numbers of *Cynometra* and smaller quantities of scattered *Lophira* occur north of this boundary. To the north of the rain forest or *Cynometra-Lophira-Tarrietia* association, Taylor (1952) describes a broad zone called the *Lophira-Triplochiton* association which was thought to be transitional between the rain forest and the extensive *Celtis-Triplochiton* association of the moist semi-deciduous forest to the north. Field observations made by Ahn (1961), however, indicate that since both *Celtis* and *Triplochiton* are found in large numbers immediately to the north of the rain forest this so-called transitional association is poorly represented or even absent within the Jomoro district. For this reason the rest of the district has been mapped as belonging to the *Celtis-Triplochiton* association.

The *Celtis-Triplochiton* association, in which *Celtis mildbraedii* and *Triplochiton scleroxylon* form the two commonest species, also contains many other species which are rare or absent to the south. These emphasise the fact that the division into associations is, at best, only a useful simplification which hides many minor differences and exceptions. It should also be remembered that the total number of different species is very great indeed, and that many of these, such as the silk cotton (*Ceiba pentandra*) and *Piptadeniastrum africanum* (Odan) are found throughout the area. Moreover, to emphasize the distribution of one or two indicator trees may be misleading if it suggests that the various associations differ greatly from each other. In actual fact the forest appears more or less similar throughout the area and it requires a trained eye to notice the slight changes in floristic composition which occur. Identification of forest species is difficult because the leaves and flowers are often high up, out of sight and out of reach: as an aid to identification therefore, attention is also directed to the general appearance of the tree, to its branching system, and to the trunk, particularly its shape and color, the thickness, hardness, color, texture, taste and smell of the bark and the inner wood, and the nature of the sap, if any. In particularly wet places, swamp forest occurs. The commonest species is the Raphia palm and with it other spiny palms and shrubs, such as the climbing calamus palm, and various broad-leaved trees, shrubs, herbs and sedges to the wet conditions.

6.1.2.5 Primary forests of Jomoro district

The Ankasa Conservation Area represents the only significant remaining of the original forest vegetation originally present in most of the Jomoro district. Currently, the Ankasa Conservation Area comprises the Ankasa Resource Reserve (formerly Ankasa GPR) and the Nini-Suhien National Park. Both reserves derive from the Ankasa River Forest Reserve established in 1931, primary to preserve the water supply and climatic conditions essential for agriculture in the area, and later as a protected timber-producing area (Wildlife Division, 2000).

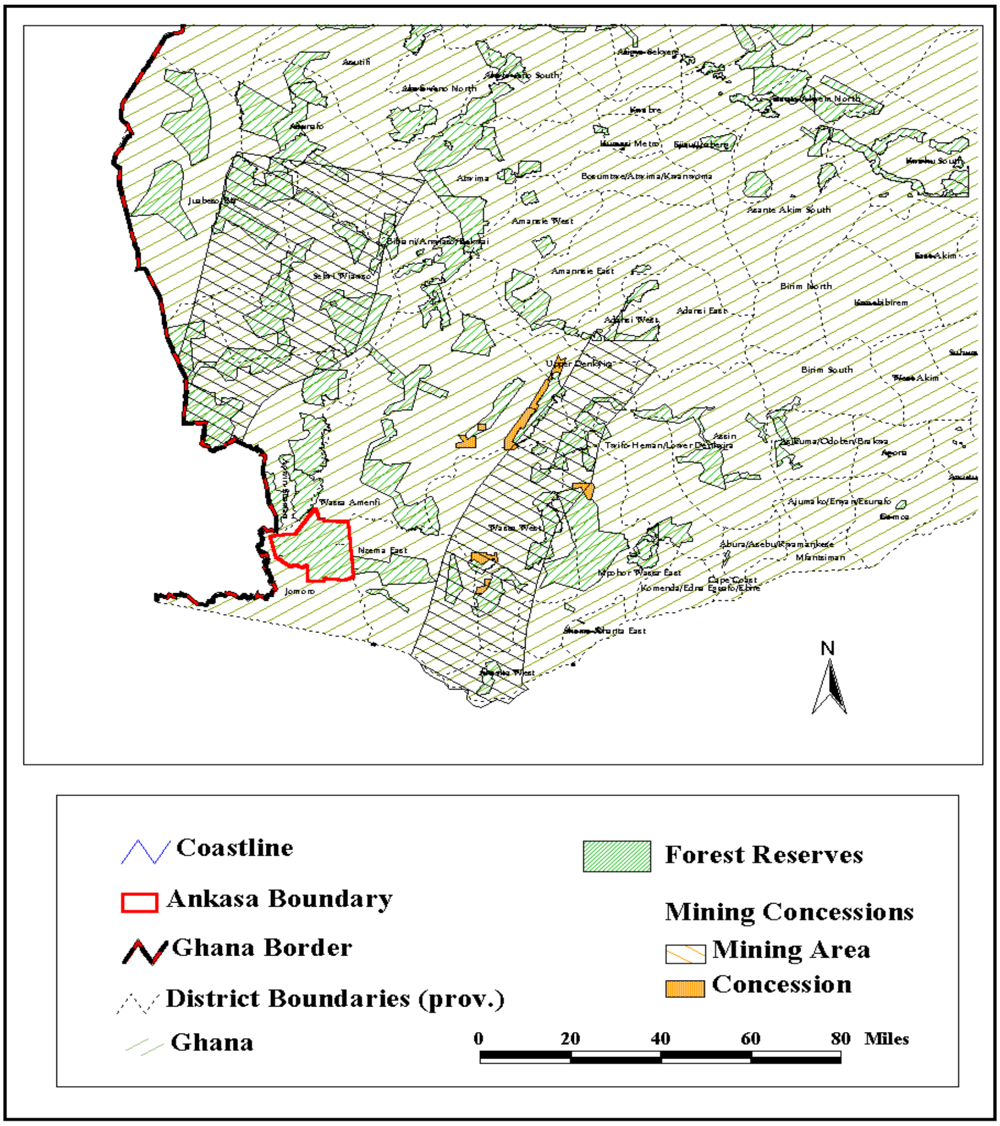

Figure 10: Protected areas in Western Ghana (source: Ghana Wildlife Division 2000).

As a Forest Reserve timber concessions were exploited up until the mid-1970s, mostly in the southern parts of the reserve, but to a lesser extent around Nkwanta. Logging was never intense, due to the scarcity of large commercial species and the rugged inaccessible terrain. Nevertheless, because of the rapid pace at which neighboring forests were being cleared for agriculture and the unique, virtually undisturbed state of the reserve, national authorities decided to reinforce its protective status as a representative specimen of the natural rainforest ecology. The reserve was thus re-designated in August 1976 as a wildlife conservation area to comprise the Ankasa GPR, covering 343km^2 (67%), and the Nini-Suhien National Park, covering the remaining 166km^2. The GPR portion has subsequently been referred as a ‘Resource Reserve’ (Wildlife Division 2000). Ankasa is Ghana’s most “special” forest with the highest Genetic Heat Index. Ankasa is ‘crawling’ with Black Star species – high conservation priority species endemic to a small part of the globe. A number of species occur which have uncertain or no names, which have been awarded gold stars pending the confirmation of their taxonomic status (Ghana Wildlife Division, 2000). One species of tree in particular (yet to be named) was discovered along the Ankasa River. This species seems to represent a new Genus for science. Botanists are of the firm opinion that more species are yet to be discovered. Ankasa represents the supposed epicenter of one of several Pleistocene refugia around the Gulf of Guinea, ranking alongside forests of southwest Ivory Coast and Mount Cameroon. It is classified as lying within the wet evergreen zone. Relatively little is known of the vegetation of Ankasa compared to the rest of Ghana, largely because the Forestry Department deemed that the Ankasa Forest was of low timber importance and has not placed any Inventory Plots there. The most recent detailed studies[15] have shown the presence of approximately 800 vascular plant species. Vegetation can be broadly divided into seven types (Table 4):

[15] (Hall and Swaine, 1976; Hawthorne and Abu Juam, 1998)

Table 4: Summary of Ankasa vegetation categories[16]

Vegetation Type	Typical Species	Landscape
VEG1	*Diospyros sanza-minika*	Well drained hill tops and slopes
VEG2	Intermediate 1<->3	Non-swamp slopes and watercourses
VEG3	*Octoknema, Piptadeniastrum, Strombosia*	Milder slopes and flat land, especially around Nkwanta
VEG4	*Eleaeis, Uapaca (Theobroma)*	Secondary forest, perhaps once farmed-with *Eleais* and Cocoa.
VEG5	*Protomegabaria (++)*	Riversides, often associated with steep banks
VEG6	Intermediate 3-7	Swampy land, less extreme than 6
VEG7	*Hallea, Anthostema*	Flat, swampy land, often with many shallow drainage lines, especially in mid-east

This division is based on the landscape association with the main trend related to drainage. There is no consistent single continuum between the landscape classifications from hilltop to swamp. Various intermediate samples are common.

The species commonly emergent in this kind of rain forest, in order of frequency, are *Pipta-deniastrum africanum (Piptadenia africand), Distemonanthus benthamianus, Anopyxis klaineana, Nauclea diderichii (Sarcocephalus diderichii), Ceiba pentandra, Terminalia ivorensis, T. superba, Chlorophora excelsa, Hannoa klaineana* and *Guarea cedrata.* The two main layers of the forest are irregular and often merge into each other and so lose their identity. The understorey is particularly well developed, forming a dense layer which lets through very little sunshine. Because of this the undergrowth is poor, consisting of small shrubs and slender seedlings of tree species represented in the upper layers. In many places a scrambling shrub is found, *Scaphopetalum amoenum*, and here

[16] Hawthorne and Abu Juam *ibid*

the forest floor is usually quite bare of other shrubs. Grasses are usually absent from the rain forest, except along paths and in disturbed areas.

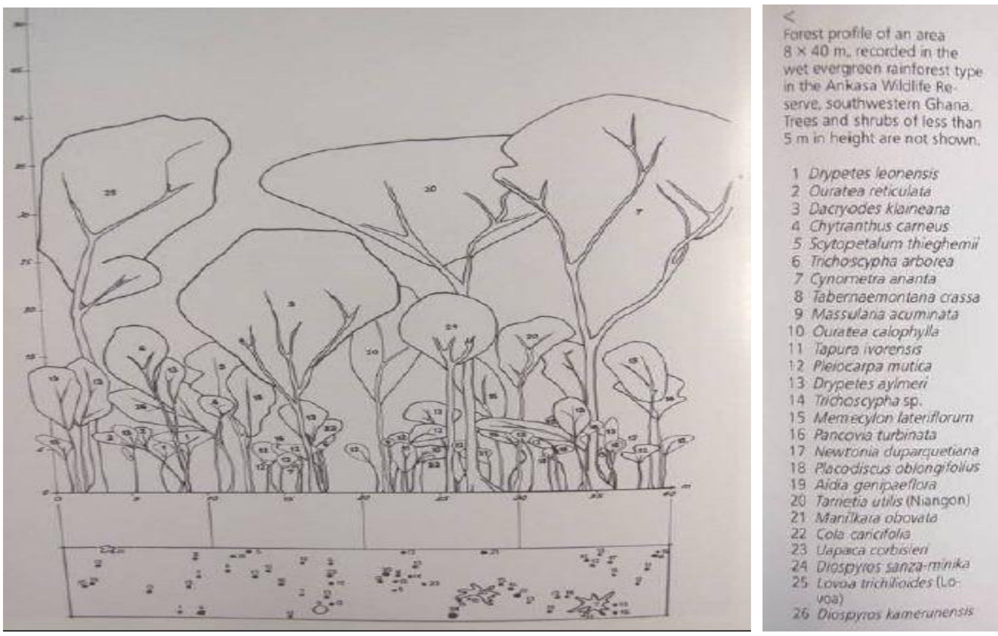

Figure 11: Structure and composition of the primary forests of the district

The indicator trees, *Lophira alata*, *Cynometra ananta* and *Tarrietia utilis* are all frequent. *Cynometra* and *Tarrietia* in particular are gregarious and may locally be very common indeed. Associated with these indicator trees are *Diospyros sanza-minika* (ebony), a small semi-gregarious tree, also found in smaller quantities north of the rain forest zone, and *Protomegabaria stapfiana*, which is particularly common on less well drained lower-slope areas. Many other tree species of the rain forest, though not indicator trees, are commoner in the rain forest than elsewhere. These include Ongokeagore (*O. klaineana*), also somewhat gregarious, *Strombosia glaucescens* var. *lucida, Dacryodes klaineana (Pachylobus barteri), Berlinia* sp., several species of *Chrysophyllum, Garcinia gnetoides, G. mannii, Mammea africana*, a species of *Parinari, Pentadesma butyracea, Trichoscypha arborea*, several species of *Vitex* and of *Xylopia, Allanblackia floribunda, Scottelia chevalieri, Dialium dinklagei, Anopyxis klaineana, Pentaclethra macrophylla, Octhocosmus africanus, Carapa procera, Canarium schweinfurthii* and *Turraenthus africanus (T. vignei).* All these species occur frequently in both the upper and lower layers of the rain forest, together with other trees growing throughout the forest zone, such as *Piptadeniastrum africanum, Fagara macrophylla, Pycnanthus angolensis, Combretodendron macrocarpum (Petersia africana), Distemonanthus bentha-mianus,* *Khaya ivorensis, Nauclea diderichii, Ceiba pentandra, Chlorophora excelsa* and others. The shrubby undergrowth is very poorly developed and sometimes absent. The commonest species in this layer, where it is present, are *Conopharyngia chippii, Pleiocarpa mutica, Mareya micrantha (M. spicata), Cola chlamydantha*, species of *Pavetta* and *Randia*, and *Baphia nitida* (Ahn 1961).

Anyway, although Ankasa has been well preserved and so reach in terms of biodiversity, one cannot dismiss the likely threats of encroachment posed by illegal harvesters of Non-Timber Forest Products (it is more evident confronting

Figure 12 a-b reported below).

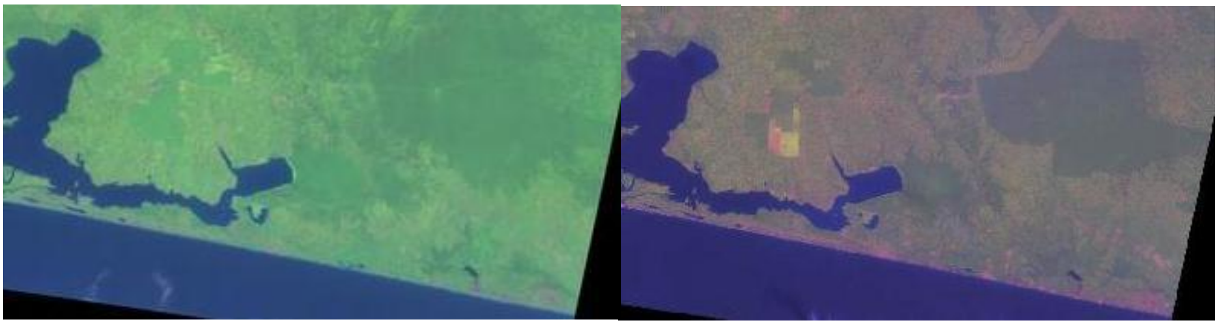

Figure 12 a-b: On the left side a view of the Jomoro District in 1986 (source: Landsat 1986) and on the right side the same view in 2000 (source: Landsat 2000).

6.1.2.6 Main tree crops of the Jomoro district

Cocoa: the black gold of Ghana

Since its introduction to Ghana in 1879[17], cocoa has become both economically as well as culturally significant to the country. Despite this fact, cocoa farming has been alleged to be one of the factors that have contributed to deforestation in Ghana (Asare, 2005). Considering the crucial role of cocoa for the national agricultural sector, Ghana asked through the *Working Group on ecosystem friendly cocoa production* to take into account cocoa plantations under REDD plus national strategy (FC, 2010). For over a century, cocoa has been the major driver of land use change in the high forest zone, particularly in the Jomoro district, and the new full-sun varieties which are now widely adopted have accelerated the pace of deforestation. The traditional varieties require much denser crown cover and, in the past, their need for high atmospheric humidity encouraged the farming population to support the forest reserve policy (FC, 2010). Traditionally, most cocoa farms are established by removing the forest understory and thinning the forest canopy so that cocoa seedling can grow into productive trees by utilizing the 'forest rent' of the newly cleared area and the shade provided by the remaining trees (Asare, 2005). In the Jomoro district, Cocoa is cultivated in areas which fall under two broad ecological zones (Amanor, 1996):

• Moist Forest: which consists of the wet evergreen, moist ever green and moist semi-decideous with rainfall in excess of 1200 mm per annum and;

• Dry Forests: which consist of semi-decideous inner zone and dry semi-decideous outer fire zone with rainfall between 1000-1200 mm per annum.

Currently the Jomoro district remains the last frontier for the expansion of cocoa due to the presence of patches of non-reserved and reserved forest in the country. Almost the 50% of the total Ghana's cocoa production is produced in Western Region, particularly in the Jomoro district (Abenyega and Gockowski, 2002) and this let understand the importance of this tree plantation for local economy.

[17] For further information of the story of cocoa in Ghana see the Annex 1 par.1

Scientific name	***Theobroma cacao*** **L., 1753**
Family	*Sterculiacea*
Distribution	 Cocoa is produced in countries within 10°N and 10°S of the Equator. It is native in Brazil, Mexico, USA and it is exotic in Belize, Cameroon, Colombia, Congo, Costa Rica, Cote d'Ivoire, Democratic Republic of Congo, Dominica, Ecuador, Gabon, Ghana, Guinea, India, Indonesia, Jamaica, Madagascar, Malaysia, Nigeria, Papua New Guinea, Philippines, Samoa, Sao Tome et Principe, Sierra Leone, Sri Lanka, Surinam, Tanzania, Togo, Trinidad and Tobago, Uganda, Venezuela. In its natural habitat, T. cacao is an understorey plant of forest in the wet humid tropics.
Ecology	Altitude: 100-300 m, Temperatures: maximum annual average of 30-32 °C and a minimum average of 18-21 °C, Mean annual rainfall: 1000-3000 mm, humidity: is generally high, often as much as 100 % during the day, falling to 70-80 % during the night. Soil type: Cocoa is grown in a wide variety of soil types. *Physical properties* - Cocoa needs a soil containing coarse particles to leave free space for roots and with a reasonable quantity of nutrients to a depth of 1. 5m to allow the development of a good root system. Below that level it is desirable not to have impermeable material so that excess water can drain away. Cocoa will withstand waterlogging for short periods but excess water should not linger. The cocoa is sensitive to a lack of water so the soil must have both water retention properties and good drainage. *Chemical properties* - The chemical properties of the topsoil are most important as there are a large number of roots here for absorbing nutrients. Cocoa can grow in soils with a pH in the range of 5.0-7.5. It can therefore cope with both acid and alkaline soil, but excessive acidity (pH 4.0 and below) or alkalinity (pH 8.0 and above) must be avoided. Cocoa is tolerant of acid soils provided the nutrient content is high enough. The soil should also have a high content of organic matter, 3.5% in the top 15 cm of soil. Soils for cocoa must have certain anionic and cationic balances. Exchangeable bases in the soil should amount to at least 35 % of the total cation exchange capacity (CEC) otherwise nutritional problems are likely. The optimum total nitrogen/total phosphorus ratio should be around 1.5. Light and shade: The cocoa tree will make optimum use of any light available and has been traditionally grown under shade. It's natural environment is the Amazonian forest which provides natural shade trees. Shading is indispensable in a cocoa tree's early years. Cacao is naturally out-breeding, and various insects are associated with its pollination, the main ones being thrips, midges, ants and aphids. It has a complex system of self-incompatibility. After successful pollination, fertilization takes place within 36 hours; the sepals, petals and staminodes drop away and the stamens and pistil wither. The young pod, known as the cherelle, begins to develop by longitudinal elongation, followed by increase in width. The period between fertilization and pod maturation varies from 150 to 180 days, depending on the variety. The pod turns light yellow when ripe and is ready for harvesting at this stage.
Varieties	***Theobroma cacao cacao*** – **Criollos**- dominated the market until the middle of the eighteenth century but today only a few, if any, pure Criollo trees remain. ***Theobroma cacao sphaercarpum***- **Forastero-** is a large group containing cultivated, semi-wild and wild populations of which the Amelonado populations are the most extensively planted. Large areas of Brazil and West Africa are planted with Amelonado. Amelonado varieties include, Comum in Brazil, West African Amelonado in Africa, Cacao Nacional in Ecuador and Matina or Ceylan in Costa Rica and Mexico. Recently large plantations throughout the world used Upper Amazon hybrids. The **Trinitario** populations are considered to belong to the Forasteros although they are

	descended from a cross between Criollo and Forastero. Trinitario planting started in Trinidad and spread to Venezuela and then was planted in Ecuador, Cameroon, Samoa, Sri Lanka, Java and Papua New Guinea.
Botanic description	Theobroma cacao is cauliflorous and semi-deciduous. The tree is low, reaching an average height of 5-10 m. The main trunk is short; branches in whorls of 5, dimorphic; vertical chupons growing from the trunk have leaves arranged in 5/8 phyllotaxy. The lateral branches (fans) have 1/2 phyllotaxy. Petiole with 2 joined pulvini, one at the base and the other at the point of insertion of the leaf. Stipules 2, deciduous. Lamina elliptical-oblong or obovate-oblong, simple, 10-45 cm long; generally smooth, sometimes hairy, rounded and obtuse at the base, pointed apex. Inflorescence dichasial; primary peduncle very short, often thick and lignified. Flower peduncle 1-4 cm long. Sepals 5, triangular, whitish or reddish in colour. Petals 5, joined at the base into a cuplike structure, whitish-yellow with dark purple bands adaxially; ligules spathulate, yellowish. Stamens 5, fertile, alternating with 5 staminodes, the 2 whorls uniting to form a tube. Anthers 2, stamens fused. Ovary superior with a single style terminating in 5 sticky stigmatic surfaces. Fruit variable in shape, ovoid, oblong; sometimes pointed and constricted at the base or almost spherical, with 10 furrows of which 5 are prominent. Axial placentation, seeds embedded in mucilage, flat or round with white or purple cotyledons. The generic name comes from the Greek 'theos' (god), and 'broma' (food) and means the 'food of the gods'.
Functional uses	***Products***  *Food*: The cocoa bean, with up to 50% fat, is a valuable source of vegetable fat, cocoa butter. The residual cocoa powder is used in cakes, biscuits, drinking chocolate and other confectioneries. *Fodder*: The cocoa-pod husk has a low alkaloid content, while tannin is practically absent. The crude fibre content is low; it is completely unlignified and compares favourably with Panicum maximum and Centrosema pubescens. *Fuel*: The cocoa bean testa has a calorific value of 16 000-19 000 BTU/kg, a little higher than that for wood. *Lipids*: The ash from pod husks contains potassium oxide, which can be extracted in the form of potassium hydroxide, a useful alkaline in the saponification process. Cocoa-bean fat from unfermented cocoa beans can be extracted and used in soap making. *Alcohol*: The cocoa-pod husk can be hydrolysed under pressure for fermentation into alcoholic drinks. *Medicine*: The rural people in Amazonas State, Brazil, rub cocoa butter on bruises. ***Services*** *Soil improver*: there is considerable nutrient cycling through the development of a deep leaf litter under the cocoa canopy. *Intercropping*: Cocoa has traditionally been established in thinned forest following logging and 1-3 years of food-crop production before the canopy closes. Crops such as maize, cocoyam, yams and plantain are commonly intercropped with cocoa in Ecuador, Jamaica and West Africa.

Table 5: *Theobroma Cocoa* L. (sources: International CoCoa Organization (ICCO)[18] and ICRAF database[19], Photo G.E. 2010).

[18] Data available on http://www.icco.org/default.aspx

[19] Data available on http://www.worldagroforestry.org/sea/Products/AFDbases/af/asp/SpeciesInfo.asp?SpID=1641

Rubber

The rubber tree (*Hevea brasiliensis* (Willd.) Muell.-Arg.), of the family Euphorbiaceae, originates from the Amazon basin forest and is now cultivated for latex production in all tropical zones by about 9,675,000 ha (Wauters et al., 2008). The Hevea reached Ghana in 1893[20] and according to Odoom (1998) assumed a peculiar management models:

- the small holder system where the small holder does not own the land but is allotted it by a large company, which owns the land and which provides a guaranteed market, a loan, advice and inputs of planting material, fertilizer etc;
- the outgrower scheme, which is similar to the smallholder system, but the farmer owns, leases or share-crops the land;
- the leaseback system, in which a farmer owns the land but does not farm it, leasing it instead to a private company.

Nowadays the Ghana Rubber Estate Limited (GREL) can be considered the only producing company in Ghana (Burger and Smith, 1997) with a total land concession of 15,000 ha, a total planted area of 13,093 ha and 9,555 ha under tapping (GREL, 2010). Its market is mainly based for the 96% on the export sales with final destination in UK, Germany, France, Spain, Italy, Turkey, USA and Burkina Faso and for the 4% on local sales.

Scientific name	***Hevea brasiliensis (Willd.) Muell.-Arg***
Family	*Euphorbiaceae*
Distribution	Native: Bolivia, Brazil, Colombia, Peru, Venezuela Exotic : Brunei, Cambodia, China, Ghana, Ethiopia, India, Indonesia, Laos, Liberia, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand, Uganda, Vietnam
Ecology	Rubber in the wild grows in the tropical evergreen rainforest of the Amazon Basin, often in periodically flooded areas, but larger trees are found on the well-drained plateaux. In its natural habitat, it forms part of the middle storey of the tropical forest. Rubber is successfully cultivated under humid lowland tropical conditions, roughly between 15°N and 10°S, with comparatively little variation in temperature. Planting above 400-500 m is not recommended because trees at higher altitudes tend to be smaller, with less vigorous growth, and with reduced production of both latex and timber. In high-rainfall areas, good internal drainage of the soil is important. In some areas, rubber can tolerate a 2-3 month period of drought. Strong winds may snap trunks and branches; however, more wind-resistant clones do exist. Altitude: 300-500 m, Mean annual temperature: 23-35 °C, Mean annual rainfall: 1500-3000 (max. 4000) mm Soil type: Tolerates some waterlogging and a wide pH range (4-8) but does better in acid soils. Lime is harmful, and shallow or poorly drained or peaty soils should be avoided. Thrives best in deep, well-drained loamy soil

[20] For further information of the story of rubber in Ghana see the Annex 1 par.2

	covered by natural undergrowth or a leguminous cover crop and protected from erosion.
Botanic description	Hevea brasiliensis is a quick-growing tree, rarely exceeding 25 m in height in plantations, but wild trees of over 40 m have been recorded. Bole usually straight or tapered, branchless for 10 m or more, up to at least 50 cm in diameter, without buttresses; bark surface smooth, hoop marked, grey to pale brown, inner bark pale brown, with abundant white latex; crown conical, branches slender. Root system with a well-developed taproot and far-spreading laterals. Leaves alternate, palmate and each leaf with 3 leaflets. Leaflets elliptic petiolated, with a basal gland, pointed at the tip with lengths varying up to 45 cm; glabrous, with entire margin and pinnate venation. Inflorescence in the form of pyramidal-shaped axillary panicles produced simultaneously with new leaves and arranged in cymose form. Flowers small, greenish-white, dioecious, female flowers usually larger than the male ones. In the female flower, gynaecium composed of 3 united carpels forming a 3-lobed, 3-celled ovary with a single ovule in each cell. Seeds large, ovoid, slightly compressed, shiny, 2-3.5 x 1.5-3 cm, testa grey or pale brown with irregular dark brown dots, lines and blotches. The testa being derived from the female parent and the seed shape being determined by the pressures of the capsule, it is possible to identify the female parent of any seed by its markings and shape; this is the most reliable method of identifying clonal seed. Endosperm white in viable seeds, turning yellow in older seeds. Seeds weigh 2-4 g. The generic name is derived from a local word in the Amazon, 'heve' meaning rubber.
Functional uses	***Products*** *Food*: Although poisonous, seeds of rubber can be eaten as a famine food after processing, which involves prolonged soaking or boiling to remove the cyanic poisons. Some of the denser wild stands of rubber in the Amazon are said to be due to artificial enrichment by indigenous peoples to increase food supply. Seeds contain 40-50% oil, which dries well and is suitable for use as food and for technical purposes. *Fodder:* Seeds are sometimes eaten off the ground by cattle. Press cake or extracted meal can be cautiously used as feed for stock. *Apiculture:* So much nectar is secreted by the extra-floral nectaries that rubber is an important source of honey. *Fuel*: Rubberwood was formerly regarded as a byproduct of the rubber plantations and used for the production of charcoal or as fuelwood, for brick making, tobacco drying and rubber drying. *Fibre*: Offcuts and other rubberwood residues have been used successfully in Malaysia for the production of particle board, wood-cement board, and medium-density fibreboard. *Timber*: Heartwood pale cream, often with a pink tinge when fresh, darkening on exposure to pale straw-coloured or pale brown, not clearly demarcated from the sapwood. Grain straight to shallowly interlocked. Texture moderately coarse but even; sawn rubberwood often shows black stripes with the inclusion of bark material, the result of poor tapping practices with damaged or removed cambium; in freshly sawn wood there is a characteristic and distinct smell of latex. Most of the timber is used to manufacture furniture. Other uses include interior finish, moulding, e.g. for wall panelling, picture frames, drawer guides, cabinet and other handles, parquet flooring, many household utensils, blockboard cores, pallets, crates, coffins, veneer, and glue-laminated timber, e.g. for staircases and door and window components. Since the timber is only moderately durable when exposed to the elements, it should not be used for exterior purposes. *Latex or rubber*: Latex, the source of hevea or para rubber, is obtained by tapping the trunks of the trees. The latex coagulates with the aid of acetic acid, formic acid and alum. Cured rubber is used for all types of rubber products. Lipids: Seeds are the source of para rubber seed oil. Boiling removes the poison and releases the oil, which can be used for illumination. Kernels (50-60% of the seed) contain semi-drying pale yellow oil used in soap making, paints and varnishes. *Poison*: Kernel oil is effective against houseflies and lice. *Other products*: Rubberwood waste is an excellent medium for the growing of mushrooms, especially oyster mushrooms (Pleurotus spp.). The mottled seeds of H. brasiliensis are still used for fish bait by rural folk along the Amazon River. ***Services*** *Soil improver*: Press cake or extracted meal can be used as fertilizer. *Intercropping*: Intercropping with coffee or cocoa, perhaps in conjunction with ipecac, is possible. A fodder crop such as Cajanus might be tried for lac production instead of the usually recommended cover crops (e.g. Calopogonium, Centrosema, Flemingia, Psophocarpus, Pueraria). After a few years under legumes, no nitrogen fertilizer may be needed, but phosphorus, magnesium and potassium may be limiting in some areas.

Table 6: *Hevea brasiliensis* (Willd.) Muell.-Arg., (sources: ICRAF database).

Coconut

Cocos nucifera L. was introduced in Ghana in 1910 (Johnson and Harries, 1976). According to Owusu Nipah (1994), coconut palm is the most important cash crop in the four coastal regions of Ghana (Greater Accra, Central, Volta and Western Region). Before 1920, its cultivation, as an estate crop, was confined to the Keta area, and then spread to other areas of Ghana particularly along the coast covering an area of 43,000 ha with about 80 % restricted to the southwestern coastal belts (Arkhust, 1991). Coconut production in Ghana is mainly in smallholdings (0.5-5.0 ha). Out of the annual national production of 224 million nuts, 179 million (80 %) were produced by smallholders from an area of 36 000 hectares (Arkhust, 1991).

In the last forty years, large parts of the Jomoro District have been converted into plantations. Initially, coconut constituted the main base of this land-use, followed by oil palm and cocoa (Ghana Wildlife Division, 2001). The indigenous *Nzemas* mainly placed coconut on plain lands with predominantly sandy loam soils of relative poor quality, whereas oil palm and cocoa preferably were planted on clay soils of higher quality. Coconut plantations were mainly started in the southern area, particularly around *Amokwaw* and *Sowodazem* and now they cover huge contiguous areas with most palms over 25 years old (Ghana Wildlife Division, 2001).

