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KUMASI, GHANA

Land Use and its Management, Indigenous and Climate Smart Adaptation Strategies in Kloto  
District, (Togo, West Africa)

By

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A thesis submitted to the Department of Civil Engineering, Faculty of Civil and Geo-  
Engineering, College of Engineering, Kwame Nkrumah University of Science  
and Technology, Kumasi in partial fulfilment of the requirement for the degree of

DOCTOR OF PHILOSOPHY

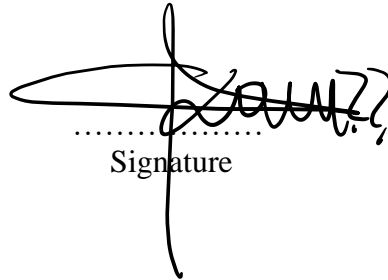
Climate Change and Land Use

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**DECLARATION**

I hereby declare that this submission is my own work towards the PhD in Climate Change and Land Use and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma at Kwame Nkrumah University of Science and Technology, Kumasi or any other educational institution, except where due acknowledgment is made in the thesis.

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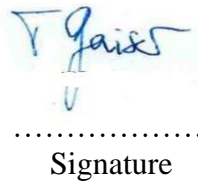


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## ABSTRACT

This study established firstly, forest reference level in terms of land area extent as well as area losses and gains through the transitions across forest, cocoa agroforestry, cassava, maize, settlement and other land uses in the Kloto district (Togo). The pixel-based classification was adopted and combined with the extended change matrix quantity and intensity analysis using three years within a 32-years period (1985–2017), and field datasets. Results indicated an active forest loss (19.5%) with dormant gain (0.8%). Forest is involved in most transitions as the most targeted category with the largest transition being from forest to cocoa agroforestry while, the lowest transitional change occurred from forest, cocoa agroforestry, maize, cassava and settlement to unclassified classes (e.g. road, water body) and vice versa. Other important transition categories were from forest to settlement, cassava and maize. Secondly, it investigated smallholder's climate change perception, proximate drivers of cropland and forest degradation for implementing climate smart agricultural systems. Net change analysis