Scientific name	***Cocos nucifea L.*** **(1753)**
Family	*Arecaceae*
Distribution	Origin of C. nucifera is disputed but evidence favors Southeast Asia, with subsequent migration east and west, to the Pacific and Latin America, and to India, Madagascar and East Africa. Coconuts did not reach West Africa until they were taken there by the Portuguese, around the Cape of Good Hope, after AD 1500. Coconut palms are now found throughout the tropics wherever local conditions are favorable. The native range of C. nucifera is uncertain, because the species was introduced throughout the tropics long ago. Native : Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam Exotic : Argentina, Benin, Bolivia, Brazil, Burkina Faso, Cameroon, Chad, Chile, China, Colombia, Cook Islands, Cote d'Ivoire, Ecuador, Fiji, French Guiana, Gambia, Ghana, Guinea, Guyana, Haiti, India, Jamaica, Kenya, Kiribati, Liberia, Madagascar, Mali, Marshall Islands, Mauritania, New Caledonia, Niger, Nigeria, Papua New Guinea, Paraguay, Peru, Samoa, Senegal, Sierra Leone, Solomon Islands, Sri Lanka, Surinam, Togo, Tonga, Uganda, United States of America, Uruguay, Vanuatu, Venezuela, Zanzibar
Ecology	C. nucifera is unknown in the wild state. In the coastal areas of the tropics and subtropics where it is grown, it requires a hot, moist climate and deep alluvial or loamy soil, thriving especially near the seaboard, but also considerable distance

inland, provided climatic conditions and soil are suitable. Rocky, laterite or stagnant soils are unsuitable.

Altitude: 520-900 m, Mean annual temperature: 20-28 °C, Mean annual rainfall: 1000-1500 mm, Soil type: C. nucifera is tolerant to soil variations but its natural preference is for sandy, well-aerated and well-drained soils. It has considerable ability to adapt to soils of heavier texture.

Botanic description

Cocos nucifera trees have a smooth, columnar, light grey-brown trunk, with a mean diameter of 30-40 cm at breast height, and topped with a terminal crown of leaves. Tall selections may attain a height of 24-30 m; dwarf selections also exist. Trunk slender and slightly swollen at the base, usually erect but may be leaning or curved. Leaves pinnate, feather shaped, 4-7 m long and 1-1.5 m wide at the broadest part. Leaf stalks 1-2 cm in length and thornless. Inflorescence consists of female and male axillary flowers. Flowers small, light yellow, in clusters that emerge from canoe-shaped sheaths among the leaves. Male flowers small and more numerous. Female flowers fewer and occasionally completely absent; larger, spherical structures, about 25 mm in diameter. Fruit roughly ovoid, up to 5 cm long and 3 cm wide, composed of a thick, fibrous husk surrounding a somewhat spherical nut with a hard, brittle, hairy shell. The nut is 2-2.5 cm in diameter and 3-4 cm long. Three sunken holes of softer tissue, called 'eyes', are at one end of the nut. Inside the shell is a thin, white, fleshy layer known as the 'meat'. The interior of the nut is hollow but partially filled with a watery liquid called 'coconut milk'. The meat is soft and jellylike when immature but becomes firm with maturity. Coconut milk is abundant in unripe fruit but is gradually absorbed as ripening proceeds. The fruits are green at first, turning brownish as they mature; yellow varieties go from yellow to brown. The generic name seems to be derived from the Portuguese 'coco', meaning 'monkey'.

Functional uses

Products

Food: Copra, the dried coconut endosperm, contains an edible cooking oil (coconut oil). The apical region of C. nucifera ('millionaire salad') is a food delicacy in areas where it is grown. Other food derivatives of coconut include coconut chips, coconut jam, coconut honey, coconut candy and other desserts.

Fodder: Copra meal and coconut cake, the residues of oil extraction from copra containing approximately 20% protein, 45% carbohydrate, 11% fibre, fat, minerals and moisture, are used in cattle feed rations.

Apiculture: C. nucifera is an important pollen source for honey production. Where sap is tapped from unopened inflorescences for toddy-making, many bees drain in the collecting pots. The honey may be greenish-yellow like the motor oil and crystal clear if monofloral. Granulation is medium (takes up to 3 months).

Fuel: The high moisture content of C. nucifera wood and the difficulty of splitting it has made it relatively unpopular as firewood. Coconut shell charcoal is a major source of domestic fuel in the Philippines. It is also exported to Japan and the USA. Coconut oil can be used as a substitute for diesel oils, for electric generating plants and motor vehicles. However, this use is non-economic in most situations at the present prices of fuel oil.

Fibre: Three types of fibres are obtained from the coconut husks: mat fibre or yarn fibre, used in making mats; bristle fibre, used for brush making; and mattress fibre, used in stuffing mattresses and in upholstery. Leaflets are used in braiding mats, baskets and hats.

Timber: C. nucifera timber has traditionally been used in tropical countries for the

	structural framework of houses. Coconut timber taken from the lower and middle parts of the trunk can be used for load-bearing structures in buildings, such as frames, floors and trusses. Coconut trunks can be used for poles, as they have great strength and flexibility. The wood can also be used for furniture and parquet flooring. *Lipids*: The oil contains fatty alcohol and glycerine used in soaps, detergents, shampoos cosmetics, pharmaceuticals and explosives. Alcohol: Sap from the tender, unopened inflorescence (coconut palm sap) is used in the producing areas for toddy, or tuba, a beverage obtained by natural fermentation. Tuba contains 6-7.5% alcohol. The distillation of fermented coconut toddy yields a spirit called arrack, produced commercially in Sri Lanka and the Philippines. *Other products*: Coconut-shell flour, obtained from grinding clean, mature coconut shells to fine powder, is used as a filler in thermoplastic industry and an abrasive for cleaning machinery. Coconut-shell charcoal may be processed further into activated carbon that has many industrial applications, including general water purification, crystalline sugar preparation and gold purification. The edible mushrooms of the genus Auricularis grow well on coconut stems and are readily sold in China and elsewhere. ***Services*** *Soil improver*: Burnt husks form a useful sort of potash that is used to fertilize the trees. The husks also make valuable mulch for moisture conservation in the dry season and help to suppress weeds. *Ornamental*: Planted widely as an ornamental tree. *Intercropping*: Coconut palm is one of the most widely grown tree crops in the tropical countries. Its growth characteristics are ideal for small production and also for combining with other crops. The crown morphology and the relatively wide spacing facilitate the planting of a wide spectrum of field crops in coconut plantations. It has therefore been intercropped with cereals (cassava, sweet potatoes, yams) or fruits (bananas, passion fruit, pineapples and ground nuts) in many countries including Thailand, India, Sri Lanka, the Philippines etc

Table 6 : *Cocos nucifera* L. (sources: ICRAF database[21], Photos G.E.2010).

[21] Data available on:
http://www.worldagroforestry.org/sea/Products/AFDbases/af/asp/SpeciesInfo.asp?SpID=545

Oil palm

Elaeis guineensis Jacq. is indigenous to the tropical rainforest belt of West and western Central Africa between Guinea and northern Angola (11° N to 10° S). Dutch were the first to introduce the plantation system in Ghana about the beginning of the eighteenth century (Gyasi 1996). Nowadays in Ghana have been established three major plantations, government-owned but foreign-assisted:

- Ghana Oil Palm Development Co. (GOPDC) located around Kwae;
- the government/privately owned Twifo Oil Palm Plantations Ltd. (TOPP) located around Twifo Praso/Ntafrewaso and
- the government/privately owned Benso Oil Palm Plantations Ltd. (BOPP) located around Benso/Adum Banso

This agro-industrial crop, which has a wide variety of uses, was a leading foreign exchange earner for Ghana, mainly on the basis of small-scale peasant production in an oil-palm belt near the littoral, from about the mid-nineteenth century to the beginnings of the twentieth century but managed on modern corporate agro-business lines. The plantations have been developed on land compulsorily acquired from peasants by the government in the humid tropical environment of the interior, which favors the oil-palm. Traditionally, the natural environment, including the land, has constituted the basis of the farming, hunting, and gathering economies in the plantation areas. Consequently, the expropriation of over 16,000 ha of peasant lands for the plantations, with little or no compensation for the cottages, camps, and farms lost, together with various land-use or proprietary rights, could be expected to precipitate social resistance. Perhaps the most serious adverse effect has been the rapid transformation of the forest ecosystem and its resilient diversified ecologically based traditional economy into a vulnerable artificial monocultural system (Gyasi, 1996). Instability, risks, or uncertainties are inherent features of the natural environment, which the peasant farmers recognize. Traditionally, the peasants try to minimize these environmental risks, combat soil erosion, optimize utilization of the different soil nutrients, and enhance food security by intermixing crops of varying degrees of environmental sensitivity and different nutritional value, and by other forms of agricultural diversification and risk minimization. The resilient, diversified indigenous agriculture, modeled on the forest ecosystem and based on eco-farming principles borne out of the peasants' intimate knowledge of the natural environment, is being replaced by the risk-prone monocultural system, with devastating consequences for the forest ecosystem.

Scientific name	*Elaeis guineensis* Jacq.
Family	*Arecaceae*
Distribution	Native : Cameroon, Cote d'Ivoire, Democratic Republic of Congo, Ghana, Guinea, Sierra Leone, Uganda. Exotic : China, Colombia, Congo, Costa Rica, Ecuador, Honduras, India, Indonesia, Kenya, Madagascar, Malaysia, Nigeria, Papua New Guinea, Philippines, Singapore, Solomon Islands, Sri Lanka, Tanzania, Togo, Venezuela, Zanzibar.  E. guineensis, a native of forested portions of western and central Africa, particularly along rivers, has been spread across Africa by human migrations or intergroup exchange. It may have first been domesticated in Chad, taken to the Congo Basin and eastern Africa long before the arrival of Europeans, and to Sudan 5000 years ago. Africans probably took E. guineensis to Madagascar in the 10th century, the same time it is thought to have been established on the southern coast of Kenya, Pemba and Zanzibar. The Dutch introduced it to Southeast Asia. The Bogor Botanic Garden received some seedlings in 1848 from Amsterdam Botanical Gardens. The progeny from this introduction were planted initially between 1880 and 1900 as ornamentals on tobacco estates around Deli and Medan and laid the foundation for the oil palm industry in Southeast Asia. The Singapore Botanic Garden received seeds from Java in 1870, and this helped to diffuse E. guineensis throughout Malaysia and into Sumatra. As markets for oil palm expanded in Europe, the exotic E. guineensis was cultivated on plantation scale starting in 1911. The 1st plantations were established in Malaysia in 1917. In India it was first introduced in 1834 in the botanic garden in Calcutta, and trial plantings were started in 1930 in Kerala. The 1st commercial plantings were started in Kerala in the 1970s. Slave traders took E. guineensis to the New World, but until recently it has not been cultivated to any extent except in Bahia, Brazil.
Ecology	Altitude: Up to 900 m, Mean annual temperature: 27-35 deg. C, Mean annual rainfall: 2000-3000 mm Soil type: It has a fibrous root system and benefits from deep soils that are fertile, free from iron concretions and well drained. It also tolerates a fair range of soil pH (4-6), although neutral soils are favorable. It is difficult to determine the natural habitat of the oil palm because, while it does not grow in primeval forest, it flourishes in habitats where forests have been cleared. It requires a relatively open area to grow and reproduce itself and thrives best when soil moisture is maintained. Normally, E. guineensis occurs in disturbed forests and along rivers and streams, both in its native range in West Africa and in some introduced areas. It is a succession species favoured by slash and burn, and its gene pool has expanded as farmers clear land and create more open habitat for the germination of its seeds.
Botanic description	Elaeis guineensis is a handsome tree reaching a height of 20 m or more at maturity. The trunk is characterized by persistent, spirally arranged leaf bases and bears a crown of 20-40 massive leaves. The root system consists of primaries and secondaries in the top 140 cm of soil. Leaves numerous, erect, spreading to drooping, long, reaching 3-5 m in adult trees; leaf stalks short with a broad base. Spiny, fibrous projections exist along the leaf margins from the leaf sheath, wearing away on old leaves to jagged spines. Leaf blades have numerous (100-160 pairs), of long leaflets with prominent midribs, tapered to a point; arranged in groups or singly along the midrib, arising sometimes in different planes. Male and female inflorescences occur on 1 plant; sometimes a single inforescence contains both male and female flowers. Inflorescences arise among the leaf bases in large, very dense clusters, with innumerable small flowers, enclosed in the bud stage in 2 large

	fibrous bracts, which finally become deciduous. Male flowers single or in pairs in recesses on the branchlets, each with 3 sepals, 3 petals with edges touching in bud, 6 stamens, and a small, sterile pistil. Female flowers subtended by 2-3 small bracts, with 3 sepals, 3 petals overlapping in bud in a ring of small, sterile stamens, and a 3-celled ovary with 3 spreading stigmas. Fruits borne in bunches. The average weight of each bunch is 23 kg, but a bunch may weigh up to 82 kg. A bunch contains between 200 and 2000 sessile ovoid drupes, 4 cm long and 2 cm broad, with pointed apex. The fruit coat colour varies from yellow to orange or nearly black. Four oil palm varieties have been distinguished on the basis of the fruit structure, especially the thickness of the endocarp: E. g. var. macrocarpa with 40-60% shell, E. guineensis var. dura with 20-40 % shell, E. g. var. tenera with 5-20 % shell and E. guineensis var. pisifera, a shelless form. The generic name comes from the Greek word 'elaion' (oil), referring to the oil extracted from the palm.
Functional uses	***Products*** *Food*: Palm oil is popular in West Africa and Malaysia for cooking. It is now imported by India to meet local shortages in edible oil, being cheaper than many other vegetable oils. In West Africa, palm oil is often added directly to bring richness to soups and sauces. Addition of oil to cereal preparations greatly increases their calorific density, which is particularly advantageous for young children. Palm oil is also used as frying oil in the preparation of snacks such as bean cakes and fried plantain. Its 10% linoleic acid content makes it an excellent source of carotene. This is important in reducing incidence of vitamin A deficiency and the occurrence of nutritional blindness. Oil palm also provides heart-of-palm. *Fodder*: Pressed cake is used as cattle feed. *Apiculture*: The juice from fermenting fruit is collected by bees. The honey is dark amber with an astringent flavour. *Fuel*: It is technically possible to produce from palm oil either carbohydrates for conversion to alcohol or a methanolizable oil as a diesel substitute. In Togo, the pressed fruits are dried and fashioned into cakes for cooking fuel. *Lipids*: Palm kernel oil contains about 50 % oil. This oil is used in hard water soaps, the manufacture of glycerin, shampoos and candles. The better grades are used in manufacturing margarine. *Alcohol*: Palm wine is the delicious wine obtained by tapping the base of the immature inflorescence of the oil palm. Freshly tapped, undiluted and chilled, palm wine is pleasant to drink and is very high in yeast content. The sale of palm wine is considered more profitable than the sale of the fruits and oil. ***Services*** *Reclamation*: Oil palm is a good crop for rehabilitating degraded areas. In Sumatra it has successfully been established on abandoned farmlands taken over by Imperata cylindrica. *Shade or shelter*: E. guineensis shade is lighter than that of other plantation crops such as rubber or cocoa and is suitable for substantial quantities of undergrowth, attracting livestock. Attention has been given to raising livestock in oil palm plantations as a subsidiary source of income. Palm fronds are useful for thatch. *Soil improver*: The potash-rich residue from boilers is routinely recycled onto plantations to help enrich the soils for instance in Malaysia. Labour and transportation costs may discourage such recycling. *Ornamental*: E. guineensis has been planted as an ornamental on tobacco estates around Deli and Medan in Sumatra. *Intercropping*: Coffee and cocoa are small trees that can be planted among E. guineensis trees. Shading with E. guineensis presents certain difficulties, because while cocoa benefits from greater shade when it is young, the shade that the palm provides becomes increasingly undesirable as the cocoa plantation matures.

Tabella 7: *Elaeis guineensis* Jacq. (sources: ICRAF database[22], Photos G.E.2010).

[22] Data available on:
http://www.worldagroforestry.org/sea/Products/AFDbases/af/asp/SpeciesInfo.asp?SpID=724

6.1.2.7 Main land uses of the Jomoro district

Respect of the district area, the land outside the forest reserve of Ankasa is used for the 36% for tree crop cultivation, 4% for fallow lands and 8% for settlements (JDA, 2009). Coconut, cocoa, rubber and oil palm are the main tree crops grown. The average size of farm for tree crops is estimated to be 10.8 ha while farm sizes form food crops range between one and thirty-four acres. The major food crops grown are cassava, plantain, cocoyam, garden eggs and pepper. Apart from Ankasa, the rest of the land is characterized by the following land uses as declared in the Medium term Development Plan of Jomoro District on the base of MOFA's data:

LAND USE	**LAND USE (2002)**		**LAND USE (2005)**	
	AREA UNDER CULTIVATION (hectares)	**%**	**AREA UNDER CULTIVATION (hectares)**	**%**
FOREST RESERVE	27,734	18	27,734	18
TREE CROPS	71,024	47	72,112	48
FOOD CROPS	36,924	25	47,386	25
FALLOW LANDS	4,652	3	2,143	1
SETTLEMENT	10,057	7	12,442	8
TOTAL	**150,391**	**100**	**151,817**	**100**

Table 8: Land Use in Jomoro District[23].

TYPE OF CROP	**AREA ha 2002**	**%**	**AREA ha 2005**	**%**
Cassava	18,829	51	19,121.5	51.2
Plantain	3,271.5	8.9	3,340	9.0
Maize	11,238.6	30.4	11,338	30.4
Vegetable	2,971.5	8.1	2,991.5	8.0
Groundnuts	594.4	1.6	595	1.4
TOTAL	**36,924**	**100**	**37,386**	**100**

Table 9: Land Under Food Crop Production Source: MOFA, Jomoro 2006.

In 2005, fallow lands decreased from 3 % to 1 % due to increase in population which placed more pressure on land for settlement and farming. Cassava and maize are the main food crops cultivated in the district. Mixed cropping enables the farmer to get more from the same plot of land, thus increasing his family income (JDA, 2009).

[23] Source: MOFA (Ministry of Food and Agriculture), Jomoro

TYPE OF CROP	AREA UNDER CULTIVATION H/A 2002	%	AREA UNDER CULTIVATION H/A 2005	%
Coconut	30,450	43	30,450	42.3
Oil Palm	13,373	19	13,773	19.1
Cocoa	25,000	35.2	26,085	36.3
Coffee	891.4	1.0	500	0.6
Rubber	1,004	1.4	1,054	1.4
Citrus	305.6	0.4	250	0.3
TOTAL	**36,924**	**100**	**37,386**	**100**

Table 10: Land Under Tree Crop Cultivation - Source: MOFA, Jomoro.

Coconut cropping stagnated due to the fear of the Cape St. Paul Wilt Disease. Currently there is a program in place to replant all the plantations with the hybrid disease tolerant variety. The coconut intensification program where NPK and Ammonia Fertilizers were applied to some selected plantation to increase yield per tree/year from a low of 120 nut/tree/year to an average of 200 nuts/tree/year i.e. 100-150% increase. The decline in the production of coffee and citrus was due to the high interest shown for cocoa and oil palm cultivation which is enjoying a lot of support from Government.

6.1.2.8 Population and land tenure

On the base of Ghana Statistical Service data, the population of Jomoro district in 2010 is 2,558,113[24] with over ninety-five (95) which are predominantly rural communities. The district is located in the Akan speaking area, occupying west of the Volta Lake and south of the Black Volta. The Akans have, primarily, a communal land tenure system, which reflects a hierarchy of political authority, whereby religious and economic activities are decentralized to lower levels, while jural functions are more centralized (Ghana Wildlife Division, 1999). In line with this, in Ankasa in the Nzema West Kinship, the ultimate custody of the land is vested in the King or Omanhene, in trust for the people, whereas various paramount and divisional chiefs oversee the land. Generally every member of the tribe has equal rights to the land. First occupation and investment of labour in land clearing and cultivation established initial rights of land tillage of families or clans. Subsequent family or clan members can cultivate family or clan land anywhere, provided this is not already in use by another family member (Ghana Wildlife Division, 1999).

As Ewusi (Ewusi, 1990) has underlined, this traditional system of land allocation has proved to be far from a static set of customary rules. The introduction of cocoa and other

[24] Data available on Ghana Statistical Service web page: http://www.statsghana.gov.gh

cash crops in Ghana brought not only into greater prominence the important role of land and labor as sources of agricultural growth in Ghana. It initiated also major changes in the pattern of land ownership. It has created new relations (e.g. leasehold, abunu and abusa[25], etc.) over land and labour, which have to a large extent replaced the traditional communal system dominated by family production. Another aspect of it is that this, together with rapid population growth and migration, has produced increasing signs of economic, legal and social stress - land pressure - as existing land tenure adapts to current agricultural development and the general economic condition of the country (Ghana Wildlife Division, 1999). Even though the situation is not so acute in Ankasa, and there is still virgin land available, rapid immigration is posing increasing strains on land there. These pressures on land are complicated by diverse tenure arrangements and land transfers, which do not take cognizance of titles, or make any legal distinction between permanent and temporary possession. The consequence is the spread of land disputes and litigation in these areas, which can impede investment in land and resource conservation (Ghana Wildlife Division, 1999).

6.1.2.9 Economy

The mainstay of the district's economy is subsistence farming and petty commerce with coconut farming dominating. Land for farming in the district is acquired mainly through the share cropping system. Both inland and sea fishing is another major economic activity and is characterized by the used of canoes with out-board motors and dragnets (JDA, 2009). The fishing industry has the potential to be viable. However, the absence of storage and credit facilities serve as disincentives to fishermen due to the low rate of turnover, narrow profit margins and large spoilage especially, during low seasons. During the bumper season however, most fish caught are either thrown back into the sea or sold at low prices to traders from urban centers. Livestock production is on the rise especially pig farming because of the abundance of coconut chaff, which is used as feed (JDA, 2009). The economy of the district is mixed consisting of large traditional agricultural sector made up of mostly small-scale peasant farmers, a growing informal sector of small

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25 ***'Abunu'*** : the farmer clears and plants perennial crops. At maturity half of the produce belongs to the landowner. Recently, a cash payment is also required before the land is acquired.
'Abusa' : as for the above but at maturity one third of the produce belongs to the landowner.

businessmen, artisans and technicians and an insignificant proportion in the processing and manufacturing sector.

The major occupational structure in the district is agriculture, which absorbs 54 % of the total labor force in the district (JDA, 2009). Population engaged in industry and service is comparatively small. Farming both subsistence and commercial especially cassava (40%) coconut (16%) maize (15%) and the rest cocoa (9%) plantain (9%) and others (9%) are the principal occupation in the district. The district can be said to be an agrarian district. About 4% of the farmers cultivate on land size of 0-3 ha (JDA, 2009). In view of the fact that agriculture is also in the hands of peasant farmers using rudimentary tools and methods of farming it has serious negative implication on output levels. The service sector is dominated by public servants, traders who serve as middlemen between farmers and middle women, and those in the communication sector and drivers. Hotels and restaurants contribute a very small labour force. The industrial sector contribution to the local economy is very low. At the national level, the main contributors to this sector are mining and electricity, manufacturing, however, the contribution is declining. These sub sectors do not exist in the district. This explains why the industrial sector employs a few people (JDA, 2009).

6.2 Land use change assessment

To evaluate the effects of the forest clearing on the main C pools (soil, aboveground biomass, belowground biomass and litter), several chronosequences were reconstructed in each of the three substrates (Table 7).

Table 7: Land uses on the different geological formations.

Substrate	Land use	Number of eligible sites
Granite	Oil palm	2
	Secondary forest	2
Lower Birrimian	Forest	2
	Cocoa	2
	Coconut	3
	Rubber	2
	Mixed	2
Tertary sands	Forest	1
	Rubber	2
	Coconut	3

During the three missions carried out in 2009 and 2010, it has been surveyed the district area to find out the eligible sites to assess the changes in C stocks. The first phase of the study was finalized to locate in the Jomoro District the main land uses following the original rainforest clearance, on the three different geological formations. A brief description of each land use on each substrate is described in the paragraph below.

6.2.1 Granite

Primary forests

The primary forest site that was found and chosen as to represent the comparison with the plantations found on this substrate was the Ankasa conservation area previously described in this section. Values from literature have been considered for aboveground, belowground litter and soil.

Oil palm plantations

On the granite, were found two sites where the oil palm plantations were established after 8 and 25 years ago, immediately after the clearing of the primary forest present originally present on those areas. The former plantation OP_8 was established in 2002 while the latter

OP_{25} was established in 1985, one year after forest clearance. At the time of the survey [26] the plantation OP_{25} was at its second generation. The replacement was done in 2005, so that at the time of the survey the new plantation was only 4 years old.

Secondary forests

The secondary forest sites identified in the granite substrate were SF_{10} and SF_{21}. The first site was deforested in 2000 and then abandoned[27]. Also at the second site the original forest was cleared in 1988 and then the land was abandoned[28].

6.2.2 Lower Birrimian

Primary forests

Two primary forest sites were indentified on the Lower Birrimian substrate. The former is a patch of land close to Cocotown city, that was conserved as high forest since it represent for the local people a holy place. The utilization of wood and collections of other woody products is strictly forbidden. The second forests site is a portion of the Ankasa conservation area that is located on the Lower Birrimian substrate. This portion was indentified following the map from Ahn (1961), and after some survey a small patch was chosen. The sites were identified with the codes ANKF and CTF, respectively.

Cocoa plantations

Two cocoa plantations were identified on this substrate. The first was found at Cocotown, located along the river Tano. This area is historically famous for cocoa production from the 18th century. The chosen site, labeled as CC_{120}, was established in 1890 and continuously cultivated with cocoa. The second site, labeled as CC_{34}, was found in the village of Kofi Gyaman, located south of Cocotown. The plantation was established in 1975 after the clearing of the primary forest and continuously cultivated with cocoa.

Rubber plantations

Two sites deforested in different time were found also for rubber. The first site (RP_5) is located nearby Johnatan village and was established in 2005[29], while the second rubber

[26] OP_{25} survey :20/09/2009

[27] SF_{20} survey: 16/07/2010

[28] SF_{21} survey: 22/03/2009

[29] RP_5 survey : 13/07/2010

plantation (RP_{10}), located near New Ankasa village, was established in 2000[30]. At both sites were present the first generation of trees.

Coconut plantations

The Coconut plantation sites found on the Lower Birrimian substrate were three. The first (CN_{21}) was located near the western entrance of the Ankasa conservation area, and was established in 1988. The second site (CN_{28}) was located at Nyamenle Keya Beven nearby Sowodzadzem village and was established in 1982, while the latter site (CN_{44}) was located at between Navrongo crossroad and Abudu village and was established in 1966[31].

Mixed plantations:

The site cultivated as mixed plantation on the Lower Birrimian substrate were two. The former (MF_{36}) was donated to the owned by the king and is located near Agaege village. The mixed plantation was established in 1974. The latter site (MF_{49}) is along the way that brings to the second entrance of the Ankasa conservation area, and was established in 1960[32].

6.2.3 Tertiary sands

Primary forests

To find a patch of primary forest on the Tertiary sand substrate was really complicate since the forest in the area is almost completely disappeared due to intense cultivation. After many interview with local farmers it was identified a small patch of about 3 ha close to Bawia village. It is a community land left for future farming.

Rubber plantations

The rubber plantations found on this substrate were two, the first (RP_{14}) located nearby Bawia village was established in 1996[33], while the second one (RP_{49}), located at Mpataba village was established in 1960[34].

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[30] RP_{10} survey :27/02/2010

[31] CN_{44} survey :12/07/2010

[32] MF_{49} survey :25/03/2009

[33] RP_{14}survey : 14/07/2010

[34] RP_{49} survey :23/03/2009

Coconut plantations

Coconut plantations found on this substrate were three, the first (CN_{15}) located in the village of Betekomoa village was established in 1995[35], the second (CN_{50}) was located near Aboyele village and was established in 1960[36]; while the third one (CN_{100}) was located close Nuba village and was established in 1910 and at the time of the survey [37] the plantation was 100 years old.

[35] CN_{15} survey : 26/02/2010

[36] CN_{50} survey :24/02/2010

[37]CN_{100} survey :28/02/2010

6.3 Sampling and field work

6.3.1 Interviews and social aspects

Forest land use change is seldom straightforward, often being driven through a complex mix of socio-economic, cultural and political factors. Such factors in turn result from the combined actions, decisions and behavior of multiple agents ranging from national governments to international financiers to impoverished landless people (IUCN, 2008). Land use change is in fact a key requirement for rural incomes and making a significant reduction in poverty levels globally. Over 70% of the world's poor are located in rural areas, with land use as a major source of subsistence (Lipper and Cavatassi, 2003). A partecipatory approach to the problem is necessary to deepen in this thorny problem. For understanding the drivers of deforestation and land use change process, the role of field activities has been central and the collaboration of local people more than everything else. A field sheet interview was prepared in order to collect preliminary information on the sites for assessing past and present land uses. It has been asked as first thing, the type of plantation and the time since the clearing of the original forest. This is one of the basic information to identify the sites so to have a chronosequence from forest to the main plantations of the district. It was necessary detect what lead to the deforestation process and what drives the choice of a specific tree plantation. The farming decision is a mirror of a socio-economic condition that could moreover influence the future use of the land. Socio-economic aspects were also investigated in terms of gender issues, harvesting incomes, benefit sharing, management costs, governmental aids and problems related to plantation diseases or unproductiveness.

Picture 1: Interview at Cocotown.

The information acquired were collected as reported in the following brief scheme:

Table 8: Socio economic interview sheet.

Farmer interview

Surveyors:____ date:___/___/___

Farmer's name: ___________________________

Land tenure status:______________Government ☐ Community ☐ Private ☐

Owner name:____

Farm number:_______________ Present Land Use:______________________________

ID Area ____
Farm
location:____

Nearest village: ____

Approximate date when plantation was established: __________________________

Year of last forest cover: ____

Approximate size of tree plantation:____

Reasons for establishing the plantation:
____

Farming
practices*____
*Rotation, use of residues, slash and burn, turn for tree crops, ploughing etc

Use of fertilizers: ____

Market options: ____

Gender issue: ____

Future likely use of the land: ____

Reasons:____

Benefits sharing: ____

Within each land-use category, C stock changes and emission/removal estimations can involve the five carbon pools that are defined in Table 9. For some land-use categories and estimation methods, C stock changes maybe based on the three aggregate carbon pools (i.e., biomass, dead organic matter and soils) (IPCC, 2006). For the present study has been considered four pools counting out dead wood pool.

Table 9: Definitions for carbon pools used in AFOLU for each land-use category (IPCC 2006).

Pool		Description
Biomass	Above-ground biomass	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage. Note: In cases where forest understory is a relatively small component of the above-ground biomass carbon pool, it is acceptable for the methodologies and associated data used in some tiers to exclude it, provided the tiers are used in a consistent manner throughout the inventory time series.
	Below-ground biomass	All biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.
Dead organic matter	Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter (or the diameter specified by the country).
	Litter	Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g. 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.
Soils	Soil organic matter	Includes organic carbon in mineral soils to a specified depth chosen by the country and applied consistently through the time series . Live and dead fine roots and DOM within the soil, that are less than the minimum diameter limit (suggested 2 mm) for roots and DOM, are included with soil organic matter where they cannot be distinguished from it empirically. The default for soil depth is 30 cm and guidance on determining country-specific depths is given in Chapter 2.3.3.1.

6.3.2 Soil sampling

Within the lack of reliable methods on practical soil sampling to certify the changes in soil organic carbon stock, it has been adopted the soil sampling protocol proposed by Stolbovoy et al. (2005). At the core for the sampling protocol there is a randomized sampling template that represents a grid of 100 cells that enables a 'modified' random sample collection with a distance threshold to be carried out. The numeration of the sampling cells is selected at random with particular care being placed to prevent a previously sampled cell being too close to subsequent ones, which can occur for pure random sampling plans. Sampling plans that avoid points too close to each other, give a lower variance than simple random sampling (Bellhouse, 1977); this happens in particular for systematic sampling (Bellhouse, 1988). The sampling scheme used in this approach behaves approximately like a systematic sampling plan in the sense that points too close to each other are avoided and is more flexible than systematic plans to adjust a small sample size in areas with an irregular shape (Figure 13)

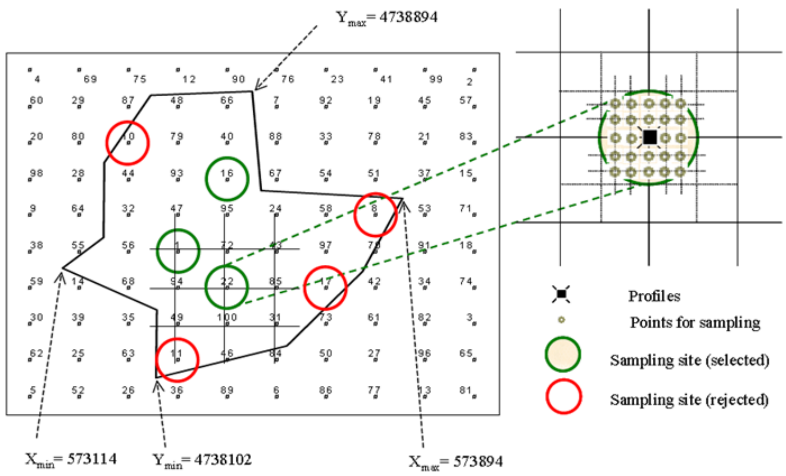

Figure 13: Schematic representation of the plot selections.

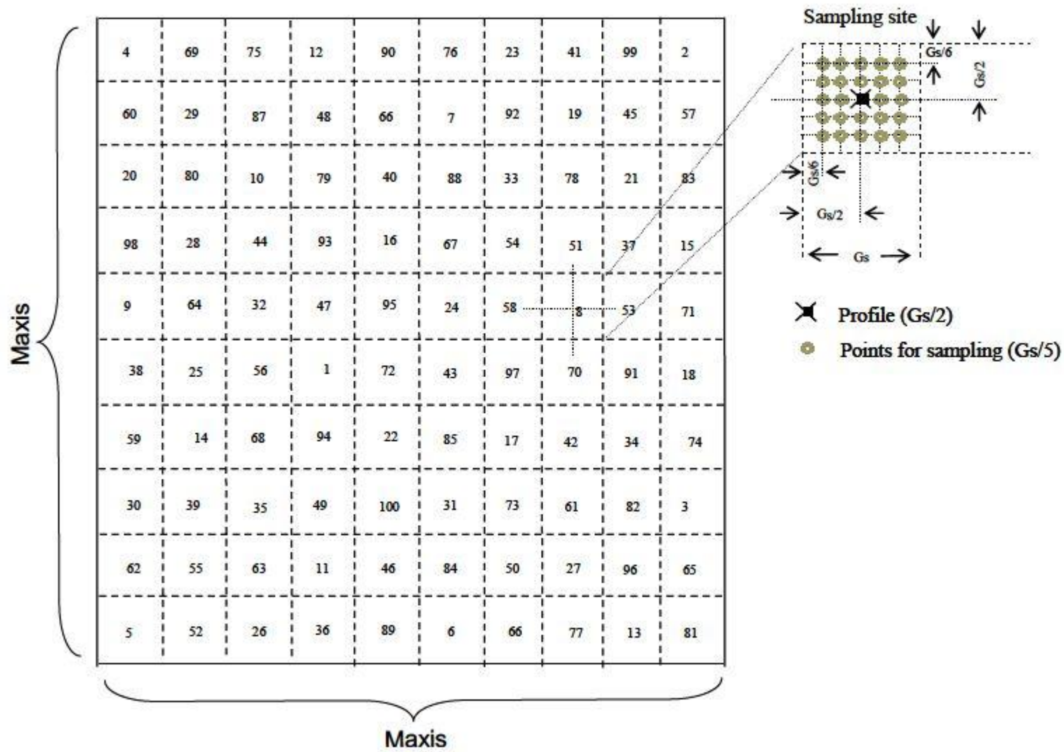

Figure 14: Area-frame randomized template and its parameterization (for explanation see text).

The spatial parameters of the template are flexible and adjusted to the size and geographical coordinates of the sampling plot (*e.g.* a field/pasture/forest). To define the dimension of the template, the longest X or Y axis (Maxis) of the plot should be found (Figure 14). The grid size (Gs) is calculated by dividing Maxis by 10. This grid is matched with the plot and is applied to position the sampling sites. The amount of the latter is defined by the plot area (Table 14). Each sampling site comprises a number of sampling points for collecting the composite soil samples and soil profile. Following ISO recommendations (ISO, 200a), the number of sampling points for the composite soil sample should be 25. To define the distances between sampling points, Gs is divided into a 5 x 5 grid, which is Gs/6. The central sampling point within the grid is assumed to be the position of the soil profile and is found by dividing Gs by 2. Soil description, collection of undisturbed cylinder samples for bulk density6, litter and coarse debris7 should be taken in this point.

For effective implementation of the randomized sampling template (Figure 13), it is important to:

• Represent the plot (field/pasture/forest) margins in X and Y coordinates of the standard local projection used for topographic or cadastral maps.
• Define the X and Y extents of the plot and take the longest axis (Maxis). Setup a square frame having Maxis size and match it with the plot. The coordinates of the corners of this square frame should be preferably integer values.
• Overlay the template with 100 grids numbered from 1 to 100, as represented in Figure 1.
• Determine the number (n) of sampling sites (grids) that is conditioned by the plot area and the need to minimize costs (Table 14).
• Select the first sampling site (grid) having the lowest number within the plot. If the next site (grid) falls outside the plot, the next sampling site (grid) must be selected until 'n' sites (grids) will be identified.

The number of the 'n' composite sampling sites (sub-plots) on the base of the area size, was determined according to Table 14.

Table 14: Recommended number of composite samples depending on the plot area according to Stolbovoy et al. (2005)[38].

Size of the area	Numbers of sub-plots
< 5 ha	3
5 - 10 ha	4
10-25 ha	5
> 25 ha	6

Following the adaptation procedure, the geographical position of the plot, together with the location of the sampling sites and soil profiles are presented in the local coordinate system. To keep a consistent register of each reliable data. sampled field, pasture or forest plot at EU level, the geographical positions should be fixed in the European Coordinate Reference Systems (CRS identifier ERTS89, Ellipsoidal CRS) (Boucher and Altamini, 1992). The position should be recorded as precise as possible by means of Global Positioning Systems (GPS) to enable return visits to the sampling site. Data can be downloaded to a portable or office computer for registration and combination with other layers of information for spatial analysis.

A record of the sampled sites and points should be kept. In order to reduce temporal variations, sampling should be confined to periods with low biological activity, such as the winter or during the dry season. Any resampling should be carried out in the same period (season) as for the initial sample for all sites. The sampling dates should be reported.

For the determination of bulk density, an undisturbed sample with a minimum volume of 100 cm^3 cylinder should be taken from non-stony soil. For every sampling site, composite samples should be taken and analyzed in the laboratory. The composite soil samples from the sampling sites should be of equal weight, except for situations where the subsoil is shallow. In such cases (e.g. an indurate horizon within the depth range of the sampled layer), the weight of each sub sample is function of the thickness of the sampled layer. The minimum weight of each composite sample should be at least 500 g to provide sufficient material to perform all necessary analysis and for future storage.

Since all the selected sites were smaller than 5 ha, 3 subplot per site were chosen and located on the site according to the above consideration. In each of the subplots, the soil samples were collected following a grid of 25 points In each point, the soil was sampled at 0-10 cm, 10-20 cm and 20-30 cm depth, so to have 25 replicates per each depth per plot. The 25 replicates of each depth were mixed in a basket directly in the field so to have one composite samples per each plot and per each depth. Considering the three plots, in each site there were three composite samples per each deptIn the middle of each plot a trench was opened down to 1 m and described by pedological horizons according to Schoeneberger et al. (2002). The two sides of the trench were sampled separately so to have two independent replicates per horizon and per plot. Considering the three plots per each area 6 independent samples per horizons were collected. The bulk density[39] was determined with the core method[40] in each horizon of the trench so that finally 3 bulk density samples per horizons and per site were collected.

[39] Soil bulk density, is defined as the ratio of dry soil mass to bulk soil volume (including pore spaces). The SI unit for density is megagrams per cubic meter ($Mg\ m^{-3}$), which is numerically equivalent to grams per cubic centimeter.

[40] A cylindrical metal coring tool of known volume is driven into the soil to a desired depth. The intact core is removed, dried in an oven, and weighed.

6.3.3 Litter

In each land use, plants absorb nutrients for the manufacture of food, meta-bolic processes, assimilation, maintenance and reproduction for sustainability. The nutrients are returned to the soil through litter fall, decomposes to release mineral nutrients for re-absorption (Owusu-Sekyere et al., 2006). Tree litter fall is one of the major above-ground input of carbon (and nutrients) into the forest and plantation floor. Such litter layer protects the underlying humus and mineral soil against drought and represents a considerable buffer improving the ecosystem capacity. However, litter fall data are scarcely available in tropical ecosystems (Zhixin and Janssens, 2006).

The litter layer was not present in all the sites because often it is burned or used as fodder or asported (coconut). Where present, the litter layer was collected within a frame 40 x 40 cm in the case of primary and secondary forests, rubber and cocoa plantations) and 3 x 3 m case of big leaves such those of the . oil palmplantations. In either case the number of collected samples was 5 in each plot for a total amount of 15 in each site. The only exception was for the oil palm plantations, were a single leaf was collected in each plot and the it was counted the number of the leaves present in the square 3 x 3m.

6.3.4 Aboveground biomass

It is obvious that in case of land use changes due to human intervention such as deforestation, the first evident impact is on the aboveground vegetation, for this reason the above-ground biomass is the primary pool of concern for REDD, although carbon stock changes in other carbon pools may also be included, depending on the magnitude and direction of change (VCS, 2007.1, 2008). It is possible to assess the carbon stock changes in the aboveground biomass by comparing the forest to the tree plantations that after the clearing were always cultivated with the same species, in each of the different substrate. The sampling protocoll used to detect changes in the aboveground biomass C pool was the one proposed by the FAO: "*Assessing carbon stocks and modelling win-win scenarios of carbon sequestration through land-use changes*" (Ponce-Hernandez, 2004). The sample plots dimensions were 10 by 10 meters and coincide with the soil sample plots. In case of species with a wider tree planting spacing the plot deimension were doubled. Figure 9 show the morphometric measuraments of the standing vegetation:

- Tree height[41] (H)
- Diameter at breast height (DBH)
- Diameter of canopy or crown in two perpendicular directions (lenght L and width W)

The tree height has been measured with a Sunto clinometer and the diameter , the crown and the sampling area border with a measuring tape.

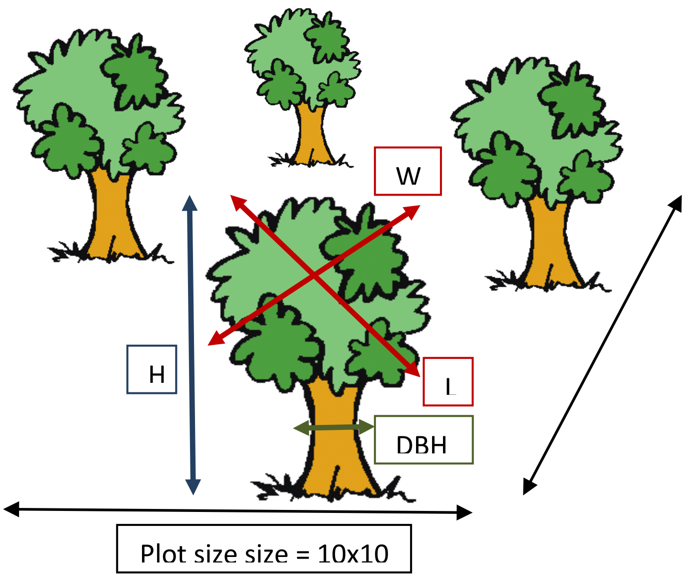

Figure 9: Schematic representation on how to measure height and diemeter of trees.

[41] Measuring all trees with a DBH> 5cm within the sampling plot according to VCS (VCS, 2010)

6.4 Data analysis

6.4.1 Soil analyses

Carbon and Nitrogen concentrations

Once in the laboratory, the soil samples were oven-dried at 60 °C and then sieved at 2 mm to separate the rock fragments from the fine earth. Both of the fractions were weighed. All the analyses were performed on the fine earth. The C and N concentrations were determined by dry combustion (Thermo Finnigan Flash EA112 CHN). According to the IPCC LULUCF guidelines (2003) the SOC stock was calculated following equation X:

Picture 2: Soil profile samples

$$SOC = \sum_{horizon=1}^{horizon=n} SOC_{horizon} = \sum_{horizon=1}^{horizon=n} ([SOC] * Bulk\ Density * Depth * (1 - frag) * 10)_{horizon}$$

[1]

where *SOC* is soil C content per unit area (Mg C ha^{-1}), *[SOC]* is C concentration in soil sample (kg C kg^{-1} soil), the *Bulk Density* is the soil density of the fine earth expressed as (Mg m^{-3}), *Depth* is the thickness of the *horizon* within the considered section (cm) and *frag* is the percent of rock fragments. As for soil samples, the litter samples were oven-dried at 60 °C, then weighed and grounded. Once all the litter samples were grounded, they have been prepared to be analyzed for total C and N by dry combustion (Thermo Finnigan Flash EA112 CHN). The C stock in the litter was estimated multiplying the weight of dry matter of the sample by the C concentration and reporting the value on a surface basis.

$$\boldsymbol{C} = \left\{\left[\left(\frac{\boldsymbol{C\%}}{\boldsymbol{100}}\right) * \boldsymbol{W}\right] * \left(\frac{\boldsymbol{10^9}}{\boldsymbol{G}}\right)\right\} \qquad \textbf{[2]}$$

where:

C = final value of C in litter layer (Mg C ha^{-1})

C% = percentage of carbon concentration in the considered sample

W = weigh of litter sample

G = surface of the grid (cm^3)

6.4.2 Aboveground C pool

To reduce the need for destructive sampling, biomass has been estimated from measured property such as stem diameter at a specified height, and the total height by using allometric equations. Such equations exist for many forest types and a small number are species specific. Destructive measurement of trees (cutting down and weighing) allow to generate allometric equations which have high but when it is done it can be applied to other tree species in the same forest area (Hairiah et al., 2001).

Picture 3: Ebano tree (Diospyros sanza-minika A. Chev.) growing in a primary forest.

A substantial number of allometric equations have been developed for various climatic zones, forest types and tree species (Brown, 1997), using a variety of algebraic forms and parameter values. Collecting more empirical equations will hardly reduce this uncertainty for any new situation, unless we can better understand the background of the allometric equations in their link with the shape of trees (Hairiah et al., 2001). In each plot, the considered trees were those with a DBH > 5 cm. The diameter has been measured at breast height with a dendrometic caliper, the height with a Suunto clinometer, the crown dimensions with a measuring tape.

Once collected DBH, height and crown dimensions of each tree inside the plots, as specific allometric equation as possible has been adopted.

In case of rotation occurred within the chronosequence[42], the estimation of aboveground biomass has been done following the method of *Time-averaged carbon stocks of a rotational production system* (Hairiah et al., 2001; Palm et al., 1999). Most agricultural, agroforestry or forestry production systems go through distinct phases in their production

[42] It is occurred in oil palm plantation.

cycle. For avoiding dealing with the details of C gains and losses within each patch in each year, it can assumed that the time-averaged C stored in each patch under the land use system averaged over the rotation time of that system represents the spatial average for all patches at any point in time. The time-averaged C stock depends on:

- The maximum and minimum C stored in the system, typically just before and just after a harvest event,
- Rates of C accumulation during the growth phase, which implies the time it takes to reach maximum C stocks from the minimum level, and
- The rotation time.

To determine the time-averaged C stock of a land use system, it is important to know the C stock at any point in time. In the simplest case, this can be described as:

· a period Tc where it is at minimum value Cmin (e.g. a cropping period after forest clearing or a harvest cycle)

· a period where carbon accumulates linearly, at a constant rate Ic (Mg C ha^{-1} yr^{-1}), from the minimum value Cmin to the maximum value Cmax in a time span of Tf. (thus Ic = (Cmax- Cmin)/Tf).

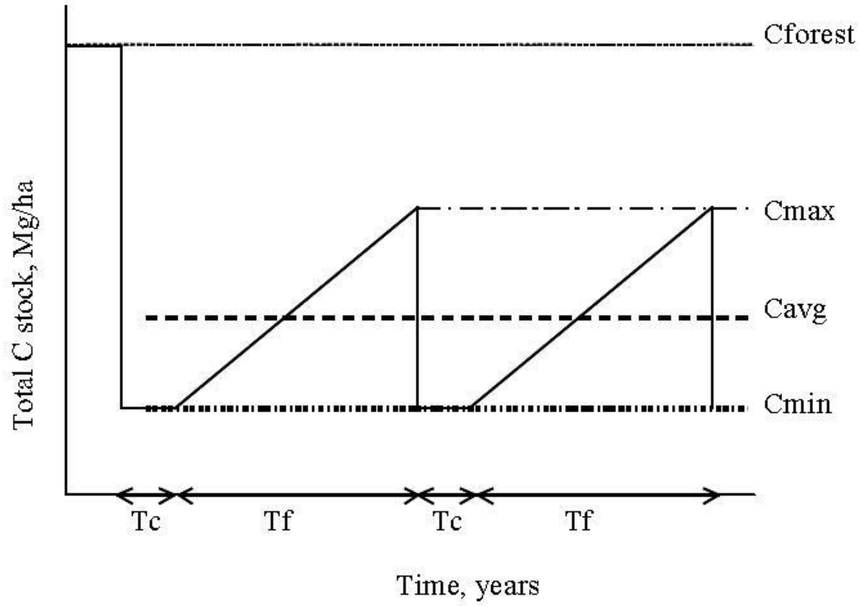

Figure 15: Diagram of C losses during forest clearing and re-accumulation during a fallow or regrowth period Tf after the cropping years Tc (Palm et al., 1999)

The time-averaged C stock for the period Tf is

$$\mathbf{Cavg_F = 0.5 * (Cmin + Cmax)} \qquad [3]$$

For the system as a whole it is:

$$\mathbf{Cavg = Tf * (Cmax + Cmin)/(2*(Tf + Tc))} \qquad [4]$$

where:

Cmin and Cmax are the minimum C stocks of the system, respectively, Tc is the length of time the system is at the Cmin value, and Tf is the length of time that it takes to reach Cmax. If Tc is negligible, we see that Cavg = 0.5 (Cmax + Cmin), and thus independent of the time Tf or the annual accumulation rate.

It can be assigned a typical 'time-averaged Carbon stock (Mg ha^{-1}), to each land use type, the net impact of land use change follows from the sign of the difference of 'Cstock (after) – Cstock (before)'. This means that an evaluation of the C stock of a land use depends on the context and the types of comparisons made: compared to natural forest, all other land use types lead to net C release to the atmosphere; compared to continuous annual crops, nearly all other land uses lead to net C sequestration.

Averaging the C stock over the life span of a system gives a simple measure of its role in the global C balance, as long as different stages of the system may be expected to occur in roughly proportional areas at any point in time.

For **OIL PALM** biomass the estimation of aboveground C content has been differently calculated. The plantations considered in the study were not characterized by adult trees but 4 years and 8 years old trees. It was present just the crown and not the trunk (Picture 4). For this reason the estimation was made on the leaves basis counting the number of leaves. Then the collectedleaf was oven dried at 60 °C, wheighted, grounded with a ball mill and then analyzed by dry combustion (Thermo Finnigan Flash EA112 CHN).

Picture 4: Oil palm plantation 4 years old

The C concentration was calculated on the total weight of the leaf in order to obtain the C content per leaf. The C content per leaf was then multiply by the numer of leaves per each tree.

$$\mathbf{AG}\ C_{OP}\ per\ tree = C\ per\ leaf * n\ of\ leaves \qquad \textbf{[5]}$$

The result was then multiply by the tree density per hectar in order to have the Mg C ha^{-1} . According to Ponce-Hernandez (2004) for **FORESTS** and **SECONDARY FORESTS was** chosen the equation proposed by Brown et al. (1997),specific for areas with annual rainfall comprised between 1500 and 4000 mm. This equation considers not only the tree diameter but also the tree height :

$$Y = \exp\{-3,1141 + 0,9719 * \ln[(DBH^2) * H]\} \qquad \textbf{[6]}$$

where:

Y = Aboveground Biomass (kg / tree)

DBH = Diameter at breast height (cm)

H = height of the tree (m)

Picture 5: Cocoa plantation in Jomoro District

Biomass per tree was multiplied by the number of trees per hectare to determine the biomass on an area basis (Mg ha^{-1}). To convert tree biomass to carbon, a coefficient of 0.5 was used (IPCC, 2003).

According to a study of Isaac et. al. (2005) carried out on cocoa plantation from the Western region of Ghana, the above mentioned equation was also used for the **COCOA** plantation of the Jomoro District.

For **COCONUT** plantation was considered a sampling area of 20 x 20 m and an allometric approach for a more accurate estimation. First has been calculated the trunk volume:

$$\boldsymbol{\mathcal{V} = Ab * H} \quad \textbf{[7]}$$

where:

V = volume of the trunk (m^3)

Ab = basal area derived from diameter data { $\frac{\pi}{4} * DBH^2$}

H = height of the trunk (m)

Once estimated the trunk volume has been adopted the following equation to estimate the trunk biomass

$$\boldsymbol{\mathcal{B} = \mathcal{V} * \mathcal{WD} * 1000} \quad \textbf{[8]}$$

where:

B = tree biomass (kg)

WD = wood density (species specific, tonnes dry matter/m^3fresh volume) [43]

Separately has been estimated the canopy biomass as portion of the trunk biomass on the base of a specific equation proposed by Frangi and Lugo (1985)

$$\boldsymbol{\mathcal{C} = \mathcal{B} * 0,5} \quad \textbf{[9]}$$

Canopy biomass = 50% of trunk biomass

The total coconut tree biomass is the result of the sum:

$$\boldsymbol{\mathcal{TBC} = \mathcal{B} + \mathcal{C}} \quad \textbf{[10]}$$

The result of this sum is the biomass of a single tree expressed in kg.

According to IPCC (2003), to convert tree biomass to carbon, it was used a coefficient of 0.5. The result was consequently converted in Mg C ha^{-1}.

[43] For coconut the wood density is 0,5 as reported in GPG LULUCF Annex 3A.1 table 3A1.9-2 (IPCC, 2003)

In the **MIXED PLANTATIONS** the biomass has been estimated on the base of the species composition. The more frequent species are: oil palm, coconut, banana and plantain.

For estimating the biomass of banana and plantain It was adopted the equation proposed by Fangi and Lugo (1985):

Picture 6: Mixed plantation

$$\boldsymbol{\mathcal{BB} = 4.5 + 7.7 * H} \qquad \textbf{[11]}$$

where:

BB = banana biomass

H = total height of the tree

The result of the equation is the biomass per tree. According to IPCC (2003), to convert tree biomass to carbon, it was used a coefficient of 0.5. The carbon per tree, expressed as kg, was then multiplied by the number of trees per hectare to determine C in aboveground biomass on an area basis (Mg C ha^{-1}).

For the **RUBBER PLANTATIONS** it was used a site specific allometric equation reported in the framework of a new methodology for CDM afforestation reforestation project proposed by the Rubber Outgrower Unit (ROU), derived from the study conducted by Wauters et al (2008):

$$\boldsymbol{\ln(C) = -5{,}76 + 2{,}576 * \ln(g)} \qquad \textbf{[12]}$$

where :

C = total C at tree level (kg C/tree)

g = tree girth (cm)

The carbon per tree in kg was then multiplied by the number of trees per hectare to determine C in aboveground biomass on an area basis (Mg C ha^{-1}).

6.4.3 Belowground C pool

The belowground biomass (BGB) was estimated as a percentage of the above ground (AGB) biomass, on the base of the root to shoot ratio. The belowground biomass has been considered 20% of the aboveground carbon stocks (e.g. Ponce-Hernandez, 2004; Houghton et al., 2001; Achard et al., 2002; Ramankutty et al., 2007) based on a predictive relationship established from extensive literature reviews (Cairns et al., 1997; Mokany et al., 2006).

$$\boldsymbol{BGB = AGB * 0.2} \qquad \textbf{[13]}$$

According to IPCC (2003), to convert tree biomass to carbon, it was used a coefficient of 0.5. The carbon per tree, expressed as kg, was then multiplied by the number of trees per hectare to determine C in aboveground biomass on an area basis (Mg C ha^{-1}).

7 Results

In this section will be described the results focalizing the attention on either land uses of the three substrates present in the of Jomoro District, Granite, Lower Birrimian and Tertiary sands[44], having a comparison in terms of stock per each single C pool. The comparison was done for each type of land use considering the primary forest present in each specific substrate as the starting point of a temporal chronosequence. Statistical differences were investigated with one-way ANOVA test, followed by Tuckey's multiple comparison test (Post test) by the use of the software Graph Pad Prism version 5 (data analysis software Inc. 2007).

7.1 Granite

7.1.1 Oil palm plantations

The results from the oil palm plantations found on granite were compared to the original vegetation on the same substrate, namely the primary forest of Ankasa, investigated in detail by Chiti et al. (2010).

Soil organic carbon pool by depth

Table 10 reports the data on soil organic carbon concentration for the three investigated depths: 0-10, 10-20 and 20-30 cm. In both sites (OP_8 and OP_{25}) the concentrations tend to slightly decrease with depth, with no statistical differences ($P<0.05$).

Table 10: Soil Organic Carbon concentration in the 0-10, 10-20 and 20-30 cm depths. Numbers between brackets represent the standard deviations (n = 3).

Depth **(cm)**	**Forest**	**OP_8 [a]**	**OP_{25} [b]**
0-10	1.8 (0.1)	1.7 (0.2)	2.0 (0.4)
10-20	1.4 (0.3)	1.5 (0.2)	1.4 (0.4)
20-30	1.2 (0.1)	1.3 (0.4)	1.5 (0.3)

[a] OP_8 = Oil palm plantation after 8 years from deforestation
[b] OP_{25} = Oil palm plantation after 25 years from deforestation

[44] Recent sand has been not considered because the original vegetation was not the rain forest and could not be compared to the others in terms of land use change. The sites on recent sands has been surveyed in order to further develop a multilayer map.

The C/N ratio is 10.89 in the primary forest and slightly increases after 8 years from deforestation, 11.78, and again increases slightly after 25 years, 12.9.

In term of SOC stock, in the oil palm plantation, the rate of decrement in the 0-10 cm soil layer after 25 years from deforestation is 38.6% (13.8 Mg C ha^{-1}). Most of the loss of SOC occurs in the first 8 years, about 3.3% per year (1.2 Mg C ha^{-1} yr^{-1}). In the range from 8 to 25 years, the change in SOC is only 1% (0.3 Mg C ha^{-1} yr^{-1}) and is not statistically significant.

In the 10-20 cm soil layer, after 25 years from deforestation the change in SOC stock is 2.8% (0.5 Mg C ha^{-1}). In the first 8 years the change is 0.2% yr^{-1} (0.04 Mg C ha^{-1} yr^{-1}). In the range from 8 to 25 years the mean annual change is only 0.3% yr^{-1} (0.1 Mg C ha^{-1} yr^{-1}) but all these changes are not statistically significant.

The rate of change in SOC stock in the 20-30 cm depth after 25 years from deforestation is totally 10.2% (1.9 Mg C ha^{-1}). The rate of change is 0.9% yr^{-1} (0.2 Mg C ha^{-1} yr^{-1}) in the first 8 years, while after it changes to 1.0% yr^{-1} (0.2 Mg C ha^{-1} yr^{-1}). None of these changes are statistically significant (Anova, p<0.005).

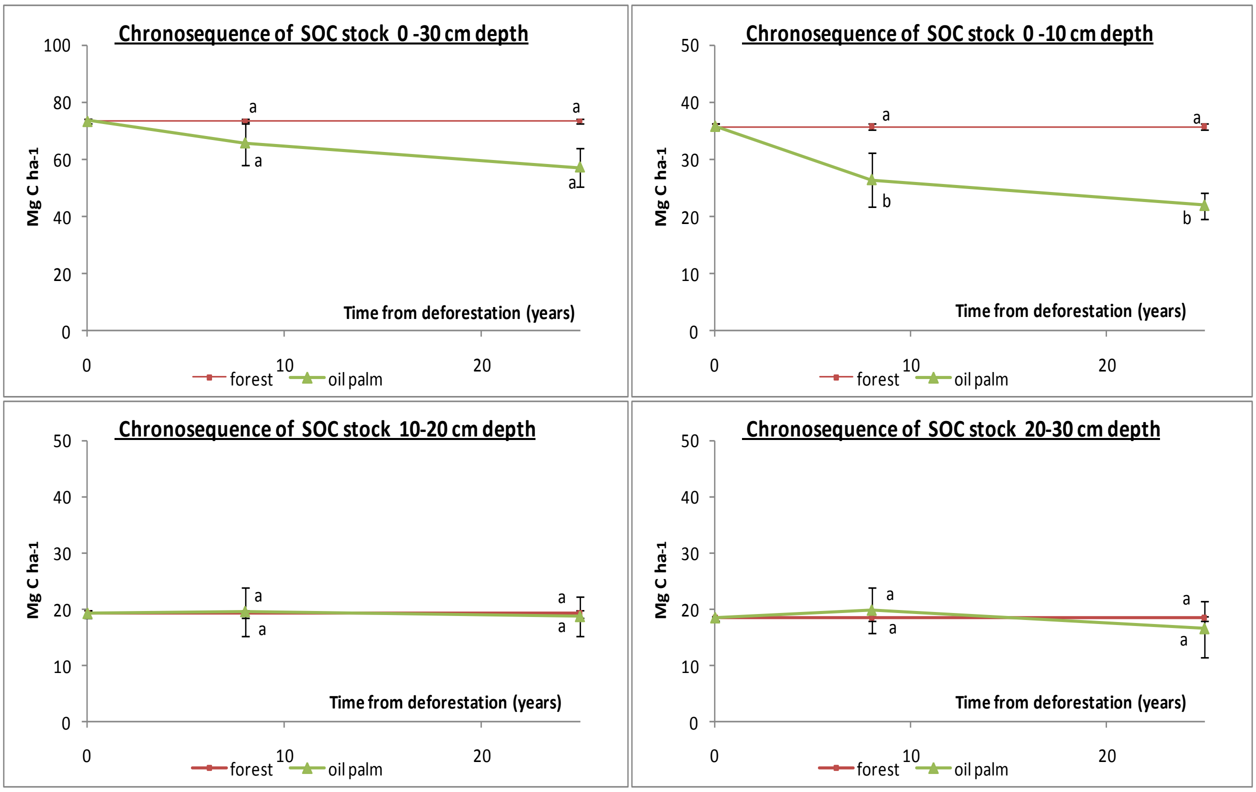

Figure 16: Chronosequence of oil palm soil carbon stock to 0-30, 0-10, 10-20, 20-30 cm depth[45]. Different numbers indicate statistical significance (p<0.05).

[45] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test)

The SOC stock in the total 0-30 cm depth after 25 years from deforestation has a change of 22.1% (16.2 Mg C ha^{-1}). In the first 8 years the change is 1.3% yr^{-1} (1.0 Mg C ha^{-1} yr^{-1}). In the range from 8 to 25 years the mean annual change is only 0.8% yr^{-1} (0.5 Mg C ha^{-1} yr^{-1}) but all these changes are not statistically significant.

Table 11: Summary of results per depth. Numbers between brackets are the standard deviations (n=3).

Depth (cm)	Forest Mg C ha^{-1}	OP_8 [a] Mg C ha^{-1}	OP_{25} [b] Mg C ha^{-1}	TRD_{25} [c] %	ARD_8 [d] %	ARD_{8-25} [e] %
0-10	35.73 (0.6)	26.43 (4.7)	21.93 (2.4)	**-38.63**	**-3.23**	-1.00
10-20	19.30 (0.7)	19.62 (4.4)	18.76 (3.5)	-2.79	+0.21	-0.23
20-30	18.47 (0.5)	19.80 (4.0)	16.58 (4.9)	-10.23	+0.91	-0.96
Tot 0-30	73.50 (1.0)	65.85 (7.6)	57.27 (6.5)	-22.08	-1.30	-0.77

Marked values are significant at P<0.05.
[a] OP_8 = Oil palm plantation after 8 years from deforestation
[b] OP_{25} = Oil palm plantation after 25 years from deforestation
[c] TRD_{25} = Total rate of decrement after 25 years from deforestation
[d] ARD_8 = Annual rate of decrement (first 8 years after deforestation)
[e] ARD_{8-25}= Annual rate of decrement from 8 to 25 years after deforestation

Soil organic carbon pool by genetic horizons

Data on concentration of soil organic carbon profile are summarized in Table 12.

Both in OP_8 and OP_{25} as well as in the forest site, the concentrations tend to slightly decrease with horizon, with no statistical differences (P<0.05).

Table 13: Soil Carbon concentration in the different genetic horizons down to 1 m depth. Numbers between brackets represents the standard deviation (n = 3). Different numbers indicate statistical significance (p<0.05).

Soil carbon concentration in percentage						
Horizon	Depth (cm)			Forest	OP [a] $_8$	OP [b] $_{25}$
	For	OP [a] $_8$	OP [b] $_{25}$			
A	5	5	8	2.8 (0.8)	3.4 (0.7)	2.1 (0.3)
Bo	40	42	40	1.0 (0.2)	1.1 (0.1)	0.9 (0.2)
C	55	53	52	0.6 (0.1)	1.0 (0.4)	1.0 (0.1)

[a] OP_8 = Oil palm plantation after 8 years from deforestation
[b] OP_{25} = Oil palm plantation after 25 years from deforestation

Considering 1 m depth, the C/N ratio of the forest is 14.18, while after 8 years from deforestation it results 12.16 and after 25 it reach 10.54.

Soil organic carbon content has been determined also by genetic horizons down to 1 m depth and it results that after 25 years from deforestation the total rate of decrement is totally 55.8% (84.0 Mg C ha^{-1}). In the first 8 years the mean annual change is 0.02% (0.03 Mg C ha^{-1} yr^{-1}) but it is not statistically significant, while in the range from 8 to 25 the mean annual decrement is 3.8% (4.9 Mg C ha^{-1} yr^{-1}).

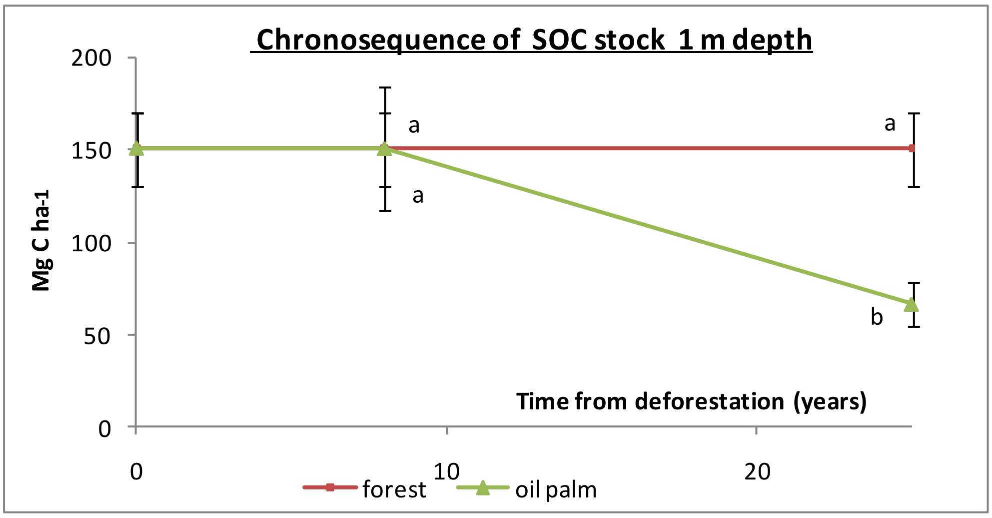

Figure 17: Chronosequence of oil palm soil carbon stock to 1 m depth[46]. Different numers indicate statistical significance (p<0.05).

Litter C pool

Litter layer was collected only in OP_{25} site since in OP_8 site was not present because regularly removed by land owner for other uses (mainly as fuelwood and fodder). The litter C stock estimated on leaf number basis, gave a result of 5.74 ± 3.16 Mg C ha^{-1}, lower when compared to the litter found at Ankasa rain forest 15 ± 9 Mg C ha^{-1} by Chiti et al. (2010).

Aboveground C pool

According to Gineste et al. (2008), mean forest aboveground C stock was estimated to be 154.2 (± 16.2) Mg C ha^{-1}. Oil palm after 4 years from plantation has been estimated to store an aboveground C stock that amounts to 3.8 (± 2.01) Mg C ha^{-1}, and after 8 years

[46] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test)

3.38 ± 0,86 Mg C ha^{-1}. Considering the oil palm's rotation time of 20 years, C average for aboveground biomass results to be 30.0 ± 8.5 Mg C ha^{-1}.

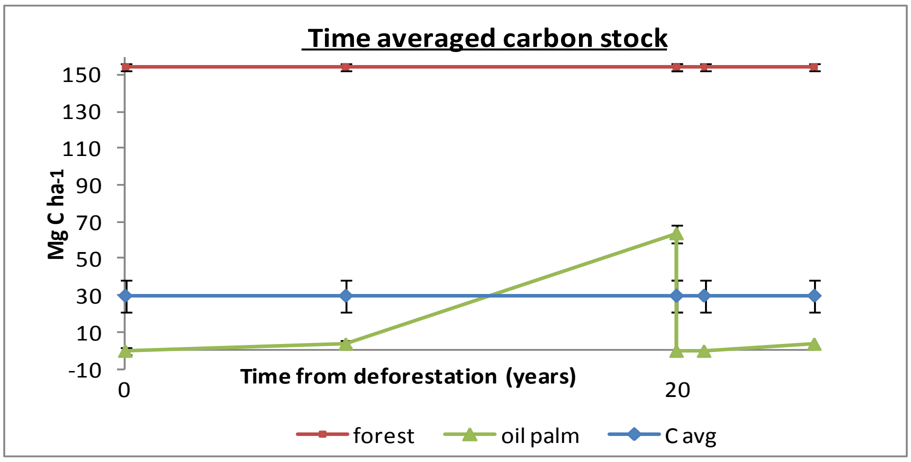

Figure 18: Diagram of aboveground C losses after forest clearing and re-accumulation during oil palm plantation system.

Belowground C pool

Belowground C stock for primary forest amounts to 40.4 ± 5.2 Mg C ha^{-1}, in 4 years old plantation the carbon stock is 0.76 ± 0.4 Mg C ha^{-1}, in 8 years old plantation is 0.68 ± 0.17 Mg C ha^{-1}. Considering the rotation time of oil palm plantation, C average for belowground biomass results to be 6.0 ± 1.7 Mg C ha^{-1}.

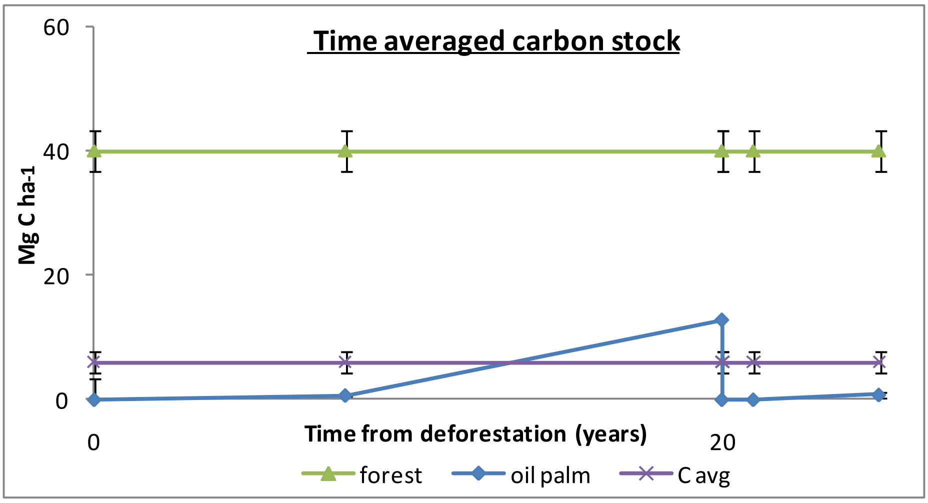

Figure 19: Diagram of belowground C losses after forest clearing and re-accumulation during oil palm plantation system.

7.1.2 *Secondary forest*

Soil organic carbon pool by depth

Soil organic carbon concentrations investigated in 0-10, 10-20 and 20-30 cm depths, are summarized in Table 14. The concentration decrease with depth in forest and SF_{10} sites while increase in SF_{21} in 20-30 cm but it is not statistically significant (P<0.05).

Table 14: Soil organic carbon concentration in the 0-10, 10-20 and 20-30 cm depths. Numbers between brackets represent the standard deviations (n = 3). Different numers indicate statistical significance (p<0.05).

Depth **(cm)**	**Forest**	**SF $_{10}$ [a]**	**SF $_{21}$ [b]**
0-10	1.8 (0.1)	3.3 (0.5)	2.5 (0.5)
10-20	1.4 (0.3)	2.1 (0.5)	2.2 (0.2)
20-30	1.2 (0.1)	2.0 (0.7)	2.7 (0.2)

[a] SF $_{10}$ = Secondary forest at 10 years from deforestation
[b] SF $_{21}$ = Secondary forest at 21 years from deforestation

In the top 30 cm of mineral soil, the C/N ratio tent to increase slightly from the primary forest, 10.9, to the site deforested 10 and 21 years ago, 13.5 and 12.7, respectively.

In the secondary forest, the rate of decrement in soil C stock in the 0-10 cm depth after 21 years from deforestation is 35.9% (12.8 Mg C ha^{-1}). In the first 10 years the mean annual change is 0.8% (0.3 Mg C ha^{-1} yr^{-1}) and it is not statistically significant whereas then until the 21th year the mean annual decrement is 2.7% (0.9 Mg C ha^{-1} yr^{-1}) it is significant at P<0.05.

Table 15: Summary of results per depth. Numbers between brackets represent the standard deviations (n = 3). Different numbers indicate statistical significance (p<0.05).

Depth **(cm)**	**Forest**	**SF $_{10}$ [a]**	**SF $_{21}$ [b]**	**TRC_{21} [c]**	**ARC_{10} [d]**	**$ARC_{10\text{-}21}$ [e]**
	Mg C ha^{-1}	**Mg C ha^{-1}**	**Mg C ha^{-1}**	**%**	**%**	**%**
0-10	35.73 (0.6)	32.83 (4.2)	22.89 (5.3)	**-35.94**	-0.81	**-2.75**
10-20	19.30 (0.7)	21.92 (6.1)	18.05 (1.9)	-6.45	+1.36	-1.60
20-30	18.47 (0.5)	19.53 (4.3)	21.43 (1.0)	+16.04	+0.58	+0.88
Tot. 0-30	73.50 (1.0)	74.29 (8.6)	62.37 (5.7)	-15.14	+0.11	-1.46

[a] SF $_{10}$ = Secondary forest at 10 years from deforestation
[b] SF $_{21}$ = Secondary forest at 21 years from deforestation
[c] TRC_{21} = Total rate of change after 21 years from deforestation
[d] ARC_{10} = Annual rate of change (first 10 years since forest clearance)
[e] $ARC_{10\text{-}21}$= Annual rate of change from 10 to 21 years after deforestation

The rate of decrement in soil C stock at 10-20 cm depth after 21 years is 6.5 % (1.2 Mg C ha^{-1}). In the first 10 years the mean annual change is 1.4% (0.3 Mg C ha^{-1} yr^{-1}), while then until the 21^{th}, the mean annual change decrease to 1.6% (0.4 Mg C ha^{-1} yr^{-1}), but none of these differences are statistically significant at $P<0.05$.

Different trend has been found in 20-30 cm depth where the soil carbon stock has a not statistically significant increment. The rate of change in SOC stock after 21 years from deforestation is 16.0% (3.0 Mg C ha^{-1}). In the first 10 years the mean annual change is 0.6% (0.1 Mg C ha^{-1} yr^{-1}), while it remain rather constant until the 21^{th} years , about 0.9% (0.7 Mg C ha^{-1}). None of these changes are statistically significant at $P<0.05$.

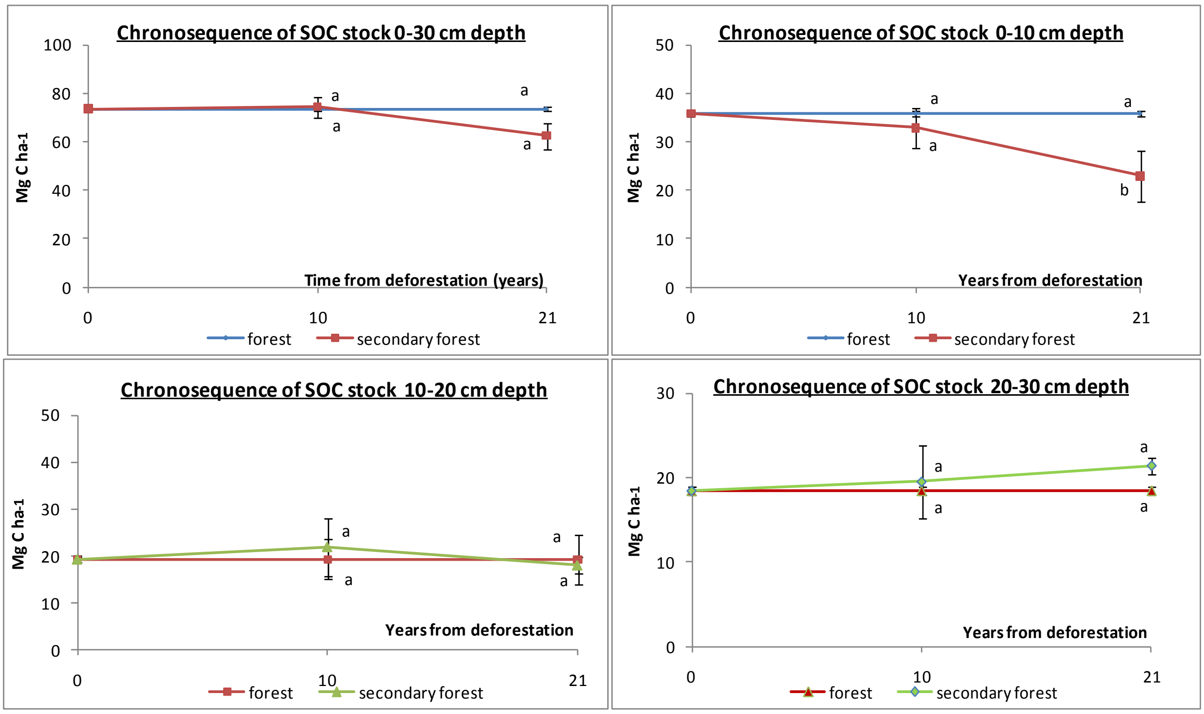

Figure 20: Comparison of the SOC stock for the upper 0-30, 0-10,10-20 and 20-30 cm of the secondary forests compared to the original vegetation of the area, the primary forest of Ankasa [47]. Different numbers indicate statistical significance ($P<0.05$)

Soil organic carbon pool by genetic horizons

Soil organic carbon concentrations in profile are summarized in Table 16. In both SF_{10} and SF_{21} as well as for the forest site, the concentrations tend to slightly decrease with horizon, with no statistical differences ($P<0.05$)

[47] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test)

Table 16: Soil organic carbon concentration in the different genetic horizons down to 1 m depth. Numbers between brackets represents the standard deviation (n = 3). Different numbers indicate statistical significance (P<0.05).

Soil carbon concentration in percentage						
Horizon	Depth (cm)			**Forest**	**SF^a_{10}**	**SF^b_{21}**
	For.	**SF^a_{10}**	**SF^b_{21}**			
A	5	12	4	2.8 (0.8)	3.9 (0.8)	4.7 (1.0)
Bo	40	41	24	1.0 (0.2)	1.2 (0.3)	1.5 (0.6)
C	55	47	72	0.6 (0.1)	0.7 (0.1)	1.2 (0.6)

[a] SF_{10} = Secondary forest at 10 years from deforestation
[b] SF_{21} = Secondary forest at 21 years from deforestation

For the original forest the C/N ratio in soil profile is 14.18, after 10 years from deforestation it results 11.9 and after 21 years from forest clearance it results to reach 11.2.

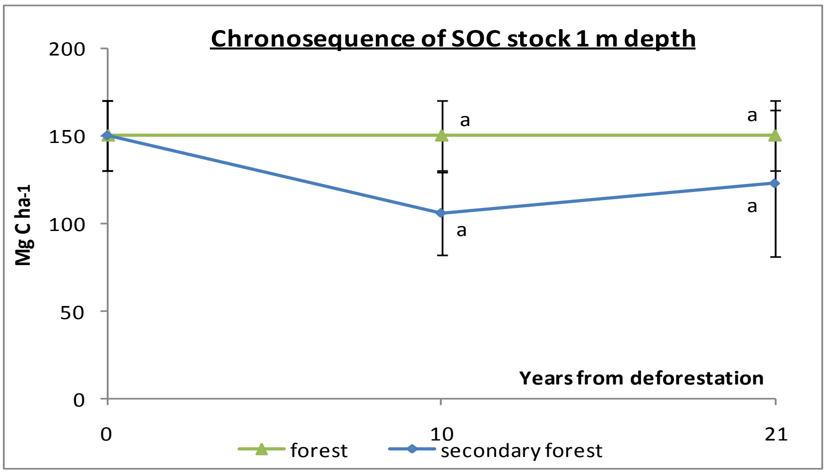

Figure 21: Chronosequence of secondary forest soil carbon stock to 1 m depth[48]. Different numbers indicate statistical significance (P<0.05).

Soil organic carbon stock has been determined also to 1 m depth, and it results that after 21 years from deforestation the total rate of change is 18.3% (27.5 Mg C ha^{-1}). In the first 10 years the mean annual rate of change is 2.9% (4.5 Mg C ha^{-1} yr^{-1}), while in the last 11

[48] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test)

years it become 1.5% (1.6 Mg C ha^{-1} yr^{-1}). None of these changes is statistically significant at $P<0.05$.

Litter C pool

Litter layer was collected both in SF_{10} site and SF_{21} site. Litter C in 10 years old secondary forest SF_{10} was estimated to be 3.4 ± 1.4 Mg C ha^{-1} whereas in 21 secondary forest SF_{21} the litter C stock was estimated to be 2.9 ± 0.7 Mg C ha^{-1}. Both of them result lower compared to Ankasa rain forest litter, 15 ± 9 Mg C ha^{-1} by Chiti et al. (2010).

Aboveground C pool

According to Gineste et al. (2008) mean forest aboveground C stock was estimated to be 154.2 (± 16.2) Mg C ha^{-1}. After deforestation on granite substrate, the 10 years old secondary forest (SF_{10}) has been estimated to store an aboveground C stock that amounts to 65.9 ± 25.9 Mg C ha^{-1}, whereas 21 years old secondary forest (SF_{21}), 146.9 ± 5.9 Mg C ha^{-1} with no statistically significant differences respect the carbon stock value of the original forest.

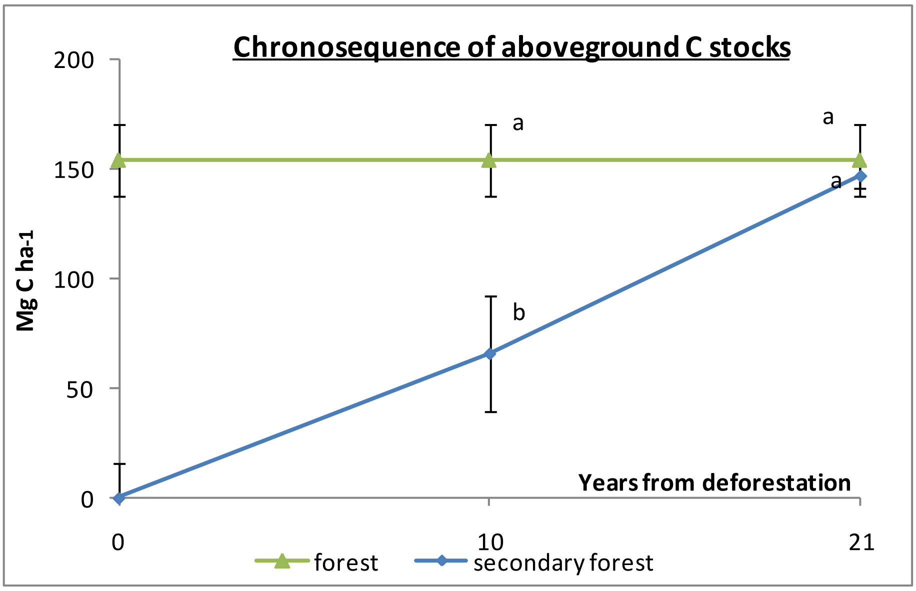

Figure 22: Chronosequence of secondary forest aboveground carbon stock. Different numbers indicate statistical significance ($P<0.05$).

Belowground C pool

Belowground C stock for Ankasa primary forest amounts to 40.4 ± 5.2 Mg C ha^{-1} (Chiti et al., 2010), in the 10 years old secondary forest SF_{10} it amounts to 17.1 ± 6.7 Mg C ha^{-1}, whereas 21 years old secondary forest $SF_{21,}$ 38.2 ± 1.5 Mg C ha^{-1} .

7.2 Lower Birrimian

7.2.1 Cocoa plantations

Soil organic carbon pool by depth

Data on soil organic carbon concentration for the three investigated depths: 0-10, 10-20 and 20-30 cm are summarized in Table 17. In both sites (CC_{34} and CC_{120}) the concentrations tend to slightly decrease with depth, with no statistical differences ($P<0.05$).

Table 17: Soil Organic Carbon concentration in the 0-10, 10-20 and 20-30 cm depths. Numbers between brackets represent the standard deviations (n = 3). Different numbers indicate statistical significance (P<0.05).

Depth **(cm)**	**Forest**	**CC_{34} [a]**	**CC_{120} [b]**
0-10	2.8 (0.3)	2.2 (0.4)	0.9 (0.2)
10-20	2.5 (0.6)	1.1 (0.1)	0.7 (0.3)
20-30	2.3 (0.7)	1.7 (0.4)	0.6 (0.2)

[a] CC_{34} = Cocoa plantation 34 years old
[b] CC_{120} = Cocoa plantation 120 years old

The C/N ratio for the upper 30 cm is 13.1 for the original forest, 11.7 and 12.9 for the sites deforested and planted with cocoa 34 and 120 years ago respectively.

In the cocoa plantation, the rate of decrease in the SOC stock in the 0-10 cm depth after 120 years from deforestation is 59.3% (20.6 Mg C ha^{-1}). In the first 34 years the mean annual decrement is 1.1% (0.4 Mg C ha^{-1} yr^{-1}), while later, until the 120th year the mean annual decrement is 0.4% (0.1 Mg C ha^{-1} yr^{-1}). The change in terms of carbon in soil at 0-10 cm depth is statistically significant from forest to cocoa plantation.

Table 18: Summary of results per depth. Numbers between brackets represent the standard deviations (n = 3). Different numbers indicate statistical significance (P<0.05).

Depth **(cm)**	**Forest**	**CC_{34} [a]**	**CC_{120} [b]**	**TRC_{120} [c]**	**ARC_{34} [d]**	**ARC_{34-120} [e]**
	Mg C ha^{-1}	**Mg C ha^{-1}**	**Mg C ha^{-1}**	**%**	**%**	**%**
0-10	34.73 (1.6)	21.66 (1.4)	14.15 (2.4)	**- 59.26**	**-1.11**	**-0.40**
10-20	29.64 (2.0)	13.59 (2.1)	11.33 (4.4)	**-61.76**	**-1.59**	-0.19
20-30	25.70 (2.3)	20.61 (4.3)	9.43 (3.3)	**-63.30**	-0.58	**-0.63**
Tot.0-30	90.07 (3.5)	55.87 (5.0)	34.91 (6.0)	**-61.24**	**-1.12**	**-0.44**

[a] CC_{34} = Cocoa plantation 34 years old
[b] CC_{120} = Cocoa plantation 120 years old
[c] TRC_{120} = Total rate of change after 120 years from deforestation
[d] ARC_{34} = Annual rate of change (first 34 years since forest clearance)
[e] ARC_{34-120}= Annual rate of change from 34 to 120 years after deforestation

At 10-20 cm depth the rate of decrease in the SOC stock after 120 years from deforestation is 61.8% (18.3 Mg C ha^{-1}). In the first 34 years the mean annual decrement is 1.6% (0.5 Mg C ha^{-1} yr^{-1}). From the thirty-fourth year to the hundred-twentieth year, the mean annual change is 0.2% (0.03 Mg C ha^{-1}) but is not statistically significant.

At 20-30 cm depth the rate of decrease in SOC stock is 63.3% (16.3 Mg C ha^{-1}) after 120 years from deforestation. In the first 34 years the mean annual change is 0.6% (0.1 Mg C ha^{-1} yr^{-1}) but it is not statistically significant. From the thirty-fourth year to the hundred-twentieth year, the mean annual decrement is 0.6% (0.1 Mg C ha^{-1}).

The SOC stock in the total 0-30 cm depth results to be statistically significant. After 120 years from deforestation SOC has a decrement of 61.2% (55.2 Mg C ha^{-1}). In the first 34 years the mean decrement is 1.1% yr^{-1} (1.0 Mg C ha^{-1} yr^{-1}). In the range from 34 to 120 years the mean annual decrement is only 0.4 % yr^{-1} (0.2 Mg C ha^{-1} yr^{-1}).

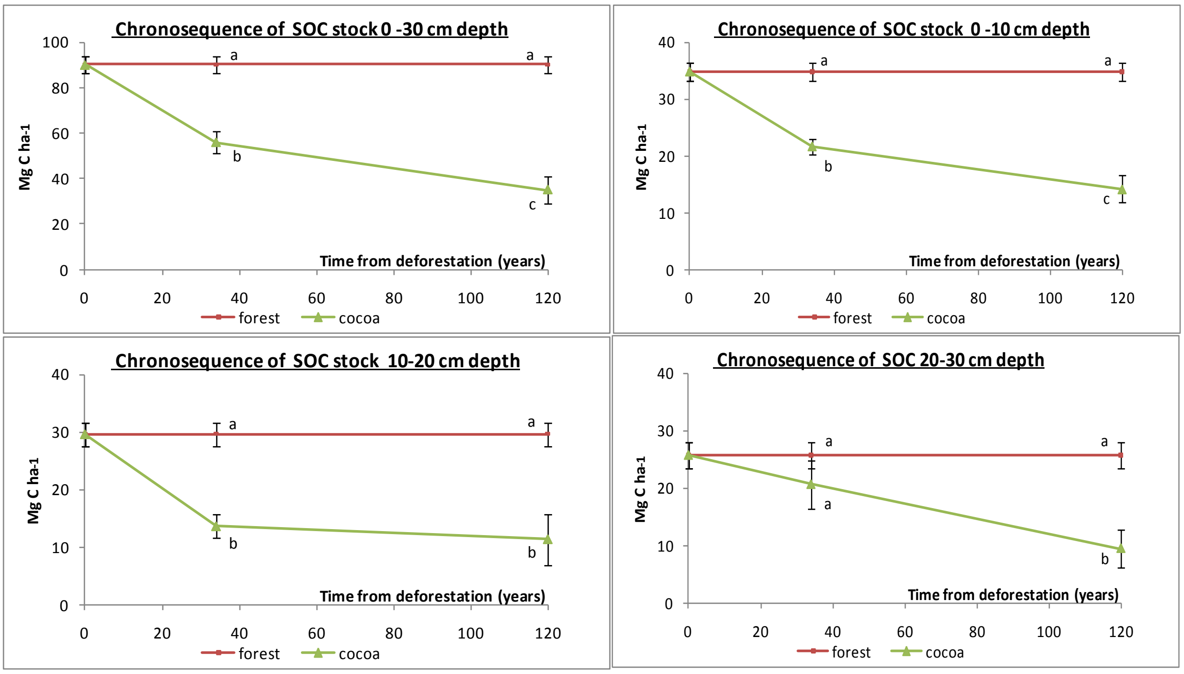

Figure 23 : Chronosequence of cocoa soil carbon stock to 0-30, 0-10, 10-20, 20-30 cm depth[49]. Numbers between brackets represent the standard deviations (n = 3). Different numbers indicate statistical significance (P<0.05).

[49] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test)

Soil organic carbon pool by genetic horizons

Concentrations of soil organic carbon along the profile are summarized in Table 19. In both CC_{120} and forest site, the concentrations tend to slightly decrease with horizon, whereas in CC_{34} it increase but always with no statistical differences (P<0.05).

Table 19: Soil organic carbon concentration in the different genetic horizons down to 1 m depth. Numbers between brackets represents the standard deviation (n = 3).

Soil carbon concentration in percentage						
Horizon	Depth (cm)			Forest	CC_{34} [a]	CC_{120} [b]
	For.	CC_{34} [a]	CC_{120} [b]			
A	7	3	11	5.7 (1.6)	2.1 (0.3)	0.9 (0.1)
Bo	42	42	49	1.4 (0.4)	1.1 (0.1)	0.7 (0.3)
C	51	55	40	0.8 (0.3)	1.7 (0.4)	0.6 (0.2)

[a] CC_{34} = Cocoa plantation 34 years old
[b] CC_{120} = Cocoa plantation 120 years old

Soil organic carbon stock to 1 m depth after 120 years from deforestation results to have a total rate of decrement of 36.3% (54.9 Mg C ha^{-1}). In the first 34 years the mean annual change is 0.2% (0.2 Mg C ha^{-1}), not statistically significant, while from the thirty-fourth year to the hundred-twentieth year, the annual decrement is 0.4% (0.5 Mg C ha^{-1} yr^{-1}), and is statistically significant from the value of the forest.

For the original forest the C/N ratio in soil profile is 11.9, after 34 years of cocoa plantation is 10.9 and after 120 years 9.1.

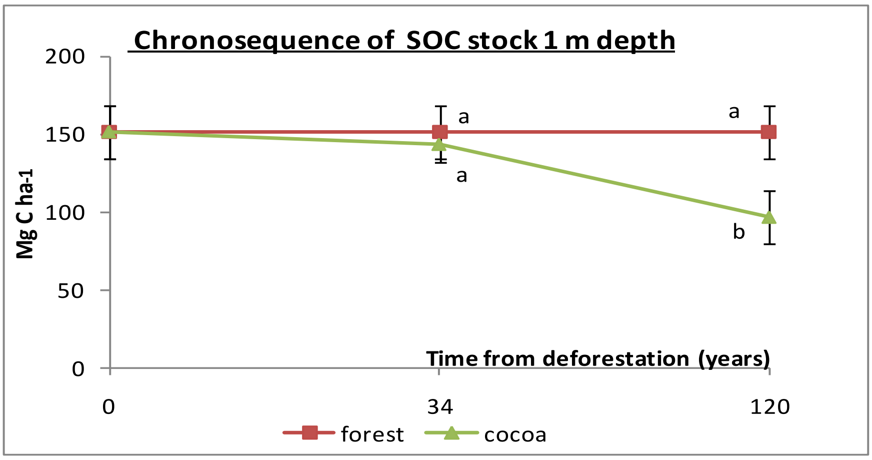

Figure 24: Chronosequence of cocoa soil carbon stock to 1 m depth[50]. Different numbers indicate statistical significance (P<0.05).

[50] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test).

Litter C pool

Litter layer was collected in two forest sites and the mean C stock per hectare results to be 8.3 ± 4.6 Mg C ha^{-1}. Litter C in 34 years old cocoa plantation was estimated to be 2.9 ± 0.8 Mg C ha^{-1} whereas in 120 years old cocoa plantation the litter C stock was estimated to be 3.9 ± 0.6 Mg C ha^{-1}. The both of them result lower compared to rain forest litter stock above mentioned.

Aboveground C pool

Mean forest aboveground C stock was estimated to be 120.8 ± 75.5 Mg C ha^{-1}. After deforestation on Lower Birrimian substrate, the 34 years old cocoa plantation (CC_{34}) has been estimated to store an aboveground C stock that amounts to 29.5 ± 14 Mg C ha^{-1}, whereas 120 years old plantation (CC_{120}) is 18.5 ± 5.8 Mg C ha^{-1}. The different amount of carbon stock is probably led by a different management history of the plantation. The 120 years old plantation has never been replanted and it has never been put through rotation because the new trees are spontaneously generated by chupons or suckers that are leaved without any pruning activity. This is also evident from a different tree density per hectare, in fact, although the carbon stock in aboveground biomass is lower in 120 years old plantation than in 34 years old plantation, the tree density for the first is 2350 tree ha^{-1}, it is instead 1200 tree ha^{-1} for the second.

Belowground C pool

Belowground C stock for forest sites amounts to 31.2 ± 19.9 Mg C ha^{-1}, in the 34 years old cocoa plantation (CC_{34}) amounts to 7.6 ± 3.6 Mg C ha^{-1}, whereas 120 years old plantation (CC_{120}) is 4.8 ± 1.5 Mg C ha^{-1}.

7.2.2 Rubber plantations

Soil organic carbon pool by depth

Data on soil organic carbon concentration for the three investigated depths: 0-10, 10-20 and 20-30 cm are summarized in Table 20. In both sites (RP_5 and RP_{10}) the concentrations tend to slightly decrease with depth, with no statistical differences (P<0.05).

Table 20: Soil Organic Carbon concentration in the 0-10, 10-20 and 20-30 cm depths. Numbers between brackets represent the standard deviations (n = 3).

Depth **(cm)**	**Forest**	**RP_5 [a]**	**RP_{10} [b]**
0-10	2.8 (0.3)	1.9 (0.3)	1.6 (0.4)
10-20	2.5 (0.6)	1.6 (0.3)	1.5 (0.6)
20-30	2.3 (0.7)	1.3 (0.2)	1.2 (0.2)

[a] RP_5 = Rubber plantation 5 years old
[b] RP_{10} = Rubber plantation 10 years old

The C/N ratio for the upper 30 cm depth is 13.1 for the original forest, 12.3 and 11.8 after 5 and 10 years of rubber plantation.

Rubber plantations result to have, after 10 years from deforestation, a decrease in the SOC stock from the 0-10 cm layer depth amounting to 36.7% (12.7 Mg C ha^{-1}). In the first 5 years the mean annual decrease is 5.9% (2.0 Mg C ha^{-1}), while from the fifth year to the tenth year, the mean annual decrement is 2.1% (0.5 Mg C ha^{-1}) but is not statistically significant.

Table 21: Summary of results per depth. Number between brackets represent the standard deviations (n =3). Different letters indicate statistical significance (P<0.05).

Depth **(cm)**	**Forest** Mg C ha^{-1}	**RP_5 [a]** Mg C ha^{-1}	**RP_{10} [b]** Mg C ha^{-1}	**TRC_{10} [c]** %	**ARC_5 [d]** %	**$ARC_{5\text{-}10}$ [e]** %
0-10	34.25 (2.1)	24.57 (3.1)	21.99 (5.3)	**- 35.80**	**-5.65**	-2.1
10-20	29.64 (2.8)	21.92 (3.4)	20.14 (4.7)	**-32.05**	-5.21	-1.63
20-30	25.70 (2.9)	17.89 (2.9)	15.38 (1.9)	**-40.15**	**-6.08**	-2.79
Tot. 0-30	90.07 (3.5)	64.38 (5.5)	57.51 (7.4)	**-36.15**	**-5.71**	1.37

[a] RP_5 = Rubber plantation 5 years old
[b] RP_{10} = Rubber plantation 10 years old
[c] TRC_{10} = Total rate of change after 10 years from deforestation
[d] ARC_5 = Annual rate of change (first 5 years since forest clearance)
[e] $ARC_{5\text{-}10}$= Annual rate of change from 5 to 10 years after deforestation

The change of soil carbon from forest to rubber plantation at 0-10 cm depth is always negative, the depletion of soil carbon content is significant (P<0.05) when compared to forest.

At the depth of 10-20 cm, rubber plantations result to have a significant decrease in the SOC stock after 10 years from deforestation, amounting to 32.1% (9.5 Mg C ha^{-1}). In the first 5 years the mean annual change is 5.2% (1.5 Mg C ha^{-1} yr^{-1}) but is not statistically significant (P<0.05), while from the fifth year to the tenth year where the mean annual change is 1.6% (0.4 Mg C ha^{-1}).

After 10 years form deforestation, in 20-30 cm layer, rubber plantations result to have a significant rate of decrement in SOC stock amounting to 40.2% (10.3 Mg C ha^{-1}). In the first 5 years the mean annual decrease is 6.1% (1.6 Mg C ha^{-1}), while from the fifth year to the tenth year, the mean annual change is 2.8% (0.5 Mg C ha^{-1} yr^{-1}) but is not statistically significant.

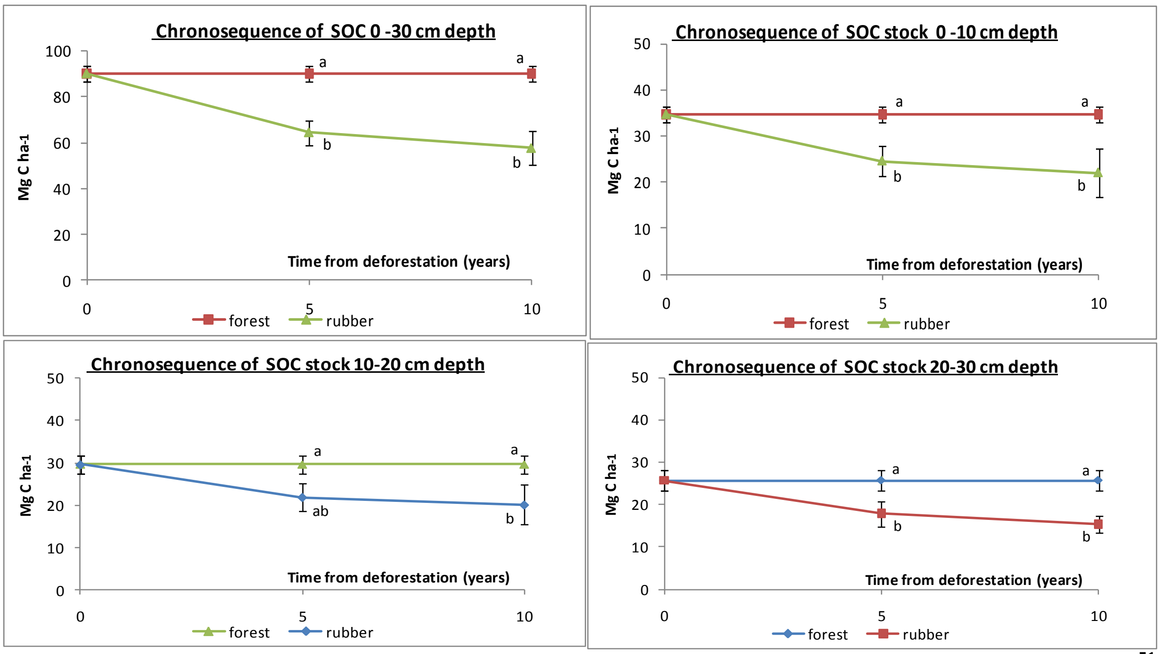

Figure 25: Chronosequence of cocoa soil carbon stock to 0-30, 0-10, 10-20, 20-30 cm depth[51]. Numbers between brackets represent the standard deviations (n = 3). Different numbers indicate statistical significance (P<0.05).

The SOC stock in the total 0-30 cm depth results to be statistically significant. After 10 years from deforestation SOC has a decrement of 36.15% (32.6 Mg C ha^{-1}). In the first 5 years the mean decrement is 5.71% yr^{-1} (5.1 Mg C ha^{-1} yr^{-1}). Only in the range from 5 to 10 years the mean annual decrement of 2.13% yr^{-1} (1.4 Mg C ha^{-1} yr^{-1}) is not statistically significant.

[51] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test)

Soil organic carbon by genetic horizons

Data on concentration of soil organic carbon profile are summarized in Table 22. In both sites (RP_5 and RP_{10}) the concentrations tend to slightly decrease with horizon, with no statistical differences (P<0.05).

Table 22: Soil organic carbon concentration in the different genetic horizons down to 1 m depth. Numbers between brackets represents the standard deviation (n=3). Different letters indicate statistical significance (P<0.05).

Soil carbon concentration in percentage						
Horizon	Depth (cm)			**Forest**	**RP_5 [a]**	**RP_{10} [b]**
	For.	RP_5 [a]	RP_{10} [b]			
A	7	21	9	5.7 (1.6)	1.5 (0.5)	2.2 (0.8)
Bo	42	79	28	1.4 (0.4)	0.8 (0.1)	1.3 (0.4)
C	51	-*	63	0.8 (0.3)	-*	0.7 (0.04)

[a] RP_5 = Rubber plantation 5 years old
[b] RP_{10} = Rubber plantation 10 years old
* = value of the horizon not reported because the B horizon reach 1 m.

The C/N ratio for the whole profile is 11.9 in the original forest, 12.9 and 12.1 after 5 and 10 years of rubber plantation respectively.

After 10 years from deforestation the total rate of change in the total SOC stock to 1 m depth is 30% (45.4 Mg C ha^{-1}). In the first 5 years the mean annual change is 4.8% (7.4 Mg C ha^{-1}). From the fifth year to tenth year, the annual rate of change is 1.5% (1.7 Mg C ha^{-1}). None of these changes is statistically significant at P<0.05.

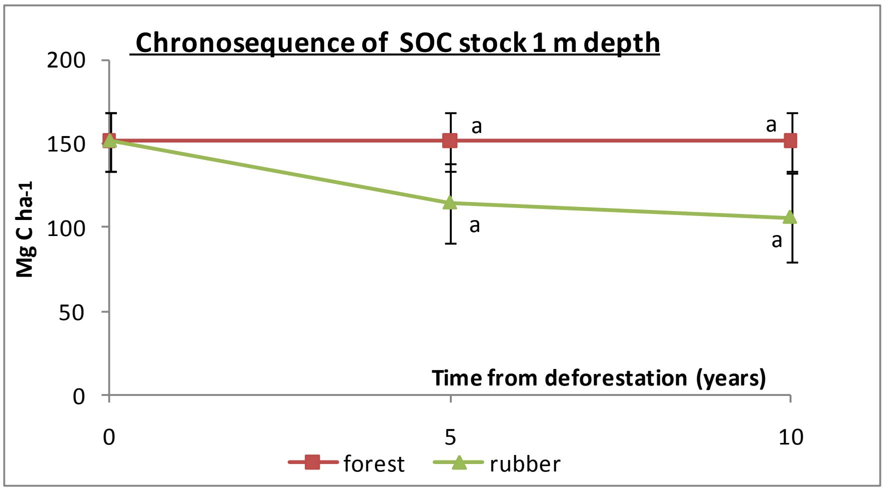

Figure 26: Chronosequence of rubber soil carbon stock to 1 m depth. Different letters indicate statistical significance (P<0.05).

Litter C pool

Litter layer was collected in the two forest sites (CTF and ANKF) and the mean C stock per hectare results to be 8.3 ± 4.6 Mg C ha^{-1}. Litter C in 5 years old rubber plantation (RP_5) was estimated to be 1.8 ± 0.3 Mg C ha^{-1} whereas in 10 years old rubber plantation (RP_{10}) the litter C stock was estimated to be 4.5 ± 1.3 Mg C ha^{-1}. The both of them result lower compared to rain forest litter stock above mentioned.

Aboveground C pool

Mean forest aboveground C stock was estimated to be 120.8 ± 75.5 Mg C ha^{-1}. After deforestation on Lower Birrimian substrate, the 5 years old rubber plantation (RP_5) has an aboveground C stock amounting to 14.3 ± 2.7 Mg C ha^{-1}, whereas 10 years old plantation (RP_{10}) has been estimated to store an amount of 56.7 ± 12.6 Mg C ha^{-1}.

Belowground C pool

Belowground C stock for forest sites amounts to 31.2 ± 19.9 Mg C ha^{-1}, in the 5 years old rubber plantation (RP_5) amounts to 2.8 ± 0.6 Mg C ha^{-1}, whereas 10 years old plantation (RP_{10}) is 11.4 ± 2.5 Mg C ha^{-1}.

7.2.3 Coconut plantations

Soil organic carbon pool by depth

Data on soil organic carbon concentration for the three investigated depths: 0-10, 10-20 and 20-30 cm are summarized in Table 23. In forest site and CN_{44} site the concentrations tend to slightly decrease with depth, with no statistical differences ($P<0.05$) whereas in sites CN_{21} and CN_{28}, the concentrations tend to slightly decrease with depth to 20 cm and then increase in 20-30 cm depth with no statistical differences ($P<0.05$).

Table 23: Soil Organic Carbon concentration in the 0-10, 10-20 and 20-30 cm depths. Numbers between brackets represent the standard deviations (n = 3). Different letters indicate statistical significance (P<0.05).

Depth (cm)	**Forest**	**CN_{21} [a]**	**CN_{28} [b]**	**CN_{44} [c]**
0-10	2.8 (0.3)	2.4 (0.4)	2.0 (0.6)	1.4 (0.3)
10-20	2.5 (0.6)	1.6 (0.3)	1.5 (0.3)	0.7 (0.2)
20-30	2.3 (0.7)	1.9 (0.2)	1.7 (0.7)	0.6 (0.2)

[a] CN_{21} = Coconut plantation 21years old
[b] CN_{28} = Coconut plantation 28 years old
[c] CN_{44} = Coconut plantation 44 years old

The C/N ratio for depth to 30 cm in the original forest is 13.1; after 21 years of coconut plantation, it results 13.09; after 28 years it is 12.8 and after 44 years it reaches 10.6.

Since forest clearance and coconut plantations establishment, the soil C stock at 0-10 cm depth results changed. In 44 years from the deforestation the rate of decrement amounts to 41.9% (14.5 Mg C ha^{-1}). In the first 21 years after deforestation the mean annual change is 0.9% (0.3 Mg C ha^{-1} yr^{-1}) but is not statistically significant. From the twenty-first year to the twenty-eighth, the mean annual change is 3.9% (1.1 Mg C ha^{-1} yr^{-1}) and this is also a not statistically significant change as well as the rate of change amounting to 0.04% (0.01 Mg C ha^{-1} yr^{-1}) from the twenty-eighth to the forty-fourth year. Thus results that the change from forest to coconut plantation in terms of soil organic carbon is not significant in the first 21 years whereas there is a significant depletion at 28 and 44 years after deforestation.

Table 24: Summary of results per depth. Number between brackets represent the standard deviations (n =3). Different letters indicate statistical significance (P<0.05). Different letters indicate statistical significance (P<0.05).

Depth (cm)	**Forest** Mg C ha^{-1}	**CN$_{21}$**[a] Mg C ha^{-1}	**CN$_{28}$**[b] Mg C ha^{-1}	**CN$_{44}$**[c] Mg C ha^{-1}	**TRC$_{44}$**[d] %	**ARC$_{21}$**[e] %	**ARC$_{21-28}$**[f] %	**ARC$_{28-44}$**[g] %
0-10	34.25 (2.1)	28.01 (5.3)	20.31 (3.1)	20.19 (4.2)	**-41.05**	-0.87	-3.93	-0.04
10-20	29.64 (2.8)	18.89 (1.6)	15.40 (1.3)	10.44 (2.8)	**-64.77**	**-1.73**	-2.64	-2.01
20-30	25.70 (2.9)	21.96 (2.2)	16.10 (2.3)	8.96 (2.8)	**-65.16**	-0.69	-3.81	**-2.77**
Tot. 0-30	90.07 (3.5)	68.85 (6.0)	51.80 (4.1)	39.59 (5.8)	**-56.05**	**-1.12**	**3.54**	1.47

[a] CN_{21} = Coconut plantation 21years old
[b] CN_{28} = Coconut plantation 28 years old
[c] CN_{44} = Coconut plantation 44 years old
[d] TRC_{44} = Total rate of change after 44 years from deforestation
[e] ARC_{21} = Annual rate of change (first 21 years since forest clearance)
[f] ARC_{21-28}= Annual rate of change from 21 to 28 years after deforestation
[g] ARC_{28-44}= Annual rate of change from 28 to 44 years after deforestation

In 10-20 cm depth the trend is a decrement in soil C stock. In 44 years from the deforestation the rate of decrement amount to 64.8% (19.2 Mg C ha^{-1}). In the first 21 years after deforestation the mean annual decrement is 1.7% (0.5 Mg C ha^{-1} yr^{-1}). From the twenty-first year to the twenty-eighth, the mean annual change is 2.6% (0.5 Mg C ha^{-1} yr^{-1}) but is not statistically significant as well as from the twenty-eighth to the forty-fourth year where the rate of change is 2.0% (0.3 Mg C ha^{-1} yr^{-1}). Thus the change from forest to coconut is always statistically significant whereas within coconut at different age it is not.

In 20-30 cm depth the trend is a decrement in soil C stock. In 44 years from the deforestation the rate of decrement amount to 65.2% (16.7 Mg C ha^{-1}). In the first 21 years after deforestation the mean annual change is 0.7% (0.2 Mg C ha^{-1} yr^{-1}) but is not statistically significant. After 28 years from deforestation the change is statistically significant. From the twenty-first year to the twenty-eighth, the mean annual change is 3.8% (0.8 Mg C ha^{-1} yr^{-1}) and it is not significant whereas from the twenty-eighth to the forty-fourth year the rate of decrement is 2.8% (0.4 Mg C ha^{-1} yr^{-1}) results statistically significant.

The soil organic carbon stock at 0-30 cm depth has a statistically significant decreasing trend. In 44 years from the deforestation the rate of decrement is 56.1% (50.5 Mg C ha^{-1}). In the first 21 years after deforestation the mean annual decrement is 1.1% (1.0 Mg C ha^{-1} yr^{-1}). From the twenty-first year to the twenty-eighth, the mean annual change is 3.5% (2.4 Mg C ha^{-1} yr^{-1}) whereas from the twenty-eighth to the forty-fourth year the rate of decrement is 1.5% (0.8 Mg C ha^{-1} yr^{-1}).

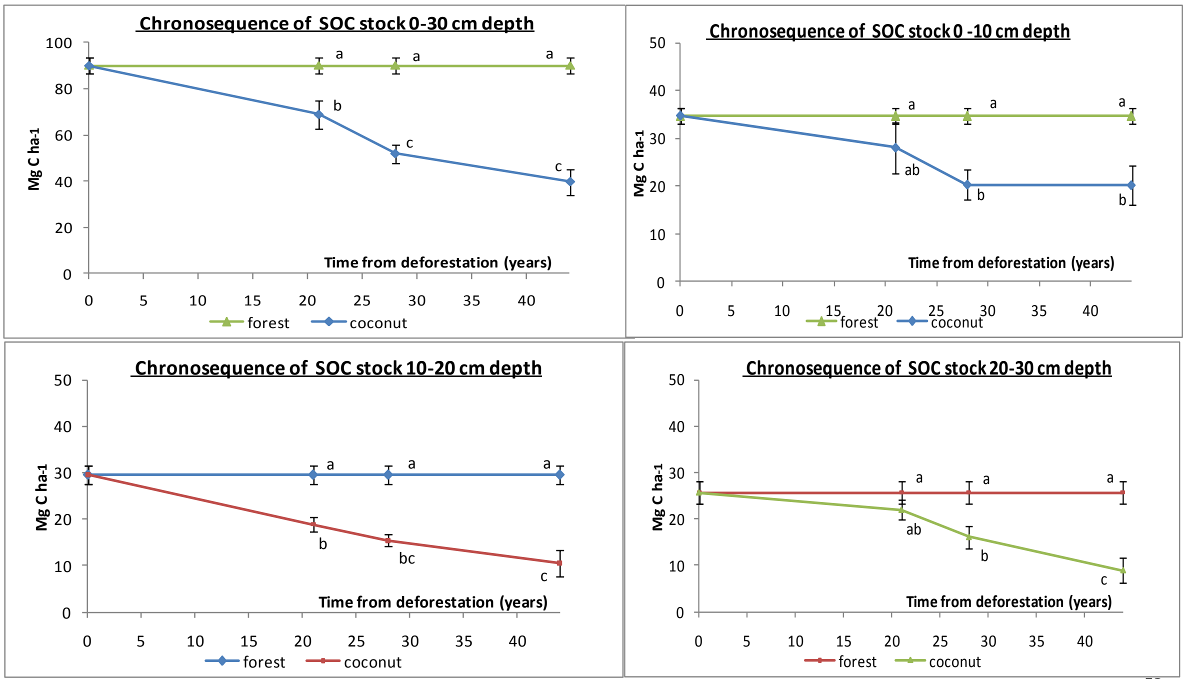

Figure 27: Chronosequence of coconut soil carbon stock to 0-30, 0-10, 10-20 and 20-30 cm depth[52]. Different letters indicate statistical significance (P<0.05).

Soil organic carbon pool by genetic horizons

Data on concentration of soil organic carbon profile are summarized in Table 25. In all the sites (CN_{21}, CN_{28}^{b} and CN_{44}^{c}) the concentrations tend to slightly decrease with horizon, with no statistical differences (P<0.05).

[52] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test)

Table 25: Soil organic carbon concentration in the different genetic horizons down to 1 m depth. Numbers between brackets represents the standard deviation (n = 3). Different letters indicate statistical significance (P<0.05).

Horizon	Depth (cm)				Soil carbon concentration in percentage			
	For.	**CN_{21} [a]**	**CN_{28} [b]**	**CN_{44} [c]**	**Forest**	**CN_{21} [a]**	**CN_{28} [b]**	**CN_{44} [c]**
A	7	11	5	13	5.7 (1.6)	2.8 (0.3)	2.7 (0.6)	1.3 (0.6)
Bo	42	41	23	32	1.4 (0.4)	1.1 (0.2)	1.2 (0.8)	0.4 (0.3)
C	51	-*	72	55	0.8 (0.3)	-*	0.7 (0.2)	0.2 (0.01)

[a] CN_{21} = Coconut plantation 21years old
[b] CN_{28} = Coconut plantation 28 years old
[c] CN_{44} = Coconut plantation 44 years old
* = bedrock

The C/N ratio in the original forest profile is 11.9 after 21 years of coconut plantation, it results 13.0, after 28 years it results to reach 11.6 and after 44 years it reaches 9.5.

In profile analysis the trend of decrement is more evident. In 44 years from the deforestation the rate of decrement amount to 65.7% (99.4 Mg C ha^{-1}). In the first 21 years after deforestation the mean annual decrement is 2.1% (3.1 Mg C ha^{-1} yr^{-1}). From the twenty-first year to the twenty-eighth, the mean annual change is 1.1% (0.9 Mg C ha^{-1} yr^{-1}) but it is not statistically significant as well as from the twenty-eighth to the forty-fourth year where the rate of change is 2.2% (1.7 Mg C ha^{-1} yr^{-1}). The change from forest to coconut in terms of soil carbon stock to 1 m depth is statistically significant.

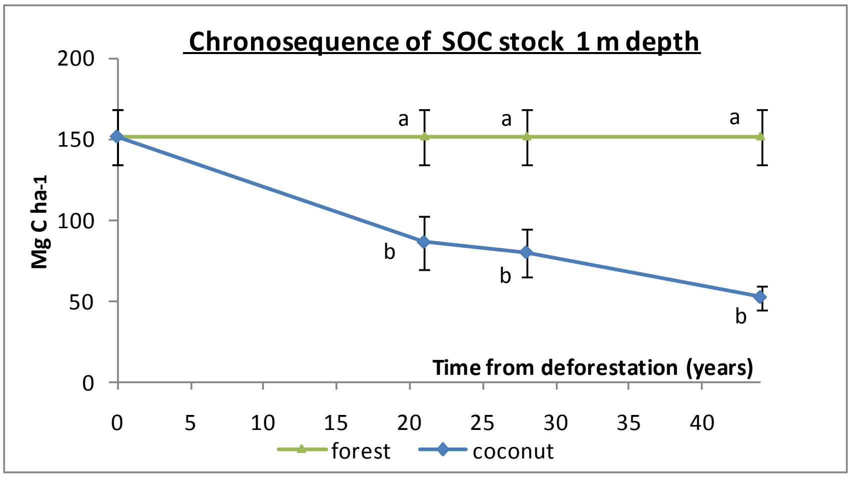

Figure 28: Chronosequence of coconut soil carbon stock to 1 m depth. Different letters indicate statistical significance (P<0.05).

Litter C pool

Litter layer was never present in any of the coconut plantation sites investigated because regularly removed for other uses.

Aboveground C pool

Mean forest aboveground C stock was estimated to be 120.8 ± 75.5 Mg C ha^{-1}. After deforestation the 21 years old coconut plantation has an aboveground C stock amounting to 15.2 ± 4.9 Mg C ha^{-1}, the 28 years old plantation has been estimated to store an amount of 30.±5.19 Mg C ha^{-1} whereas the 44 years old plantation stores 35.5 ± 9.6 Mg C ha^{-1}.

Belowground C pool

Mean forest belowground C stock was estimated to be 31.3 ± 19.9 Mg C ha^{-1}. After deforestation the 21 years old coconut plantation has a belowground C stock amounting to 3.1 ± 1.0 Mg C ha^{-1}, the 28 years old plantation has been estimated to store an amount of 6.2 ± 1.0 Mg C ha^{-1} whereas the 44 years old plantation stores 7.1 ± 1.9 Mg C ha^{-1}.

7.2.4 Mixed plantations

Soil organic carbon pool by depth

Data on soil organic carbon concentration for the three investigated depths: 0-10, 10-20 and 20-30 cm are summarized in Table 26. In forest site and MP_{36} site the concentrations tend to slightly decrease with depth, with no statistical differences ($P<0.05$) whereas in site MP_{49} the concentrations tend to slightly decrease with depth to 20 cm and then increase in 20-30 cm depth with no statistical differences ($P<0.05$).

Table 26: Soil Organic Carbon concentration in the 0-10, 10-20 and 20-30 cm depths. Numbers between brackets represent the standard deviations (n = 3). Different letters indicate statistical significance (P<0.05).

Depth (cm)	Forest	MP_{36} [a]	MP_{49} [b]
0-10	2.8 (0.3)	2.2 (0.6)	2.3 (0.5)
10-20	2.5 (0.6)	1.6 (0.4)	1.3 (0.4)
20-30	2.3 (0.7)	1.4 (0.4)	1.5 (0.4)

[a] MP_{36} = Mixed plantation 36 years old
[b] MP_{49} = Mixed plantation 49 years old

The C/N ratio calculated for depth to 30 cm shows that in the original forest the C/N ratio is 13.1; after 36 years of mixed plantation, it results 12.9; after 28 years it is 13.2.

In the first layer of 0-10 cm, after 49 years from the deforestation the rate of change amount to 11.9% (4.2 Mg C ha^{-1}). In the first 36 years after deforestation the mean annual change is 0.5% (0.2 Mg C ha^{-1} yr^{-1}). From the thirty-sixth year to forty-ninth, there is a slight increment of 0.7% (0.2 Mg C ha^{-1} yr^{-1}). None of these changes is statistically significant, this means that at 0-10 depth there is not an evident change from forest to mixed plantation in the soil carbon content.

Table 27: Summary of results per depth. Number between brackets represent the standard deviations (n =3). Different letters indicate statistical significance (P<0.05).

Depth (cm)	Forest Mg C ha^{-1}	MP_{36} [a] Mg C ha^{-1}	MP_{49} [b] Mg C ha^{-1}	TRC_{49} [c] %	ARC_{36} [d] %	ARC_{36-49} [e] %
0-10	34.25 (2.1)	28.01 (5.3)	20.19 (4.2)	-11.87	-0.52	-0.66
10-20	29.64 (2.8)	18.89 (1.6)	10.44 (2.8)	**-39.16**	-0.82	-1.04
20-30	25.70 (2.9)	21.96 (2.2)	8.96 (2.8)	-65.16	**-0.69**	-3.81
Tot.0-30	90.07 (3.5)	66.66 (6.6)	68.51 (7.8)	-23.94	-0.72	+0.21

[a] MP_{36} = Mixed plantation 36 years old
[b] MP_{49} = Mixed plantation 49 years old
[c] TRC_{49} = Total rate of change after 49 years from deforestation

[d] ARC_{36} = Annual rate of change (first 36 years since forest clearance)
[e] ARC_{36-49}= Annual rate of change from 36 to 49 years after deforestation

In the layer of 10-20 cm, after 49 years from the deforestation the rate of change amounts to 39.2% (11.6 Mg C ha^{-1}). In the first 36 years after deforestation the mean annual change is 0.8% (0.2 Mg C ha^{-1} yr^{-1}) but is not statistically significant as well as from the thirty-sixth year to forty-ninth where the mean annual rate of change is 1.0% (0.2 Mg C $ha^{-1}yr^{-1}$).

At 20-30 cm, after 49 years from the deforestation the rate of change in SOC is 22.7% (5.8 Mg C ha^{-1}) but it is not statistically significant. In the first 36 years after deforestation the mean annual decrement is 0.9% (0.2 Mg C ha^{-1} yr^{-1}) and it is significant at $P<0.05$. From the thirty-sixth year to forty-ninth, the mean annual rate of change 1.0% (0.2 Mg C ha^{-1} yr^{-1}) but it is not statistically significant.

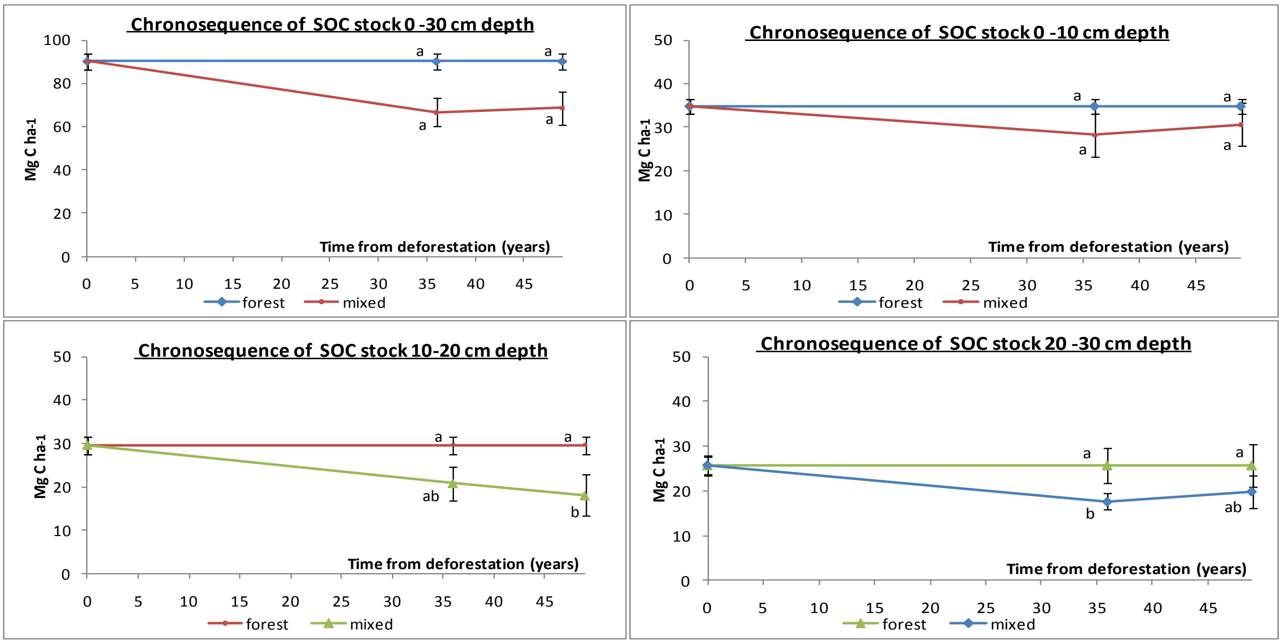

Figure 29: Chronosequence of mixed soil carbon stock to 0-30, 0-10, 10-20 and 20-30 cm depth[53]. Numbers between brackets represent the standard deviations (n = 3). Different letters indicate statistical significance (P<0.05)

At 0-30 cm depth the SOC stock has a decrement trend with no statistical significance, after 49 years from the deforestation the rate of change amount to 23.9% (21.6 Mg C ha^{-1}). In the first 36 years after deforestation the mean annual change is 0.7% (0.6 Mg C ha^{-1}

[53] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test)

yr^{-1}) whereas from the thirty-sixth year to forty-ninth, there is a slight increment of 0.2% (0.1 Mg C ha^{-1} yr^{-1}) but none of these changes are statistically significant.

Soil organic carbon by genetic horizon

Table 28 reports the data on soil organic carbon concentration for the different horizon. In both sites (MP_{36} and MP_{49}) as well as in for the forest site, the concentrations tend to slightly decrease with depth, with no statistical differences (P<0.05).

Table 28: Soil organic carbon concentration in the different genetic horizons down to 1 m depth. Numbers between brackets represents the standard deviation (n = 3). Different letters indicate statistical significance (P<0.05).

Soil carbon concentration in percentage						
Horizon	Depth (cm)			**Forest**	**MP_{36} [a]**	**MP_{49} [b]**
	For.	**MP_{36} [a]**	**MP_{49} [b]**			
A	7	16	7	5.7 (1.6)	1.4 (0.1)	2.8 (1.3)
Bo	42	-*	16	1.4 (0.4)	-*	0.9 (0.5)
C	51	84	78	0.8 (0.3)	0.8 (0.2)	0.7 (0.1)

[a] MP_{36} = Mixed plantation 36 years old
[b] MP_{49} = Mixed plantation 49 years old
* = Horizon B was not present

The C/N ratio calculated in the profile shows that in the original forest the C/N ratio is 11.9 after 36 years of mixed plantation, it results 11.8, after 49 years it results to reach 11.5.

To the depth of 1m, after 49 years from the deforestation the rate of change amount to 13.0% (19.7 Mg C ha^{-1}) but is not statistically significant. In the first 36 years after deforestation the mean annual decrement is 0.7% (1.11 Mg C ha^{-1} yr^{-1}). From the thirty-sixth year to forty-ninth, the mean annual rate of change is 1.4% (1.6 Mg C ha^{-1} yr^{-1}) and is not statistically significant.

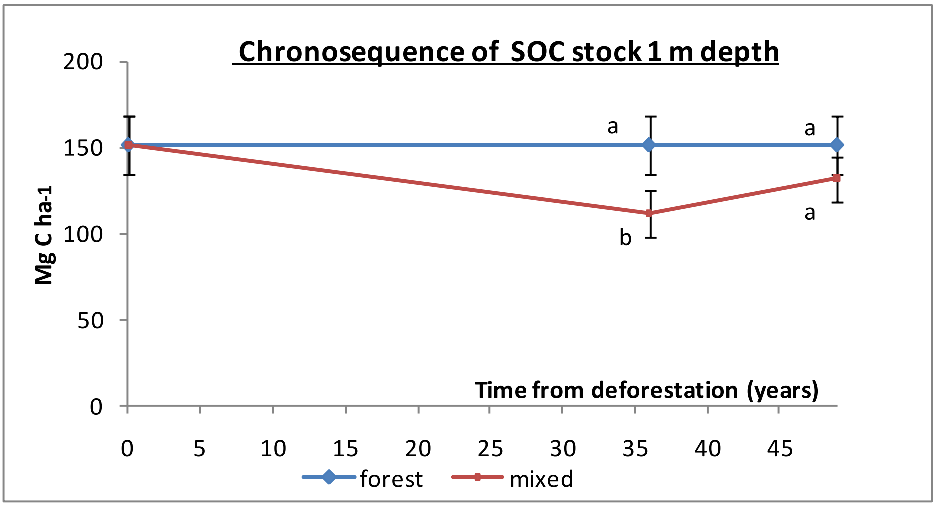

Figure 30: Chronosequence of mixed soil carbon stock to 1 m depth. Different letters indicate statistical significance (P<0.05).

Litter C pool

Litter layer was never present in any of the mixed plantation sites investigated because regularly removed for other uses.

Aboveground C pool

Mean forest aboveground C stock was estimated to be 120.8 ±75.5 Mg C ha^{-1}. After deforestation the 36 years old mixed plantation has an aboveground C stock amounting to 25.1 ± 6.47 Mg C ha^{-1}, whereas the 49 years old plantation has been estimated to store an amount of 67.20 ± 26.8 Mg C ha^{-1}.

Belowground C pool

Mean forest belowground C stock was estimated to be 31.2 ± 19.9 Mg C ha^{-1}. After deforestation the 36 years old mixed plantation has a C stock amounting to 5.0 ± 1.3 Mg C ha^{-1}, whereas the 49 years old plantation has been estimated to store an amount of 12.1 ± 5.0 Mg C ha^{-1}.

7.3 Tertiary sands

7.3.1 Rubber plantations

Soil organic carbon pool by depth

Soil organic carbon concentrations investigated in 0-10, 10-20 and 20-30 cm depths, are summarized in Table 29. The concentration decrease with depth in forest and RP_{14} sites while increase in RP_{49} in 20-30 cm but it is not statistically significant ($P<0.05$).

Table 29: Soil Organic Carbon concentration in the 0-10, 10-20 and 20-30 cm depths. Numbers between brackets represent the standard deviations (n = 3). Different letters indicate statistical significance (P<0.05).

Depth (cm)	**Forest**	**RP_{14} [a]**	**RP_{49} [b]**
0-10	2.2 (0.3)	1.4 (0.2)	1.4 (0.4)
10-20	1.4 (0.1)	1.3 (0.2)	0.8 (0.2)
20-30	1.2 (0.2)	1.1 (0.3)	1.1 (0.1)

[a] RP_{14}= Rubber plantation 14 years old
[b] RP_{49} = Rubber plantation 49 years old

The C/N ratio calculated for depth to 30 cm shows that in the original forest the C/N ratio is 12.1; after 14 years of rubber plantation, it results 12.3; after 49 years it is 11.6.
In the first layer of 0-10 cm, after 49 years from the deforestation the rate of decrement amounts to 37.7% (11.9 Mg C ha^{-1}). In the first 14 years after deforestation the mean annual decrement is 2.6% (0.8 Mg C ha^{-1} yr^{-1}while in the range from 14 to 49 the mean annual rate of change is 0.04% (0.01 Mg C ha^{-1} yr^{-1}) but this change is not statistically significant.

Table 30: Summary of results per depth. Number between brackets represent the standard deviations (n =3). Different letters indicate statistical significance (P<0.05). Different letters indicate statistical significance (P<0.05).

Depth (cm)	**Forest** Mg C ha^{-1}	**RP_{14} [a]** Mg C ha^{-1}	**RP_{49} [b]** Mg C ha^{-1}	**TRC_{49} [c]** %	**ARC_{14} [d]** %	**ARC_{14-49} [e]** %
0-10	31.53 (2.1)	19.94 (2.3)	19.64 (4.8)	**-37.73**	**-2.63**	-0.04
10-20	20.42 (2.8)	18.60 (2.0)	12.81 (2.2)	**-37.27**	-0.64	**-0.89**
20-30	16.95 (2.5)	16.49 (4.3)	15.73 (0.9)	-7.19	-0.19	-0.13
Tot. 0-30	68.91 (4.3)	55.03 (5.3)	48.18 (5.3)	**-30.08**	-1.44	-0.36

[a] RP_{14}= Rubber plantation 14 years old
[b] RP_{49} = Rubber plantation 49 years old
[c] TRC_{49} = Total rate of change after 49 years from deforestation
[d] ARC_{14} = Annual rate of change (first 14 years since forest clearance)
[e] ARC_{14-49}= Annual rate of change from 14 to 49 years after deforestation

In the layer of 10-20 cm, after 49 years from the deforestation the rate of change decrement amounts to 37.3% (7.6 Mg C ha^{-1}). In the first 14 years after deforestation the mean annual change is 0.6% (0.1 Mg C ha^{-1} yr^{-1}) but is not statistically significant. From the fourteenth year to forty-ninth, the mean annual rate of decrement is 0.9% (0.2 Mg C ha^{-1} yr^{-1}). Thus the depletion in soil organic carbon from forest to rubber plantation starts to be significant after 14 years from deforestation.

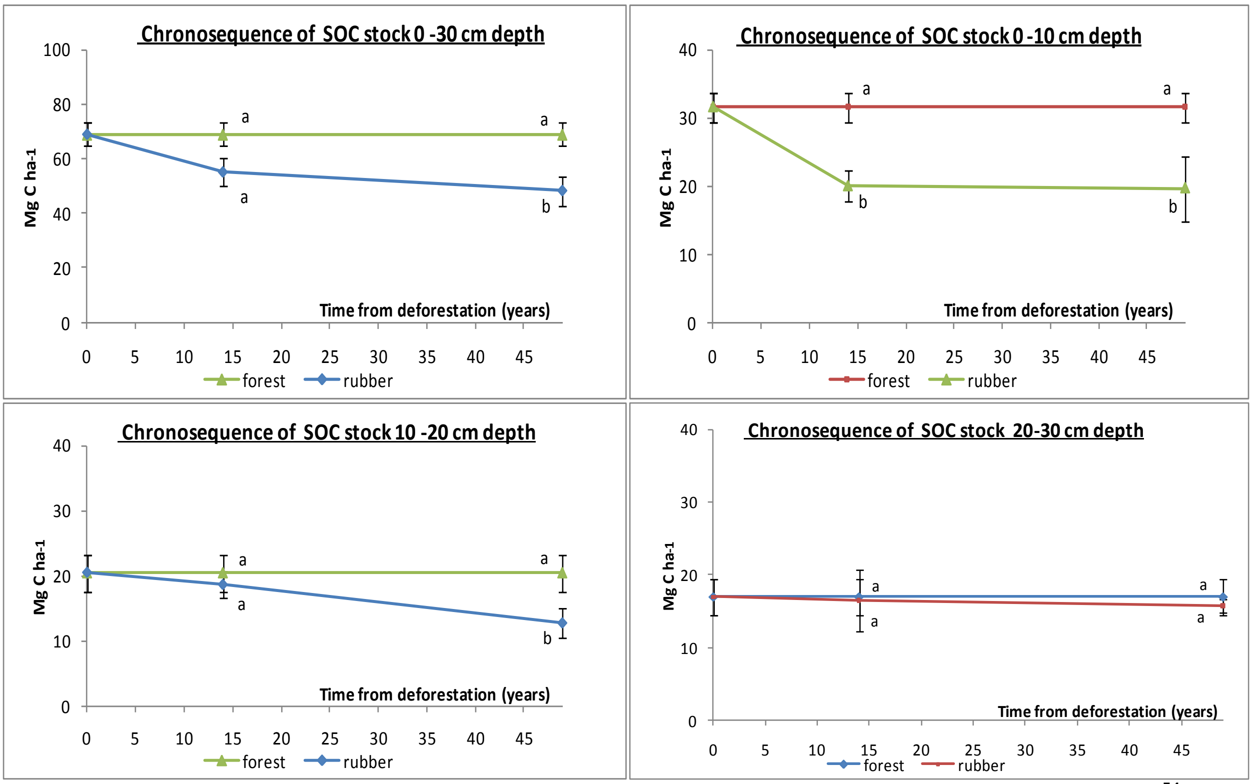

Figure 31: Chronosequence of rubber soil carbon stock to 0-30, 0-10, 10-20 and 20-30 cm depth[54]. Different letters indicate statistical significance (P<0.05).

At 20-30 cm depth, after 49 years from the deforestation the rate of change amount to 7.2% (1.2 Mg C ha^{-1}). In the first 14 years after deforestation the mean annual change is 0.19% (0.03 Mg C ha^{-1} yr^{-1}). From the fourteenth year to forty-ninth, the mean annual rate of change is 0.13% (0.02 Mg C ha^{-1} yr^{-1}). None of these changes are statistically significant thus from forest to rubber plantation to 20-30 cm depth there is not significant change in soil carbon.

[54] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test)

At 0-30 cm depth, after 49 years from the deforestation the rate of decrement is 30.1% (20.7 Mg C ha^{-1}). In the first 14 years after deforestation the mean annual change is 1.4% (1.0 Mg C ha^{-1} yr^{-1}) but it is not statistically significant (P<0.05) whereas it is significant the decrease from the fourteenth year to forty-ninth that is 0.4% (0.2 Mg C ha^{-1} yr^{-1}).

Soil organic carbon by genetic horizons

Data on concentration of soil organic carbon profile are summarized in Table 31. In both sites (RP_{14} and RP_{49}) the concentrations tend to slightly decrease with horizon, with no statistical differences (P<0.05).

Table 31: Soil organic carbon concentration in the different genetic horizons down to 1 m depth. Numbers between brackets represents the standard deviation (n = 3). Different letters indicate statistical significance (P<0.05).

Soil carbon concentration in percentage						
Horizon	Depth (cm)			**Forest**	**RP_{14} [a]**	**RP_{49} [b]**
	For.	**RP_{14} [a]**	**RP_{49} [b]**			
A	10	15	4	4.2 (0.7)	1.3 (0.3)	2.9 (0.2)
B	25	44	40	0.8 (0.2)	0.8 (0.2)	0.7 (0.1)
C	65	41	56	1.0 (0.01)	0.7 (0.5)	0.6 (0.2)

[a] RP_{14}= Rubber plantation 14 years old
[b] RP_{49} = Rubber plantation 49 years old

The C/N ratio calculated for the profile to a depth of 1 cm shows that in the original forest the C/N ratio is 10.7; after 14 years of rubber plantation, it results 12.4; after 49 years it is 12.4.

To 1 m depth, after 49 years from the deforestation the rate of change amount in soil organic carbon amounts to 44.9% (81.2 Mg C ha^{-1}). In the first 14 years after deforestation the mean annual change is 2.5% (4.5 Mg C ha^{-1} yr^{-1}) but is not significant as well as from the fourteenth year to forty-ninth, the mean annual rate of change is 0.4% (0.5 Mg C ha^{-1} yr^{-1}).

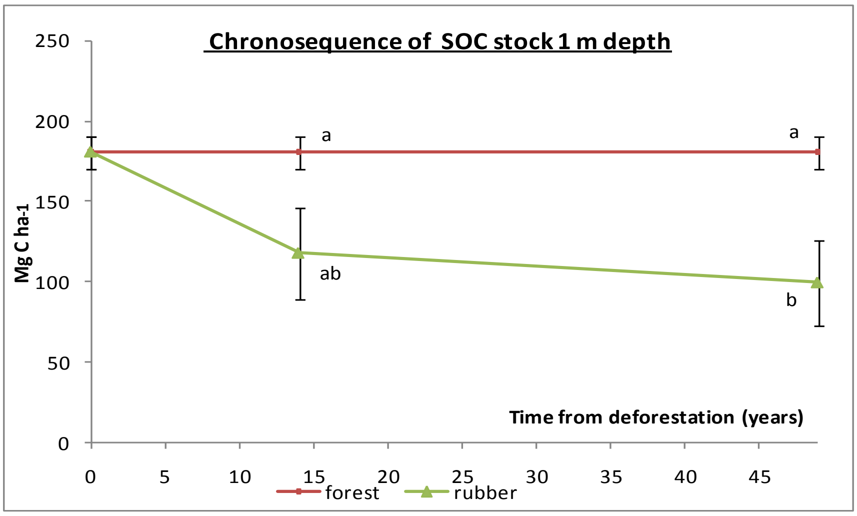

Figure 32: Chronosequence of rubber soil carbon stock to 1 m depth. Different letters indicate statistical significance (P<0.05).

Litter C pool

Litter C stock in forest site was estimated to be 2.5 ± 0.5 Mg C ha^{-1}. After deforestation on Tertiary sands, the 14 years old rubber plantation has a litter C stock amounting to 2.9 ± 0.7 Mg C ha^{-1}, whereas 49 years old plantation the litter layer amounts to 2.9 ± 0.8 Mg C ha^{-1}.

Aboveground C pool

Forest aboveground C stock was estimated to be 240.2 ± 57.9 Mg C ha^{-1}. After deforestation the 14 years old rubber plantation has an aboveground C stock amounting to 121.5 ± 25.3 Mg C ha^{-1}, whereas the 49 years old plantation has been estimated to store an amount of 214.5 ± 47.7 Mg C ha^{-1} .

Belowground C pool

Forest belowground C stock was estimated to be 62.4 ± 15.1 Mg C ha^{-1}. After deforestation the 14 years old rubber plantation has a belowground C stock amounting to 24.3 ± 5.1 Mg C ha^{-1}, whereas the 49 years old plantation has been estimated to store an amount of 42.9 ± 9.5 Mg C ha^{-1} .

7.3.2 Coconut plantations

Soil organic carbon pool by depth

Table 32 reports the soil organic carbon concentrations investigated in 0-10, 10-20 and 20-30 cm depths. The concentration decrease with depth in forest and both in CN_{15}, CN_{50} and in CN_{100} sites but it is not statistically significant ($P<0.05$).

Table 32: Soil Organic Carbon concentration in the 0-10, 10-20 and 20-30 cm depths. Numbers between brackets represent the standard deviations (n = 3).

Depth **(cm)**	**Forest**	**CN_{15} [a]**	**CN_{50} [b]**	**CN_{100} [b]**
0-10	2.2 (0.3)	1.2 (0.1)	1.2 (0.3)	1.0 (0.2)
10-20	1.4 (0.1)	1.0 (0.1)	1.0 (0.3)	0.8 (0.1)
20-30	1.2 (0.2)	1.0 (0.2)	0.8 (0.2)	0.9 (0.1)

[a] CN_{15} = Coconut plantation 15 years old
[b] CN_{50} = Coconut plantation 50 years old
[c] CN_{100} = Coconut plantation 100 years old

The C/N ratio calculated for depth to 30 cm shows that in the original forest the C/N ratio is 12.1; after 15 years of coconut plantation, it results 12.8; after 50 years it is 12.2 and after 100 years it reaches 13.1.

Since forest clearance and coconut plantations establishment, the soil C content at 0-10 cm depth results changed. In 100 years from the deforestation the rate of decrement amount to 51.9% (16.4 Mg C ha^{-1}) while in the first 15 years after deforestation the mean annual decrement is 2.9% (0.92 Mg C ha^{-1} yr^{-1}) and the decrement is statistically significant. From the fifteenth year to the fiftieth, the mean annual change is 0.13% (0.02 Mg C ha^{-1} yr^{-1}) but is not statistically significant as well as from the fiftieth to the hundredth year with the mean annual rate of change is 0.22% (0.04 Mg C ha^{-1} yr^{-1}). The change in soil carbon to 0-10 cm depth is statistically significant when the deforestation is followed by coconut plantation.

Table 33: Summary of results per depth. Number between brackets represent the standard deviations (n =3). Different letters indicate statistical significance (P<0.05)

Depth (cm)	**Forest** Mg C ha^{-1}	**CN_{15}** [a] Mg C ha^{-1}	**CN_{50}** [b] Mg C ha^{-1}	**CN_{100}** [c] Mg C ha^{-1}	**TRC_{100}** [d] %	**ARC_{15}** [e] %	**ARC_{15-50}** [f] %	**ARC_{50-100}** [g] %
0-10	31.53 (2.1)	17.80 (1.1)	17.02 (3.0)	15.15 (3.2)	**-51.94**	**-2.90**	-0.13	-0.22
10-20	20.42 (2.8)	14.36 (0.8)	14.45 (2.9)	12.22 (1.0)	**-40.15**	**-1.98**	+0.02	-0.31
20-30	16.95 (2.5)	15.15 (3.4)	11.58 (1.5)	14.20 (1.7)	-16.22	-0.71	-0.67	+0.45
Tot. 0-30	68.91 (4.3)	47.31 (3.7)	43.05 (4.5)	41.58 (3.7)	**-39.66**	**-2.09**	-0.26	-0.07

[a] CN_{15} = Coconut plantation 15 years old
[b] CN_{50} = Coconut plantation 50 years old
[c] CN_{100} = Coconut plantation 100 years old
[d] TRC_{100} = Total rate of change after 100 years from deforestation
[e] ARC_{15} = Annual rate of change (first 15 years since forest clearance)
[f] ARC_{15-50}= Annual rate of change from 15 to 50 years after deforestation
[g] ARC_{50-100}= Annual rate of change from 50 to 100 years after deforestation

The soil C content at 10-20 cm depth results changed as well as at 0-10 depth. In 100 years from the deforestation the rate of decrement amount to 40.2% (8.2 Mg C ha^{-1}). In the first 15 years after deforestation the decrement is 2.0% (0.4 Mg C ha^{-1} yr^{-1}). From the fifteenth to the fiftieth year, the mean annual change is 0.02% (0.003 Mg C ha^{-1} yr^{-1}) but it is not significant as well as from the fiftieth to the hundredth year where the mean annual rate of change is 0.3% (0.04 Mg C ha^{-1} yr^{-1}).

In 100 years from the deforestation the rate of decrement at 20-30 cm depth amount to 16.2% (2.7 Mg C ha^{-1}). In the first 15 years after deforestation the mean annual change is 0.7% (0.1 Mg C ha^{-1} yr^{-1}). From the fifteenth year to the fiftieth, the mean annual change is 0.7% (0.1 Mg C ha^{-1} yr^{-1}) whereas from the fiftieth to the hundredth year the mean annual rate of change is 0.4% (0.1 Mg C ha^{-1} yr^{-1}). None of these changes are significant.

The soil organic carbon stock at 0-30 cm depth has a statistically significant decreasing trend. In 100 years from the deforestation the rate of decrement is 39.7% (27.3 Mg C ha^{-1}). In the first 15 years after deforestation the decrement is 2.1% (1.4 Mg C ha^{-1} yr^{-1}). From the 15th year to 50th the mean annual change is 0.3% (0.1 Mg C ha^{-1} yr^{-1}) whereas from the 5th to the 100th year the rate of decrement is 0.1% (0.03 Mg C ha^{-1} yr^{-1}) but both are not statistically significant.

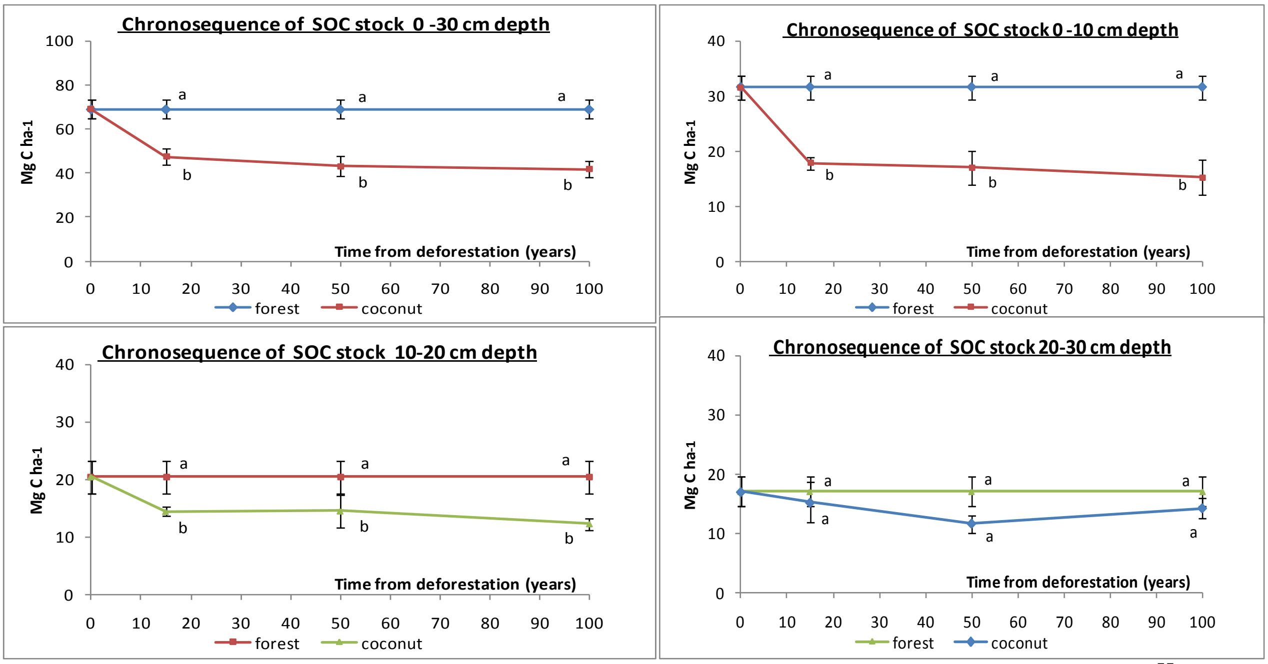

Figure 33: Chronosequence of coconut soil carbon stock to 0-30, 0-10, 10-20, 20-30 cm depth[55]. Different letters indicate statistical significance (P<0.05).

Soil organic carbon by genetic horizons

Data on concentration of soil organic carbon profile are summarized in Table 34. In all the sites (CN_{15}^{a}, CN_{50}^{b} and CN_{100}^{c}) the concentrations tend to slightly decrease with horizon, with no statistical differences (P<0.05).

Table 34: Soil organic carbon concentration in the different genetic horizons down to 1 m depth. Numbers between brackets represents the standard deviation (n = 3). Different letters indicate statistical significance (P<0.05).

					Soil carbon concentration in percentage			
Horizon	Depth (cm)				**Forest**	**CN_{15}^{a}**	**CN_{50}^{b}**	**CN_{100}^{c}**
	For.	**CN_{15}^{a}**	**CN_{50}^{b}**	**CN_{100}^{c}**				
A	10	15	15	7	4.2 (0.7)	2.3 (0.6)	1.9 (0.9)	1.8 (0.5)
B	25	35	35	43	0.8 (0.2)	1.0 (0.1)	1.0 (0.4)	0.7 (0.2)
C	65	50	50	50	1.0 (0.01)	1.0 (0.2)	0.7 (0.01)	0.6 (0.1)

[a] CN_{15} = Coconut plantation 15 years old
[b] CN_{50} = Coconut plantation 50 years old
[c] CN_{100} = Coconut plantation 100 years old

[55] Different letters indicate significant differences at P<0,05 - (One-way ANOVA-Tukey's multiple comparison test)

The C/N ratio calculated for the profile to 1 m depth shows that in the original forest the C/N ratio is 10.6; after 15 years of coconut plantation, it results 13.7; after 50 years it is 14.2 and after 100 years it reaches 13.8.

In profile analysis, in 100 years from the deforestation the rate of decrement results to be 39.0% (70.5 Mg C ha^{-1}). In the first 15 years after deforestation the mean annual change is 0.8% (1.4 Mg C ha^{-1} yr^{-1}) but is not statistically significant. From the fifteenth year to the fiftieth, the mean annual change is 0.4% (0.6 Mg C ha^{-1} yr^{-1}) is not statistically significant as well as from the fiftieth to the hundredth year where the mean annual rate of change is 0.4% (0.6 Mg C ha^{-1} yr^{-1}).

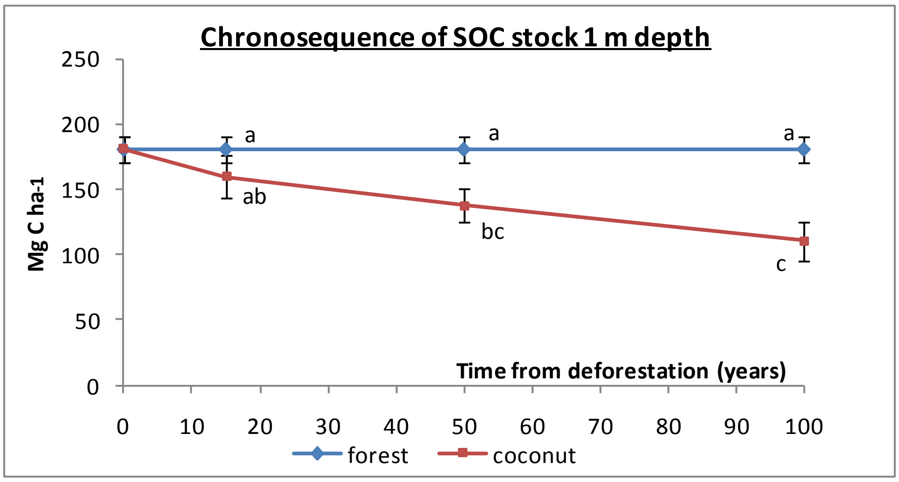

Figure 34: Chronosequence of coconut soil carbon stock to 1 m depth. Different letters indicate statistical significance (P<0.05).

Litter C pool

Litter layer was never present in any of the coconut plantation sites investigated because regularly removed for other uses.

Aboveground C pool

Forest aboveground C stock was estimated to be 240.2 ± 57.9 Mg C ha^{-1}. After deforestation the 15 years old coconut plantation has stored an aboveground C stock amounting to 31.8 ± 2.5 Mg C ha^{-1}, the 50 years old plantation has been estimated to store an amount of C 40.7 ± 6.7 Mg C ha^{-1} whereas the 100 years old plantation has an aboveground C stock amounting to 41.3 ± 9.3.

Belowground C pool

Forest belowground C stock was estimated to be 62.4 ± 15.1 Mg C ha^{-1}. After deforestation the 15 years old coconut plantation has stored belowground C stock amounting to 6.4 ± 0.5 Mg C ha^{-1}, the 50 years old plantation has been estimated to store an amount of C 8.1 ± 1.3 Mg C ha^{-1} whereas the 100 years old plantation has an aboveground C stock amounting to 8.3 ± 1.7.

7.4 Socioeconomic aspects

The investigated plantations present on the Jomoro Districts are almost all community lands, rain fed, with no plough, mulching or manuring activities and there is no use of fertilizers except for cocoa plantation.

Oil palm:

Oil palm plantation is a controversial choice for local people. In the two sites investigated, OP_8 and OP_{25}, it was evident some problem related to the complexity of the management. In the OP_8 case, a family land deforested in 2002, the choice of oil palm was lead by the characteristic of the soil, suitable for this plantation. Nonetheless many problem has been faced, grasscutters as well as harvesting time (at 7-8 years). The small production they have, they use for family needs and waiting for a better production (the plantation is reaching the age to yield), they start a poultry activity. The small benefits are shared for the family components (5 people) those who collaborate to weed day by day the area. An older plantation was the OP_{25} site. The area, deforested in 1985, and bought almost 100 years ago, belongs to Mrs Nyamek Dawuah and is managed with the help of 4 people. The plantation was at its second generation and they produce mainly oil sold to local market. The mean monthly net incomes per hectare amounts to 9.4 €[56]. The owner is planning to change the land use because of the difficulties in maintaining oil palm plantation, above all because it requires frequent weeding activities. For this reason it is planned to substitute oil palm with coconut intercropped for the first years with cassava. For both OP_8 and OP_{25} there are not specific management costs considering that the plantations are handled by family and the incomes are shared among the family components.

[56] Ghana cedis are converted in Euros as follow 1Gh cedis = 0.505 Euro (source: http://it.exchange-rates.org/currentRates/E/GHS)

Forest and Secondary forest:

Usually forested areas and secondary forests are not source of incomes for local population. These areas are often considered sacred and only few activities are allowed. Cocotown forest on Lower Birrimian for instance is a royal family land and people are not allowed to enter or hunt in that area, as well as forest on Tertiary sands which is a community land but where any activity is permitted. Secondary forests are generally used for sporadic hunting activities and sometimes for harvesting non timber products. These are the result of the abandonment of farms as for SF_{10} site, which was originally a forested area, cleared (in 2000) for farming but abandoned because it was a portion of a wider area and the owner was not able to farm all the land. According to what expressed by the owner of the land, in two years the land will be farmed with cocoa plantation. The choice of this plantation is due to a faster income (cocoa start producing after 3 years, and only two workers to manage the plantation). SF_{21} site has more or less the same pathway. It was a forested area (since 1988), it was cultivated for almost one year with cassava and coconut but these do not succeed because of pests (grasscutters) so it has been decided to abandon the land. Secondary forests are often attempts of farming not succeeded and many of these lands are bound to be further farmed again.

Cocoa:

Cocoa is one of the most gainful plantations in the area. The 35 years plantation (CC_{34}), a land gave for rent to the farmer for 1 Gh cedis (almost 0.5 €) per acre per year, produces a mean net income of 153,3 € per month per hectare shared among the family components (15 children and the tenant's wife). The 120 years old plantation (CC_{120}) is a stool land managed by different families (namely three: Esowa, Apenteng and a royal family), it produces a mean net income of 124.4 € per month per hectare. It is handled mainly by males but a 20% is also managed by female. The profits are shared among the family components working in the plantation. Farmers do not receive any governmental help apart from DDT and equipment to spray distributed for free by Ghana Cocoa Board and usually spread every 8 month 2 liters per acre (CC_{120} site). The use of fertilizer is present only for KC site, once in a year, 153 kg per acre (1 acre = 0.405 hectares). The fertilizer used is NPK 0-22-18+9CaO+7S+6MgO(s) containing Calcium, Sulfur and Magnesium. For CT site they do not use fertilizer because of the nearness to Tano river which floods out once in a year. There is not any plan for the future, the land use will remain the same for both of the sites.

Rubber:

Both of the rubber plantation sites (RP_5 and RP_{10}) on Lower Birrimian were private land. The choice of planting rubber has been taken because it is one of the most gainful plantation and GREL company provides several incentives to farm this species. GREL indeed provides seedlings, workers and small loans to farm and weed, fertilizer for the first 3 years and assistance for pest and diseases with tree replacement. The management in rubber plantation is in general more intense and complicate than the other plantations. The rubber tree is mainly used for its rubber latex. For obtaining the latex, the bark of each tree of the plantation, starting at the age of 5-7, is cut (about 1,5 mm deep without damaging the cambium). This action known as tapping has to be done every day up to filling the box and by doing so opening the latex vessels in the bark, which are arranged in concentric cylinders and run in counter-clockwise spirals up the trunk. Only the basal part (1.3 m) of the trunk is tapped (most latex vessels develop here). Farmers daily renew the cut and by removing the bark and opening the latex vessels in the bark until the base of the trunk is reached. Then one continues with the other side of the trunk. Because the cambium synthesizes new bark and capillary vessels in which the latex is transported one can cut the tree again at breast height after 15 years (Janssens et al., 2003). Once the little box is full, they leave the latex to dry. They sell the dried latex to the GREL company. The income is divided by the workers, the family's farmer/owner and the GREL company to repay the loan. In the 5 years old plantation RP_5 they plan to have a future revenue of 174.2 € per month per hectare with costs amounting to 20.2 € per month per hectare. In 10 years old plantation the mean revenue amounts to 213.4 € per month per hectare.

Picture 7: Rubber tipping

Picture 8: Farmers selling dried latex

The mean monthly costs for workers for tapping and weeding activities amounts to 17.6 €. On Tertiary sands substrate, the 14 years old plantation (RP_{14} site) on a private land generates profits shared among the family components. The mean revenue is 102.3 € per month per hectare while the costs are 19.2 € per month per hectare. Also these plantations are supported by GREL company which is also the exclusive buyer of the latex. One of the oldest rubber plantations lays in an area deforested in 1960 (RP_{49}). The land belongs to Mpataba communities that bought the land from the government in 1996 and after sold to GREL company. Each village has its portion of the land where people work and the benefits are shared among the communities. The mean net income per month per hectare in this case is 101.0 €. According to what expressed by the owners/farmers of these lands none of the plantation will be replaced with other species.

Coconut:

Coconut plantations are common both on Lower Birrimian and Tertiary sands substrate as well as on the Recent sands substrate on the coastal line. Usually the coconut start producing at the age of 7-8 years and people collect seeds when these fallen down. The seeds are sold to local markets, Accra market or to a Nigerian company to be processed to obtain coconut oil. The work is commonly held by males and the net incomes are shared among the family components. The revenue varies if they sell directly oil or seed. For instance, on a 28 years old plantation site, the production of oil leads to a revenue of 44.2 € per month per hectare while the same yield of seeds, sold not processed, gives a monthly revenue amounting to 76.6 € per hectare. The costs for external workers amount to 16 € per month per hectare. In the site where the plantation was 44 years old, they sell to local market the peeled seeds and the revenue goes to the 5 brothers composing the family and working on the plantation. The mean monthly net income amounts to 62.4 € per hectare. The 15 years old plantation is held by a woman (Cecilia Okran-Esuah) who shares the incomes among her 8 children. The costs in this plantation are zero because all the family works on it. The mean monthly net income amounts to 63.1 € per hectare. In the 50 years old plantation site, the incomes go only to the head of the family who decide the way to share the amount among the components (two wives and 13 children). The mean monthly revenue is 50.7 € per hectare and the cost are 18 € per hectare per month. The older

coconut plantation is CN_{100}, deforested more than 100 years ago. The seed production is sold to the local market or to the Nigerian company: The mean monthly revenue is 41.6 € per hectare and the costs are 16.6 € per month per ha.

Mixed plantation:

Mixed plantations are common in the Jomoro District's Lower Birrimian substrate and the species composition is really sundry. The revenue generated by this kind of plantation depends above all on the choice of the species. As previously anticipated, the more frequent species are coconut, oil palm and banana. Commonly these kind of plantation are established for satisfying family needs but sometimes these are sufficient to sell some of the production (oil palm and coconut seeds) to be processed (for obtaining palm oil and coconut oil) to further sell to the local market. For the 49 years plantation (coconut 22.2%, oil palm 33.3% and banana 44.5%) the mean monthly revenue amounts to 42.1 € and the land is managed by the family components without external helps. Different revenue comes from a land deforested in 1973 with a 36 years plantation (mainly coconut 60% and oil palm 40%). In this case the revenue amount is more than doubled compared to the previous one. It is in fact a revenue of 88.6 € and the mean monthly costs to weed are 8.9 €.

8 Discussions

8.1 Granite

On Granite substrate, the deforestation leads to a change in terms of carbon stock in both secondary forest and oil palm plantation even if with different trends. Regarding the soil carbon stock variations, it is well known that forest soils may lose a considerable part of their soil organic matter (and thus soil organic carbon) content after converted to agricultural land (Hassink and Whitmore, 1997; Van Noordwijk et al., 2000). Solomon et al. (2002) and Sombroek et al. (1993) reported a decline in the SOC stock of 52% and from 20-50%, respectively, after forest clearing and continuous low input cropping, and this case is not an exception. There is in fact a significant decrease (38.6% after 25 years) in the first 10 cm replacing the forest with oil palm plantation. On the contrary, the decrease is not significant in the other depths (10-20, 20-30) although at 1 meter depth, already after 10 years from deforestation the soil organic carbon loss results to be significant, 55.8 % of that currently present in the corresponding primary forest. This do not happens in the same way when the forest land is replaced by secondary forest. Although the soil organic carbon stock decrease significantly only in the first 10 cm depth, similarly to the oil palm plantation, a different behavior is showed at 1 m depth, even if not statistically significant. This fact confirms the findings of Ramankutty et al. (2007) that if the land is abandoned and the forest regrows, the soil carbon stock can build up again back to the original level although taking several decades to achieve a new equilibrium.

Taking into consideration the aboveground carbon stocks dynamics, for the oil palm plantation, the Cmax (20 years) aboveground carbon stock is 63.4 ± 16.1 Mg C ha^{-1}, it is similar to what estimated by Germer and Sauerborn (2008) with the same time average method (60 ± 20 Mg C ha^{-1}). Comparing the Cavg aboveground C stock of the oil palm's rotation time of 20 years, (which results to be 30.0 ± 8.5 Mg C ha^{-1}) to the mean forest aboveground C stock of 154.2 ±16.2 Mg C ha^{-1} by Gineste et al. (2008) results indicate a loss in terms of C stock amounting to 124 Mg C ha^{-1}, almost the 80.5% of the original C stock. Considering the secondary forest, the behavior is opposite, the C stock of 146.9 ± 5.9 Mg C ha^{-1} results to be not significantly different compared to the carbon stock value of the original forest after 20 years from its clearance, confirming aboveground carbon can re-accumulate if the land is abandoned and allowed to regrow back into a forest (Ramankutty et al. 2007).

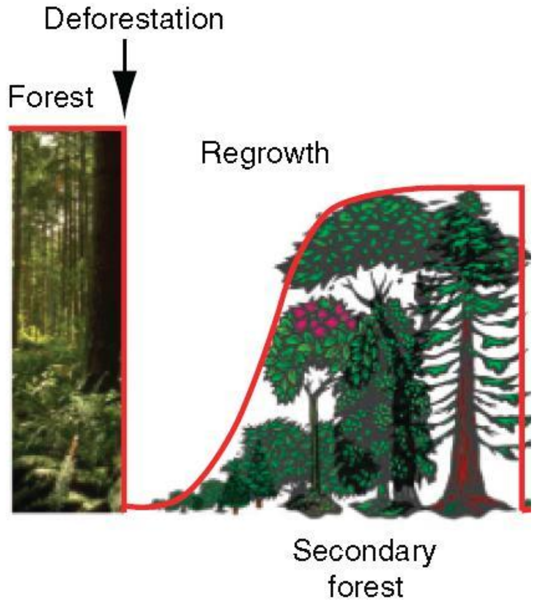

Figure 35: Carbon dynamics following deforestation. (Source: Ramankutty et al. 2007).

Regarding the belowground carbon stocks, the changes show the same trend of the aboveground carbon stocks. Specifically the 68.3% of the initial carbon stock is lost after conversion of forestland to oil palm plantation while it almost returns to the original stock value of 40.4 ± 5.2 Mg C ha^{-1} after 21 of secondary forest (38.2 ± 1.5 Mg C ha^{-1}).

Litter carbon stock is also subject to a depletion passing from forest to other land uses but what can be underlined is that in this study case, the secondary forest at 21 years results to have a lower litter carbon stock than in the oil palm plantation at 25 years and this could be explained with the different kind of litter. If the forest litter carbon stock is 15 ± 9 Mg C ha^{-1}, the amount in the oil palm is 5.74 ± 3.16 Mg C ha^{-1}, while in secondary forest is only 2.9 ± 0.7 Mg C ha^{-1}.

8.2 *Lower Birrimian*

Lower Birrimian substrate presents various and more heterogeneous kind of land uses although the deforestation process produced the same effects in terms of loss respect the original forest's carbon stocks. For soil organic carbon stocks the significant decrement at 30 cm depth is evident for cocoa (61.3% after 120 year), rubber (36.2% after 10 years) and coconut (56.1% after 44 years), but not for mixed plantation that after 49 years has a significant decrease only at 10-20 cm depth (39.2%). The large decrement of rubber compared to cocoa plantation is confirmed also by other studies in Ghana on similar substrates and similar farming practices (no fertilizers and no manure). Duah-Yentumi et al (1998) found indeed at Kade that soil under 40-year-old rubber had significantly lower C content when compared with soils under virgin forest or 20-year-old cocoa. Studies on soil under 25 years old cocoa plantation in Western Region has been made by Isaac et al. (2005) and, the results are similar to what obtained in the present study (20.6 Mg C ha^{-1} at 0-10 cm depth of this study compared to 18.2 Mg C $ha^{-1\ at}$ 15 cm for Isaac et al.) although the plantation age is different.

Cocoa soil organic carbon stock to 1 m depth after 120 years from deforestation results in a decrease of 36.3% (54.9 Mg C ha^{-1}). The changes in SOC stock were no significantly different also in the rubber plantation after 10 years from deforestation and in the mixed plantation after 49 years of the same land use. Considering 1 m depth, the trend of SOC decrease in the coconut plantations is more evident. After 44 years from the deforestation the total decrease amount to 65.7% (99.4 Mg C ha^{-1}) of the original SOC stock.

The clearance of forestland in favor of cocoa plantation leads to a depletion in terms of aboveground carbon stock that after 120 years of cultivation is not still compensated. The loss after 120 year is 84.7%. None of the other land uses of this substrate is able to reach the level of C stock actually present in the forest: the rubber at 10 years loses 53.1%, the coconut plantation 70.6% at 44 years and the mixed plantation 44.4% at 49 years. Belowground C stock follows the trend of the aboveground and decrease of 84.6% at 120 years old plantation passing from to 31.2 ± 19.9 Mg C ha^{-1} to 4.8 ± 1.5 Mg C ha^{-1}. In the 10 years old rubber plantation the belowground carbon stock is 11.4 ± 2.5 Mg C ha^{-1}as a result of 63.5% of decrement whereas the 44 years old coconut plantation stores 7.1 ± 1.9 Mg C ha^{-1} with a depletion of 77.2%. The 49 years old mixed plantation has instead the 61.2% of belowground C less than the forest. Litter carbon stock in forest sites results to be 8.3± 4.6 Mg C ha^{-1} and neither the 120 years cocoa (3.9 ± 0.6 Mg C ha^{-1}) nor the 10 years rubber (4.5 ± 1.3 Mg C ha^{-1}) result to stock that amount. Litter layer was never present in any of the coconut and mixed plantation sites investigated because regularly removed for other uses (fuelwood, fodder and other domestic uses).

8.3 Tertiary sands

On Tertiary sands the clearance of forest generated a statistically significant loss of SOC at 30 cm and 1 m, both in rubber plantation and in coconut plantation. The 30.1% of SOC has been lost in observed in the top 30 cm of the rubber plantation after 49 years from deforestation, while the 39.7% in the same depth of the coconut plantation after100 years from deforestation. The dynamic of SOC socks in the first 30 cm depth is similar for rubber and coconut. The decrease is significant only in the depth 0-10 and 10-20 cm, as observed also by Sombroek et al. (1993) who observed, after a forest clearing, a decrease in SOC stock from 20 to 50% in the upper soil layers, but little at depth. But on Tertiary sands the reduction of soil organic carbon stock to 1 m depth is significant with a loss of 44.9% after 49 years of rubber cultivation and 39.0% in after 100 years of coconut cultivation. Regarding the aboveground C stock, forest one's was estimated to be 240.2 ± 57.9 Mg C ha^{-1} and is was subject to a depletion less evident in rubber plantation than in coconut plantation. In fact, after only 49 years from rubber establishment, the aboveground carbon stock has been re-accumulated up to 214.5 ± 47.7 Mg C ha^{-1}, only 10.7% of the original forest value. For the coconut plantation after 100 years from forest clearance the loss result to be 82.8% of the original forest value, decreasing the SOC stock from 214.5 ± 47.7 to 41.3 ± 9.3 Mg C ha^{-1}. This marked difference between the two plantations is due to the different characteristics and structure of rubber and coconut, both in terms of tree density per ha and for single tree morphology, which leads to a different potential C stock. The belowground carbon stock has the same dynamic of the aboveground with the 31.3% of loss due to rubber establishment and the 86.7% for the 100 years coconut plantation. Regarding the stock on litter layer, the forest and the rubber plantation have similar amounts, 2.5 ± 0.5 Mg C ha^{-1} in the forest and 2.9 ± 0.8 Mg C ha^{-1}in the 49 years rubber plantation. Litter under coconut stand was never found.

The total carbon stocks investigated in Jomoro District are summarized in the Figure 36 and Figure 37 here below.

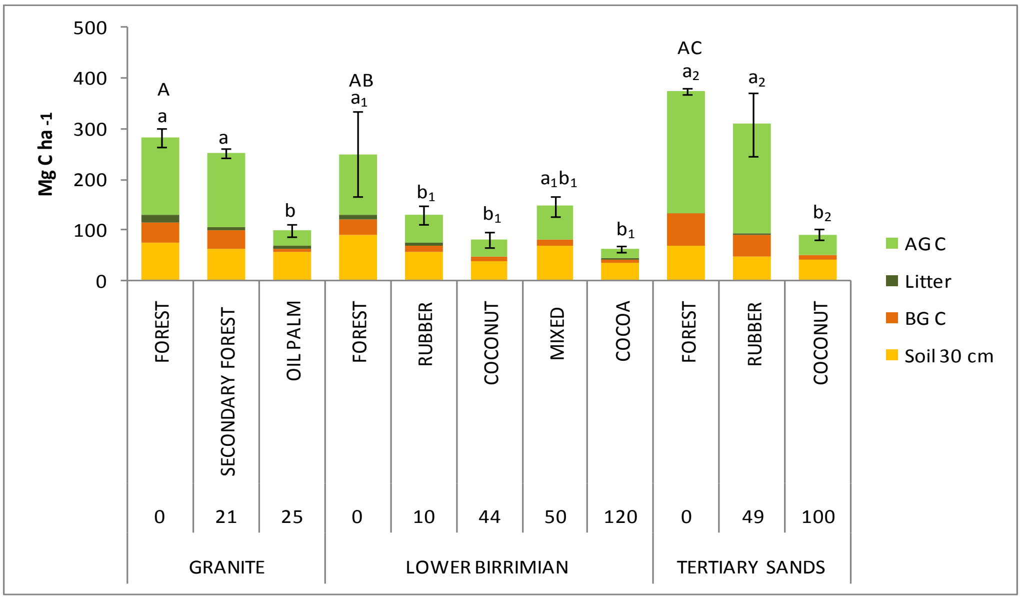

Figure 36: Total carbon stocks (soil C stock at 30 cm depth) per single land use on each substrate

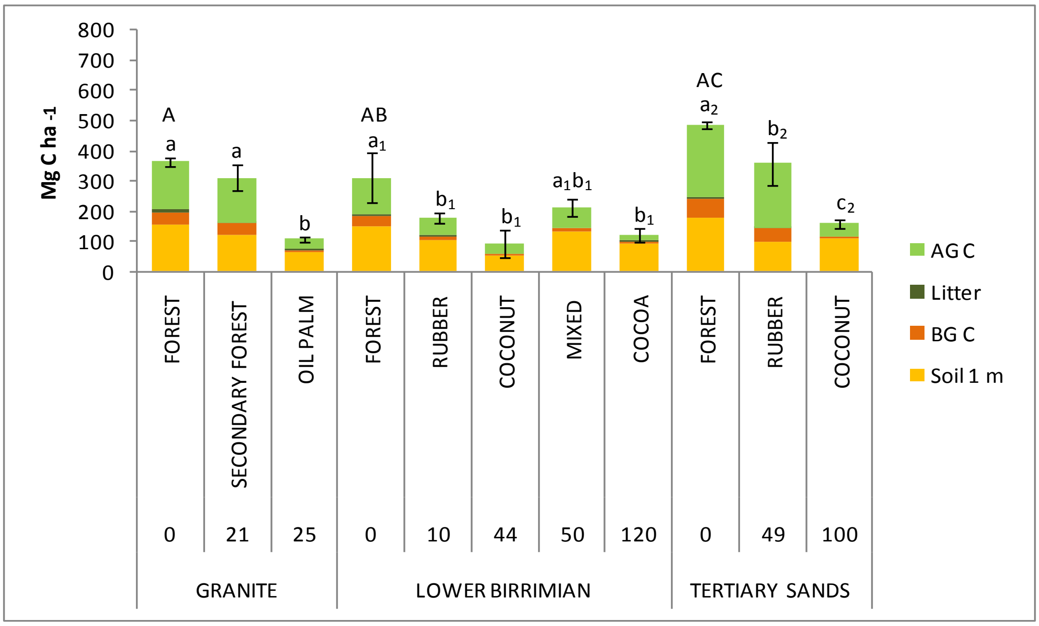

Figure 37: Total carbon stocks (soil C stock at 1 m depth) per single land use on each substrate

The total forest carbon stock results the higher value in all the substrates compared to the other land uses and there is a statistically significant difference only between Lower Birrimian and Tertiary sands’ forests both considering the soil carbon stock of 1 m and 30 cm.

Rubber plantation on Tertiary sands results to re-accumulate the total carbon stock almost reaching the forest value but this is true only considering the stock with soil up to 30 cm depth. It is in fact statistically significant different from the total value of forest if considering the total stock with 1m depth of SOC. Secondary forest on Granite has instead reaches almost the same stock of forest both considering the 30 cm and 1 m. All the other land uses compared to their forest reference value result to lose in terms of total carbon stock (both referring to total stock 30 cm depth SOC and 1 m SOC). The only exception is the mixed plantation but this could be the results of a different use of the plantation residues that are often reintegrate in the soil layer.

Considering the total carbon stocks from an economic point of view, it results that there is no convenience for local people to avoid deforestation in favor of REDD+ option.

Table 35: Financial aspects of deforestation

Substrate	Land use	Age	Total stock (30 cm soil depth) Mg C ha^{-1}	Total loss Mg C	Mean annual loss CO_{2e}[57]	Net incomes from plantations € ha^{-1} $year^{-1}$	Revenue from REDD+[58] € ha^{-1} $year^{-1}$
Granite	**Forest**		**283.04**				
	Secondary forest	21	**250.86**	**32.18**	**5.62**	**-**	**61.8**
	Oil palm	25	**99.05**	**183.99**	**26.99**	**112.2**	**296.8**
Lower Birrimian	**Forest**		**250.43**				
	Rubber	10	**130.18**	**120.25**	**44.09**	**2349.8**	**485.02**
	Coconut	44	**82.30**	**168.13**	**14.01**	**749**	**154.12**
	Mixed	50	**147.79**	**102.64**	**7.53**	**505.0**	**82.79**
	Cocoa	120	**62.12**	**188.31**	**5.75**	**1493.2**	**63.29**
Recent sands	**Forest**		**373.87**				
	Rubber	49	**308.63**	**65.24**	**4.88**	**1212**	**53.70**
	Coconut	100	**91.13**	**282.74**	**10.37**	**299.3**	**114.04**

The annual net incomes generated by different plantation are in fact more attractive than what could be generated protecting forest from deforestation under REDD+ activity. The only option could be the oil palm plantation but it is not particularly relevant choice considering the early age of the plantation and thus the relative low income at the first

[57] 1 Mg CO_{2e}corresponds to 1Mg C multiplied by 44/12

[58] Price of 1Mg CO_{2e} = 11 Euros http://www.carbonpositive.net/viewarticle.aspx?articleID=2230

stage. The estimates are furthermore optimistic considering that no transaction costs are included in the estimate and that has been considered a medium-high price of CO_2e[59]. In addition should be considered other negative aspects that could undermine the REDD+ convenience for local people such as the land tenure conflicts and the unclear benefit sharing.

9 Conclusions

The study of the changes in the different C pools due to deforestation, indicates a substantial loss of C in all the cases. Only the secondary forest appears as the only vegetation type able to recover C lost during deforestation process. Rubber on Tertiary sands also revealed to re-accumulate carbon, reaching the original forest total carbon stock (TCS is the sum of aboveground, litter, belowground and SOC), but only when considering the upper 30 cm of mineral soil, while it has not the same trend if considering the total stock down to 1 m depth (Figure 36, Figure 37). This evidences the importance in considering soil profile information to detect soil carbon losses that otherwise will be not been detected. Oil palm, coconut (both on Lower Birrimian and on Tertiary sands substrates) and cocoa plantations result to lead to a decrease in TCS (considering soil both in the case of 30 cm and 1 m depth). Hence, this study indicates that avoiding deforestation could notably help to preserve the carbon present in the different pools and consequently maintain soil fertility, protect biodiversity and all the positive aspects related to forest preservation. At the same time this study underlines the contradictions of a mechanism (REDD+) which asks to avoid deforestation against a very small financial incentive. The evidence is revealed in this study in the case of secondary forest, which could be considered the winning option in terms of carbon stock re-accumulation and it could be obvious to think that after a deforestation process, this type of land use should be preserved but this is not a sustainable option. Secondary forest is in fact the only land use which does not produce income or even services for local population except for some sporadic hunting activity. The future of secondary forests will be again the deforestation in favor to more gainful plantation. A critical challenge to REDD+ is the establishment of rubber and cocoa plantations which are very profitable in

[59] The common price of CO_{2e} is usually lower , 4.7 Euros per Mg (source: Clément Chenost et al.2010)

the Jomoro District area and thus could lead to a higher pressure and consequently to the exploitation of forested areas. A policy which aims to avoid deforestation should also guarantee a more convenient option for local population. If planting cocoa and rubber produce an income more than 5 times higher the one produced by REDD+, it is evident that this latter option will be not winning. Unfortunately dealing with carbon do not always means dealing with people. Beyond the value of forests for climate regulation and the market value of forest products there is also an intrinsic value of forest ecosystems and biodiversity, which is relevant for local people and humankind at large (Alcamo, 2003). An equal participation of local communities in the development of strategies for REDD requires more attention in order to develop locally accepted strategies that take into account the needs and rights of forest dependent people (Kowero, 2009). Financial incentives can support efforts for tropical forest conservation and reward sustainable forest management but, if carbon prices are too low to provide sufficient monetary incentives for forest conservation, other land uses such as the production of cash crops/plantations are likely to out-compete strategies for REDD (OECD/FAO, 2007; Spracken et al., 2008 and Butler et al., 2009). The financial incentives that are planned to be available under the REDD+ mechanism should be comparable to incentives from other land-use options; otherwise clearing of natural forests for land use with high financial returns could not be prevented. Carbon sequestration for Africa represents an opportunity to fund sustainable development but needs adequate financial inflows.

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14 Annex I

14.1 Brief story of cocoa in Ghana

Cocoa is not indigenous specie and it took a long and intricate way to reach Ghana. Cocoa, *Theobroma cacao*, L. is a originated from around the headwaters of the Amazon in South America. Large-scale cultivation of cocoa was started by the Spanish in the 16th century in Central America. It spread to the British, French and Dutch West Indies (Jamaica, Martinique and Surinarn) in the 17th century and to Brazil in the 18th century. From Brazil it was taken to SÃO Tome and Fernando Po (now part of Equatorial Guinea) in 1840; and from there to other parts of West Africa, notably the Gold Coast (now Ghana), Nigeria and the Ivory Coast. The available records indicate that Dutch missionaries planted cocoa in the coastal areas of the then Gold Coast as early as 1815, whilst in 1857 Basel missionaries also planted cocoa at Aburi. However, these did not result in the spread of cocoa cultivation until Tetteh Quarshie, a native of Osu, Accra, who had travelled to Fernando Po and worked there as a blacksmith, returned in 1879 with Amelonado cocoa pods and established a farm at Akwapim Mampong in the Eastern Region. Farmers bought pods from his farm to plant and cultivation spread from the Akwapim area to other parts of the Eastern Region. In 1886, Sir William Bradford Griffith, the Governor, also arranged for cocoa pods to be brought in from Sao Tome, from which seedlings were raised at Aburi Botanical Garden and distributed to farmers. In recognition of the contribution of cocoa to the development of Ghana, the government in 1947 established the Ghana Cocoa Board (COCOBOD) as the main government agency responsible for the development of the industry. Currently there are six cocoa growing areas namely Ashanti, Brong Ahafo, Eastern, Volta, Central and Western regions[60].

[60] http://www.cocobod.gh/history.php

14.2 Brief story of rubber in Ghana

In the 1893, Hevea brasiliensis (Willd.,Muell.-Arg.) was sent to Ghana at Aburi botanical gardens from Kew Gardens (London). The first rubber estate in Ghana was located at Offin River. Local farmers and European planters were provided with about 114.104 seedlings and more than a million seeds between 1904 and 1910. The Ghana Rubber Estate Limited (GREL) is now the only known producing company in Ghana (Burger & Smith, 1997). GREL started as a small private plantation established by R. T. Briscoe in 1957 at Dixcove with a plantation size of 923 hectares. The plantation was nationalized into Agricultural Development Corporation (ADC) in 1960 and later, State Farms Corporation in 1962. At that time, the rubber plantation had expanded to 36,390 hectares in Dixcove, Abura and Subri. The Ghana Government, in 1967, established a joint venture company with Firestone Tyre Company of USA to take over the rubber plantation. This joint venture company was Ghana Rubber Estates Limited (GREL). By then, the plantation had expanded to 39,390 hectares. GREL became wholly state-owned in 1980 when Firestone sold its shares in GREL to the Ghana Government. However, the Ghana Government entered into a financing agreement with the then Caisse Française de Development (CFD) now Agence Française de Development to rehabilitate and manage the company's rubber plantation and to build a new rubber processing plant at Apimenim. After the rehabilitation in 1996, the French management company, SIPH became the major shareholder of the company[61]. An integrated agriculture operation giant Rubber Plantations Limited is Ghana's second largest producer of rubber. Exotic horticulture being a labour intensive activity the company has been a major employer of people in West Akhim District in the Eastern Region of Ghana. It today has a workforce of about 800. Over 65% of the workforce comprises of women. RPG is part of Glamour group of companies one of the oldest business conglomerates in Ghana with business interests ranging from poultry, textiles, retail and consumer marketing, plastic and paper products and real estates[62].

[61] Available at : http://www.grelgh.com/

62 Source: http://www.rubberplantationghana.com/history.html

14.3 Brief story of Oil palm in Ghana

The Dutch were the first to introduce the plantation system in Ghana about the beginning of the eighteenth century. Dickson (1969) reports the establishment or attempted establishment of several Dutch plantations near the coast during the eighteenth and nineteenth centuries. Other plantations included those established by German, British, and other European interests about the end of the particularly after the passing of the Oil Palm Ordinance of 1913, when "Numerous oil-palm plantations [including those at Butre, Sese, and Winneba] were made" (Dickson 1969: 148). The Ordinance empowered the government to grant a mill operator the exclusive right to extract oil, by mechanical means, from the pericarp of palm fruits produced within 16 km of the mill. But the plantation system failed to gain a significant hold, partly because of the internal political insecurity engendered by inter-tribal warfare and by rivalry among the European powers seeking territorial hegemony, and also because of the negative attitude towards the system by the British Crown, which, from about 1850 onwards, gained the upper hand in the European struggle to colonize Ghana (Dickson 1969; Howard 1978). It appears that, despite pressure by external private commercial interests, plantations were not very much favoured by the dominant British colonial administration. This was partly because of the fear that, by dispossessing the owners of their land, the extensive land acquisitions necessary for the plantations would alienate the peasants, seriously disrupt their export production system, and precipitate local opposition of the kind provoked by the abortive Crown Lands Bill of 1894 and the Land Bill of 1897, which sought to vest in the British Crown all "waste" or unoccupied lands, forest lands, and minerals. Another reason was the conviction among British government advisers that the indigenous small-scale peasant farming system was more resilient economically than the exotic large plantations. Furthermore, the peasant system was considered to be a tried and inexpensive method of producing tropical export crops. The official ambivalence towards the plantation system had been reinforced by a decision much later against the system at a conference on the West African oil-palm industry in 1926 in Nigeria (Shepherd 1936; La-Anyane 1961, 1963; Johnson 1964; Usoro 1974; Udo 1982; Kotey 1990). Consequently, plantations did not make much impact on the environment and agricultural production during the colonial era in Ghana. The inability of peasant production to keep pace with the growing demand for palm oil and other agricultural products arose from the rapidly expanding population, the government's import-substitution policy, and its desire for accelerated socio-economic improvements. After 1957, during the post-independence period, there was a policy change involving greater emphasis on the plantation system centred on the oil-palm and rubber, *Hevea brasiliensis* (Ghana Office of the Planning Commission 1964; Ghana, Republic of, 1987; ILO 1989; Ministry of Agriculture 1990). The policy change, up to the time of the 1966 military coup d'etat, favoured state-owned and state-operated plantations. However, mainly because of capital constraints, political interference, poor planning, mismanagement, and the rigidity of the centralized state control system, these state-owned farms did not prove economically viable (Miracle and Seidman 1968). They succeeded only in worsening rural living conditions by dispossessing the peasants of their most fundamental natural resource, the land, with little or no compensation (Gyasi forthcoming), and by the deforestation and other forms of ecological and economic disturbance associated with the removal of natural vegetation to make room for monocultural plantations (Gyasi 1990). Subsequently, some of the state plantations were sold. Others were abandoned, sometimes after felling of the palms, a practice that invariably left behind derived savanna or even grass in place of the original forest cover, as in the case of Kwamoso, 60 km north-east of Accra. Attempts were made to reorganize the remaining plantations into viable economic units under decentralized state control. On the whole, however, the new policy, especially after the 1981 coup d'etat and the subsequent liberalization of the economic system, has sought to promote plantations through private enterprise, foreign aided government ventures, and joint government-private projects. The resultant plantations include the three major ones established by the government-owned but foreign-assisted Ghana Oil Palm Development Co. (GOPDC) located around Kwae; the government/privately owned Twifo Oil Palm Plantations Ltd. (TOPP) located around Twifo Praso/Ntafrewaso; and the government/privately owned Benso Oil Palm Plantations Ltd. (BOPP) located around Benso/Adum Banso. They were to grow oil-palms for the purpose of producing oil from the fruit of the palm, "probably the heaviest producer of vegetable fats" (Van Royen 1954: 166). This agro-industrial crop, which has a wide variety of uses, was a leading foreign exchange earner for Ghana, mainly on the basis of small-scale peasant production in an oil-palm belt near the littoral, from about the mid-nineteenth century to the beginnings of the twentieth century (Gyasi 1992a). The three major new palm plantations (GOPDC, TOPP, and BOPP), which have engaged my research attention since 1988, form the primary basis of the following discussion of the impact and sustainability of the plantation system in Sub-Saharan Africa. Managed on modern corporate agro-business lines, the plantations have been developed on land compulsorily acquired from peasants by the government in the humid tropical environment of the interior, which favours the oil-palm. In addition to developing the acquired areas into palm plantations, the companies involved were to encourage palm fruit production among the peasants in the plantation hinterland through the nuclear or nucleus estate system to help sustain their huge palm-oil-processing mills located inside the plantations[63].

[63] Source: http://www.wrm.org.uy/countries/Ghana/Gyasi_Oilpalm_Ghana.pdf

15 Annex 2

15.1 Soil profiles on Granite – Oil palm plantation

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: **OP$_8$** (1). (5° 46’ 30’’ N, 2° 26’ 59’’ W) – MAT: 4.5 °C - MAP: 1,110 mm – Slope: flat - Aspect: W – Land use: Oil Palm plantation - Stand age: 8 years - Understorey: virtually absent – Parent material: Pre-Cambian granite of the Cape Coast complex – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0 -4	7.5 YR 4/4	sl	2, vf - f, sbk	(d) so	(w) ps	2, f	A, S	
Bo1	4 - 48		l	2, vf - f, sbk	(d) sh	(w) ps	1, f - c	A, S	
Bo2	48 -100+	5 YR 4/6	l	1, f, sbk	(d) sh	(w) ps			
Locality: **OP$_8$** (2). (5° 46’ 32’’ N, 2° 26’ 58’’ W)									
A	0 -7	7.5 YR 4/4	sl	2, vf - f, sbk	(d) so	(w) ps	2, f	A, S	
Bo1	7 - 48		l	2, vf - f, sbk	(d) sh	(w) ps	1, f - c	A, S	
Bo2	48 -100+	5 YR 4/6	l	1, f, sbk	(d) sh	(w) ps			
Locality: **OP$_8$** (3). (5° 47’ 32’’ N, 2° 26’ 58’’ W)									
A	0 -5	7.5 YR 4/4	sl	2, vf - f, sbk	(d) so	(w) ps	2, f	A, S	
Bo1	5 - 45		l	2, vf - f, sbk	(d) sh	(w) ps	1, f - c	A, S	
Bo2	45 -100+	5 YR 4/6	l	1, f, sbk	(d) sh	(w) ps			
Locality: Ankasa old village **OP$_{25}$**(1). (5° 45’ 31’’ N, 2° 39’ 59’’ W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Oil Palm plantation – Stand age: 25 years – Understorey: virtually absent – Parent material: Pre-Cambian granite of the Cape Coast complex – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0-12	7.5 YR 4/4	sc	2, f, gr	(d) so	(w) po	2 f - m	C,W	
Bo	12-50		c	1, f-m, gr	(d) sh	(w) ps	1 f - m	A, S	
BoC	50-100+	5 YR 4/6	c	2, vf,gr	(d) h	(w) ps	1 m	A, S	
Locality: **OP$_{25}$**(2). (5° 45’ 31’’ N, 2° 39’ 57’’ W)									
A	0-4	7.5 YR 4/4	sc	2, vf - f, gr	(d) so	(w) ps	1 f - m	C,W	
Bo	4-53		sc	1, vf-f, gr	(d) sh	(w) ps	1 f - m	A, S	
C	53-100+	5 YR 4/6		m					
Locality**:** **OP$_{25}$**(3). (5° 45’ 32’’ N, 2° 39’ 56’’ W)									
A	0-8	7.5 YR 4/4	sc	2, vf - f, gr	(d) so	(w) ps	1 f - m	C,W	
Bo	8-42		sc	1, vf-f, gr	(d) sh	(w) ps	1 m	A, S	
C	42-100+	5 YR 4/6		m					

15.2 *Soil profiles on Granite – Secondary forest*

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: **SF$_{10}$** (1), (5° 40’ 4’’ N, 2° 31’ 42’’ W) – MAT: 4.5 °C - MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Secondary forest - Stand age: 10 years – Understorey: virtually absent under canopy – Parent material: Pre-Cambian granite of the Cape Coast complex – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0 -15	7.5 YR 4/4	sl	2, f, sbk	(d) so	(w) po	2, f -m		
Bo	15 - 55		sc	1, vf, sbk	(d) sh	(w) ps	1, f -m		
C	55-100+		sc	1, vf, sbk	(d) sh	(w) ps			
Locality: **SF$_{10}$** (2), (5° 40’ 3’’ N, 2° 31’ 42’’ W)									
A	0 -13	7.5 YR 4/4	sl	2, f, sbk	(d) so	(w) po	2, f -m		
Bo	13 - 53		sc	1, vf, sbk	(d) sh	(w) ps	1, f -m		
C	53-100+		sc	1, vf, sbk	(d) sh	(w) ps			
Locality: **SF$_{10}$** (3), (5° 40’ 2’’ N, 2° 31’ 43’’ W)									
A	0 -8	7.5 YR 4/4	sl	2, f, sbk	(d) so	(w) po	2, f -m		
Bo	8 - 52		sc	1, vf, sbk	(d) sh	(w) ps	1, f -m		
C	52-100+		sc	1, vf, sbk	(d) sh	(w) ps			
Locality: French man village **SF$_{21}$**(1), (5° 45’ 1’’ N, 2° 38’ 28’’ W) – MAT: 4.5 °C - MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Secondary forest – Stand age: 22 years – Understorey: virtually absent under canopy – Parent material: Pre-Cambian granite of the Cape Coast complex – Soil classification: Typic Hapludox (Soil Survey Staff, 2010)									
A	0 -2	7.5 YR 4/4	sc	2, f, sbk	(d) sh	(w) ps	2 vf - f	A, S	
Bo	2 - 14		c	1, f - m, sbk	(d) sh	(w) ps	1 f -m	A, S	
BoC	14 -100+	5 YR 4/6	c	1, f, sbk	(d) h	(w) ps			
Locality: **SF$_{21}$** (2), (5° 45’ 0’’ N, 2° 38’ 27’’ W)									
A	0 -2	7.5 YR 4/4	sl	2, f, sbk	(d) so	(w) ps	3, f	A, S	
Bo	2 -11		c	1, f - m, sbk	(d) h	(w) ps	2, f - m	A, S	
BoC	11 -100+	5 YR 4/6	c	1, f, sbk	(d) h	(w) ps	1, f		
Locality: **SF$_{21}$(**3), (5° 45’ 2’’ N, 2° 38’ 26’’ W)									
A	0 -9	7.5 YR 4/4	l	2, f, sbk	(d) so	(w) ps	2 f - m	A, S	
Bo	9 - 60		cl	1, f, sbk	(d) sh	(w) ps	1 f	A, S	
C	60 -100+	5 YR 4/6		m					

15.3 Soil profiles on Lower Birrimian – Primary forest

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: Cocotown Primary forest CTF (1), (5° 53’ 9’’ N, 2° 27’ 11’’ W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: prymary forest – Understorey: virtually absent under canopy – Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A1	0 -12	7.5 YR 4/4	sc	3, f - m, sbk	(d) sh	(w) ps	3, vf - f	A, S	
Bo1	12 - 56		sc	2, m, sbk	(d) sh	(w) ps	2, m - c	A, S	
Bo2	56 -100+	5 YR 4/6	sc	1, f, sbk	(d) sh	(w) ps	1, c		
Locality: CTF (2), (5° 53’ 8’’ N, 2° 27’ 10’’ W)									
A	0 -5	7.5 YR 4/4	sc	3, vf - f, sbk	(d) so	(w) ps	2, f - m	A, S	
Bo1	5 -48		sc	1, f - m, sbk	(d) sh	(w) ps	1, f - c	A, S	
Bo2	48 -100+	5 YR 4/6	sc	1, f - m, sbk	(d) sh	(w) ps	1, f - c		
Locality: CTF (3), (5° 53’ 8’’ N, 2° 27’ 11’’ W)									
A	0 -8	7.5 YR 4/4	s	3, f - m, sbk	(d) so	(w) ps	3, vf - f	A, S	
Bo1	8 -50		sc	1, f, sbk	(d) sh	(w) ps	1, m, c	A, S	
Bo2	50 - 75	5 YR 4/6	sc	1, f, sbk	(d) sh	(w) ps	1, m, c		
Locality: Ankasa forest ANKF (1), (5° 46’ 60’’ N, 2° 23’ 7’’ W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Primary forest – Understorey: virtually absent under canopy – Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0 -5	7.5 YR 4/4	sl	2, f, sbk	(d) so	(w) po	3, vf - f	A, S	
Bo1	5 - 42		sl	2, f - m, sbk	(d) so	(w) ps	3, c	A, S	
Bo2	42 -100+	5 YR 4/6	c	2, f, sbk	(d) sh	(w) ps	1, c		
Locality: ANKF (2), (5° 46’ 59’’ N, 2° 23’ 6’’ W)									
A	0 -6	7.5 YR 4/4	sl	2, f, sbk	(d) so	(w) po	3, vf - f	A, S	
Bo1	6 - 47		sl	2, f - m, sbk	(d) so	(w) ps	3, c	A, S	
Bo2	47 -100+	5 YR 4/6	c	2, f, sbk	(d) sh	(w) ps	1, c		
Locality: ANKF (3), (5° 46’ 56’’ N, 2° 23’ 6’’ W)									
A	0 -6	7.5 YR 4/4	sl	2, f, sbk	(d) so	(w) po	3, vf - f	A, S	
Bo1	6 - 50		sl	2, f - m, sbk	(d) so	(w) ps	3, c	A, S	
Bo2	50 -100+	5 YR 4/6	c	2, f, sbk	(d) sh	(w) ps	1, c		

15.4 Soil profiles on Lower Birrimian – Cocoa

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: Kofy Gyaman CC_{34}(1), (5° 44’ 39’’ N, 2° 43’ 9’’ W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Cocoa plantation – Stand age: 34 years – Understorey: virtually absent under canopy – Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0-8	7.5 YR 4/4	sc	2, f-m, sbk	(d) so	(w) ps	3 vf, f - 1 co	C, S	
Bo	8-65	5 YR 4/6	c	2, f, sbk	(d) sh	(w) ps	1 m-c	A, S	
BoC	65-100+		c	1, vf, sbk	(d) h	(w) ps	1 m	A, S	
Locality: CC_{34}(2), (5° 44’ 47’’ N, 2° 43’ 8’’ W) - Landform: mountain flank - Slope: flat - Aspect: NE									
A	0-3	7.5 YR 4/4	sc	2, vf, sbk	(d) so	(w) ps	3 vf, m	C, S	
BoC	3-100+	5 YR 4/6	c	1, vf, sbk	(d) sh	(w) ps	1 m	A, S	
Locality: CC_{34}(3), (5° 44’ 47’’ N, 2° 43’ 4’’ W)									
A	0-2	7.5 YR 4/4	sc	2, vf-f, sbk	(d) so	(w) ps	2 vf, m	C, S	
Bo	2-40	5 YR 4/6	c	2, f-m, sbk	(d) sh	(w) ps	1 m	A, S	
BoC	40-100+		c	1, f, sbk	(d) sh	(w) ps	1 m	A, S	
Locality: Cocotown village CC_{120}(1), (5° 53’ 1’’ N, 2° 28’ 41’’ W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Mixed tree plantation – Stand age: 120 years – Understorey: virtually absent under canopy – Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0 -10	7.5 YR 4/4	s	1, vf, sbk	(d) so	(w) po	1, vf - f	A, S	
Bo1	10 - 65		sc	1, f, sbk	(d) so	(w) ps	1, f - m	A, S	
Bo2	65 -100+	5 YR 4/6	sc	1, f, sbk	(d) so	(w) ps	1, f - m		
Locality: CC_{120}(2), (5° 53’ 1’’ N, 2° 28’ 41’’ W)									
A	0 -10	7.5 YR 4/4	sl	3, f, sbk	(d) so	(w) po	3, f	A, S	
Bo1	10 -21		s	1, f - m, sbk	(d) sh	(w) ps	1, f	A, S	
Bo2	21 -100+	5 YR 4/6	s	1, f - m, sbk	(d) sh	(w) ps	1, f		
Locality: CC_{120}(3), (5° 44’ 47’’ N, 2° 43’ 4’’ W)									
A	0 -10	7.5 YR 4/4	sl	3, f, sbk	(d) so	(w) po	3, f	A, S	
Bo1	10 -50		s	1, f - m, sbk	(d) sh	(w) ps	1, f	A, S	
Bo2	50 -100+	5 YR 4/6	s	1, f - m, sbk	(d) sh	(w) ps	1, f		

15.5 *Soil profiles on Lower Birrimian – Rubber plantation*

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: RP_5 (1), (5° 41’ 13’’ N, 2° 31’ 36’’ W) - MAT: 4.5 °C - MAP: 1,110 mm – Slope: flat - Aspect: W - Land use: Rubber plantation - Stand age: 5 years - Understorey: virtually absent under canopy - Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox Soil Survey Staff, 2010)									
A	0 -20	7.5 YR 4/4	sc	2, f -m, sbk	(d) so	(w) ps	1, f -m		
Bo	20 - 100+		sc	1, vf -m, sbk	(d) sh	(w) ps	1, m		
Locality: RP_5 (2), (5° 41’ 15’’ N, 2° 31’ 39’’ W)									
A	0 -31	7.5 YR 4/4	sc	2, f -m, sbk	(d) so	(w) ps	1, f -m		
Bo	31 - 100+		sc	1, vf -m, sbk	(d) sh	(w) ps	1, m		
Locality: RP_5 (3), (5° 41’ 17’’ N, 2° 31’ 36’’ W)									
A	0 -12	7.5 YR 4/4	sc	2, f -m, sbk	(d) so	(w) ps	1, f -m		
Bo	12 - 100+		sc	1, vf -m, sbk	(d) sh	(w) ps	1, m		
Locality: RP_{10} (1), (5° 46’ 46’’ N, 2° 25’ 55’’ W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Rubber plantation - Stand age: 10 – Understorey: virtually absent under canopy - Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0 -6	7.5 YR 4/4	sic	2, f - m, sbk	(d) sh	(w) ps	2, f	A, S	
Bo1	6 - 37		sic	2, f, sbk	(d) sh	(w) ps	1, f - c	A, S	
Bo2	37 -100+	5 YR 4/6	sic	2, f, sbk	(d) sh	(w) ps	1, c		
Locality: RP_{10} (2), (5° 46’ 43’’ N, 2° 25’ 56’’ W)									
A	0 -12	7.5 YR 4/4	sic	2, f - m, sbk	(d) sh	(w) ps	2, f	A, S	
Bo1	12 - 40		sic	2, f, sbk	(d) sh	(w) ps	1, f - c	A, S	
Bo2	40 -100+	5 YR 4/6	sic	2, f, sbk	(d) sh	(w) ps	1, c		
Locality: RP_{10} (3), (5° 46’ 42’’ N, 2° 25’ 56’’ W)									
A	0 -12	7.5 YR 4/4	sic	2, f - m, sbk	(d) sh	(w) ps	2, f	A, S	
Bo1	12 - 37		sic	2, f, sbk	(d) sh	(w) ps	1, f - c	A, S	
Bo2	37 -100+	5 YR 4/6	sic	2, f, sbk	(d) sh	(w) ps	1, c		

15.6 *Soil profiles on Lower Birrimian – Coconut plantation* *(1/2)*

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: French man village CN_{21} (1), (5° 45' 57'' N, 2° 38' 29'' W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Coconut plantation – Stand age: 21 years – Understorey: virtually absent under canopy – Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0 -18	7.5 YR 4/4	sc	2, vf - f, sbk	(d) so	(w) ps	2 f - m	A, S	
Bo	8 -70		c	1, vf-f, sbk	(d) sh	(w) ps	1 m - c	A, S	
C	70 -100+	5 YR 4/6		m					
Locality: CN_{21} (2), (5° 45' 54'' N, 2° 38' 28'' W)									
A	0 -6	7.5 YR 4/4	sl	2, vf - f, sbk	(d) so	(w) ps	1 f - m	A, S	
Bo	6 -39		c	1, vf-f, sbk	(d) sh	(w) ps	1 m	A, S	
BoC	39 -100+	5 YR 4/6		m					
Locality: CN_{21} (3), (5° 45' 55'' N, 2° 38' 26'' W)									
A	0 -8	7.5 YR 4/4	sl	2, f, sbk	(d) so	(w) ps	2 f - m	A, S	
Bo	8 - 47		c	1, f-m, sbk	(d) h	(w) ps	1 f - m	A, S	
BoC	47 -100+	5 YR 4/6		m					
Locality: Ankasa entrance CN_{28} (1), (5° 43' 5'' N, 2° 23' 25'' W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Coconut plantation – Stand age: 28 years – Understorey: virtually absent under canopy – Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0 -10	7.5 YR 4/4	s	1, f, sbk	(d) so	(w) po	3, vf - f	A, S	
Bo1	10 - 43		s	3, f - m, sbk	(d) sh	(w) ps	1, vf - f	A, S	
Bo2	43 -100+	5 YR 4/6	c	2, f - m, sbk	(d) sh	(w) ps			
Locality: CN_{28} (2), (5° 43' 0'' N, 2° 23' 25'' W)									
A	0 -4	7.5 YR 4/4	s	2, vf - f, sbk	(d) so	(w) po	3, f - vf	A, S	
Bo1	4 -22		sc	2, f - m, sbk	(d) sh	(w) ps	1, m	A, S	
Bo2	22 -100+	5 YR 4/6	sc	1, f - m, sbk	(d) sh	(w) ps	1, m		
Locality: CN_{28} (3), (5° 43' 5'' N, 2° 23' 27'' W)									
A	0 -4	7.5 YR 4/4	s	3, f, sbk	(d) so	(w) ps	3, vf - f	A, S	
Bo1	4 -20		sc	3, vf -f, sbk	(d) sh	(w) ps	2, f - m	A, S	
Bo2	20 -100+	5 YR 4/6	sc	2, vf - f, sbk	(d) sh	(w) ps	1, m - c		

15.7 *Soil profiles on Lower Birrimian – Coconut plantation* *(2/2)*

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: CN_{44} (1), (5° 42' 10'' N, 2° 38' 31'' W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Coconut plantation - Stand age: 44 years – Understorey: virtually absent under canopy – Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0 -11	7.5 YR 4/4	s	2, f -m, sbk	(m) vf	(w) ps	2, f -m		
Bo	11 - 100		s	m	(m) vf	(w) ps	1, f -m		
Locality: CN_{44} (2), (5° 42' 6'' N, 2° 38' 32'' W)									
A	0 -20	7.5 YR 4/4	s	2, f -m, sbk	(m) vf	(w) ps	2, f -m		
Bo	20 - 100		s	m	(m) vf	(w) ps	1, f -m		
Locality: CN_{44} (3), (5° 42' 2'' N, 2° 38' 37'' W)									
A	0 -13	7.5 YR 4/4	sic	2, m, sbk	(m) fr	(w) ps	1, f -m		
Bo	13 - 45		sic	m	(m) fr	(w) ps	1, f -m		
C	45 -100+	5 YR 4/6		m					

15.8 *Soil profiles on Lower Birrimian – Mixed plantation*

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: MP_{36} (1), (5° 41' 8'' N, 2° 30' 15'' W) –MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Mixed plantation – Stand age: 36 years – Understorey: virtually absent under canopy – Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0 -18	7.5 YR 4/4	sc	2, f, sbk	(d) sh	(w) ps	2, f -m		
C	18 - 100+		sc	m					
Locality: MP_{36} (2), (5° 41' 9'' N, 2° 30' 13'' W)									
A	0 -14	7.5 YR 4/4	s	2, f, sbk	(d) so	(w) ps	2, f -m		
Bo	14 - 100+		c	1, m, sbk	(d) h	(w) ps			
Locality: MP_{36} (3), (5° 41' 11'' N, 2° 30' 11'' W)									
A	0 -16	7.5 YR 4/4	sc	2, f - m, sbk	(d) sh	(w) pos			
Bo	16 - 100+		c	1, f, sbk	(d) sh	(w) po			
Locality: Abudu Dodo village. MP_{49} (1), (5° 43' 11'' N, 2° 39' 16'' W) - MAT: 4.5 °C - MAP: 1,110 mm – Slope: flat - Aspect: W - Land use: Mixed tree plantation - Stand age: 49 years - Understorey: virtually absent under canopy - Parent material: phyllite of the Pre-Cambrian (Lower Birrimian) – Soil classification: Typic Hapludox (Soil Survey Staff, 2010).									
A	0 -4	7.5 YR 4/4	c	2, f - m, sbk	(d) sh	(w) ps	2, f - m	A, S	
Bo	4 - 23		c	1, f, sbk	(d) h	(w) ps	1, m	A, S	
C	23 -100+	5 YR 4/6		m					
Locality: MP_{49} (2), (5° 43' 12'' N, 2° 39' 18'' W)									
A	0 -10	7.5 YR 4/4	c	2, f - m, sbk	(d) sh	(w) ps	1, f	A, S	
Bo1	10 -21		c	1, f - m, sbk	(d) sh	(w) ps	1, f	A, S	
Bo2	21 -100+	5 YR 4/6	c	1, f, sbk	(d) sh	(w) ps	1, f		
C			m						
Locality: MP_{49} (3), (5° 43' 3'' N, 2° 39' 15'' W)									
A	0 -9	7.5 YR 4/4	c	2, f - m, sbk	(d) sh	(w) ps	3, f - m	A, S	
Bo1	9 -22		c	1, f - m, sbk	(d) sh	(w) ps	3, m	A, S	
Bo2	22 -100+	5 YR 4/6	c	1, f - m, sbk	(d) sh	(w) ps	1, m		
C			m						

15.9 Soil profiles on Tertiary sands – Primary forest

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: NANAFOREST (1), (5° 36' 38'' N, 2° 32' 1'' W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Coconut plantation –Understorey: virtually absent under canopy – Parent material: tertiary sands – Soil classification: Xeropsamments (Soil Survey Staff, 2010).									
A	0 -10	7.5 YR 4/4	s	2, f -m, sbk	(d) so	(w) po	3, f -m		
B	10 - 35		s	2, f -m, sbk	(d) sh	(w) po	3, f -m		
C	35-62		sc	1, vf, sbk	(d) sh	(w) ps			
C1	62-100+		sc	m					
Locality: NANAFOREST (2), (5° 35' 36'' N, 2° 32' 2'' W)									
A	0 -13	7.5 YR 4/4	sl	2, f, sbk	(d) so	(w) po	2, f -m		
B	13 - 53		sc	1, vf, sbk	(d) sh	(w) ps	1, f -m		
C	53-100+		sc	1, vf, sbk	(d) sh	(w) ps			
Locality: NANAFOREST (3) (5° 36' 37'' N, 2° 33' 2'' W)									
A	0 -8	7.5 YR 4/4	sl	2, f, sbk	(d) so	(w) po	2, f -m		
B	8 - 52		sc	1, vf, sbk	(d) sh	(w) ps	1, f -m		
C	52-100+		sc	1, vf, sbk	(d) sh	(w) ps			

15.10 *Soil profiles on Tertiary sands – Rubber plantation*

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: RP_{14} (1), (5° 36’ 42’’ N, 2° 32’ 20’’ W) – MAT: 4.5 °C - MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Rubber plantation – Stand age: 14 years - Understorey: virtually absent under canopy – Parent material: tertiary sands – Soil classification: Xeropsamments (Soil Survey Staff, 2010)									
A	0 -12	7.5 YR 4/4	s	2, f, sbk	(d) so	(w) po	2, f -m		
B	12 - 65		s	1, vf, sbk	(d) so	(w) po	1, f -m		
C	65-100+			m					
Locality: RP_{14} (2), (5° 36’ 36’’ N, 2° 32’ 17’’ W)									
A	0 -15	7.5 YR 4/4	s	2, f, sbk	(d) so	(w) po	2, f -m		
B	15 - 48		s	1, vf, sbk	(d) so	(w) po	1, f -m		
C	48-100+			m					
Locality: RP_{14} (3), (5° 36’ 40’’ N, 2° 32’ 18’’ W)									
A	0 -18	7.5 YR 4/4	s	2, f, sbk	(d) so	(w) po	2, f -m		
B	18 - 65		s	1, vf, sbk	(d) so	(w) po	1, f -m		
C	65-100+			m					
Locality: Mpataba village RP_{49} (1), (5° 38’ 21’’ N, 2° 36’ 48’’ W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Rabber plantation - Stand age: 49 years – Understorey: virtually absent under canopy – Parent material: tertiary sands – Soil classification: Xeropsamments (Soil Survey Staff, 2010).									
A	0 -3	7.5 YR 4/4	s	2, vf, gr	(d) so	(w) po	3 f - m	A, S	
B1	3 - 42		s	1, f , sbk	(d) so	(w) po	1 f -m - c	A, S	
B2	42 -100+	5 YR 4/6	sc	1, f - m, sbk	(d) sh	(w) ps			
Locality: RP_{49} (2), (5° 38’ 28’’ N, 2° 36’ 45’’ W)									
A	0 -4	7.5 YR 4/4	s	2, vf - f, gr	(d) so	(w) po	3, f - m	A, S	
B1	4 -49		s	1, f, sbk	(d) so	(w) po	1, f - m - c	A, S	
B2	49 -100+	5 YR 4/6	sc	1, f - m, sbk	(d) sh	(w) ps	1, f - m		
Locality: RP_{49} (3), (5° 39’ 32’’ N, 2° 36’ 49’’ W)									
A	0 -4	7.5 YR 4/4	s	2, f, gr	(d) so	(w) po	3 f - m	A, W	
B1	4 - 39		s	1, f, sbk	(d) so	(w) po	2 m	A, S	
B2	39 -100+	5 YR 4/6	sc	1, f - m, sbk	(d) sh	(w) ps	1, m - c		
C				m					

15.11 Soil profiles on Tertiary sands – Coconut plantation (1/2)

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: Nuba CN_{15} (1), (5° 36’ 30’’ N, 2° 24’ 43’’ W) –MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat - Aspect: W – Land use: Coconut Plantation - Stand age: 15 years – Understorey: virtually absent under canopy – Parent material: tertiary sands – Soil classification: Xeropsamments (Soil Survey Staff, 2010).									
A	0 -18	7.5 YR 4/4	s	2, f, sbk	(d) so	(w) po	3, f	A, S	
B1	18 - 50		s	2, f - m, sbk	(d) sh	(w) po	2, f -m	A, S	
B2	50 -100+	5 YR 4/6	c	2, f - m, sbk	(d) sh	(w) po	1, f -m		
Locality: CN_{15} (2), (5° 37’ 31’’ N, 2° 24’ 42’’ W)									
A	0 -20	7.5 YR 4/4	s	2, f, sbk	(d) so	(w) po	3, f	A, S	
B1	20 - 55		s	2, f - m, sbk	(d) sh	(w) po	2, f -m	A, S	
B2	55 -100+	5 YR 4/6	c	2, f - m, sbk	(d) sh	(w) po	1, f -m		
Locality: CN_{15} (3), (5° 37’ 30’’ N, 2° 24’ 41’’ W)									
A	0 -12	7.5 YR 4/4	s	2, f, sbk	(d) so	(w) po	3, f	A, S	
B1	12 - 46		s	2, f - m, sbk	(d) sh	(w) po	2, f -m	A, S	
B2	46 -100+	5 YR 4/6	c	2, f - m, sbk	(d) sh	(w) po	1, f -m		
Locality: CN_{50} (1), (5° 43’ 40’’ N, 2° 23’ 32’’ W) – MAT: 4.5 °C – MAP: 1,110 mm – Slope: flat – Aspect: W – Land use: Coconut plantation - Stand age: 50 years – Understorey: virtually absent – Parent material: tertiary sands – Soil classification: Xeropsamments (Soil Survey Staff, 2010).									
A	0 -20	7.5 YR 4/4	s	2, f, sbk	(d) so	(w) po	3, vf - f		
B	20 - 100		s	2, f, sbk	(d) sh	(w) po	1, f - m		
Locality: CN_{50} (2), (5° 43’ 42’’ N, 2° 23’ 48’’ W)									
A	0 -16	7.5 YR 4/4	s	2, f, sbk	(d) so	(w) po	3, vf - f	A, S	
B	16 - 100		s	2, f, sbk	(d) sh	(w) po	1, f - m	A, S	
Locality: CN_{50} (3), (5° 43’ 36’’ N, 2° 23’ 33’’ W)									
A	0 -4	7.5 YR 4/4	s	2, f, sbk	(d) so	(w) po	3, vf - f	A, S	
B1	4 - 35		s	2, f, sbk	(d) sh	(w) po	1, f - m	A, S	
B2	35 -100+	5 YR 4/6	sc	2, f, sbk	(d) sh	(w) ps	1, m - c		

15.12 Soil profiles on Tertiary sands – Coconut plantation (2/2)

Horizon	Depth (cm)	Color[a]	Texture[b]	Structure[c]	Consistence[d]	Plasticity[e]	Roots[f]	Boundary[g]	Comments
Locality: CN_{100} (1), (5° 31’ 17’’ N, 2° 36’ 29’’ W) - MAT: 4.5 °C - MAP: 1,110 mm – Slope: flat - Aspect: W - Land use: Coconut plantation - Stand age: + 100 years - Understorey: virtually absent under canopy - Parent material: lower birrimian – Soil classification: Xeropsamments (Soil Survey Staff, 2010).									
A	0 -5	7.5 YR 4/4	s	2, f - m, sbk	(d) so	(w) ps	3, vf - f	A, S	
B1	5 - 55		s	1, m, sbk	(d) so	(w) ps	1, f - m	A, S	
B2	55 -100+			m					
Locality: CN_{100} (2), (5° 27’ 8’’ N, 2° 36’ 29’’ W)									
A	0 -10	7.5 YR 4/4	s	2, f - m, sbk	(d) so	(w) ps	3, vf - f	A, S	
B1	10 - 50		s	1, m, sbk	(d) so	(w) ps	1, f - m	A, S	
B2	50 -100+			m					
Locality: CN_{100} (3), (5° 31’ 17’’ N, 2° 37’ 33’’ W)									
A	0 -5	7.5 YR 4/4	s	2, f - m, sbk	(d) so	(w) ps	3, vf - f	A, S	
B1	5 - 50		s	1, m, sbk	(d) so	(w) ps	1, f - m	A, S	
B2	50 -100+			m					

[a] moist and crushed, according to the Munsell Charts®
[b] sc = sandy–clay
[c] 1 = weak, 2 = moderate, f = fine, vf = very fine, gr = granular, sbk = subangular blocky
[d] l= dry, m = moist, fi = firm, fr = friable, h = hard, sh = slightly hard, vfr = very friable
[e]w = wet, po = non plastic, p = moderately plastic, vp = very plastic
[f] 1 = few, 3 = many, vf = very fine, co = coarse, m = medium, vc = very coarse
[g] a = abrupt, g = gradual, s = smooth, w = wavy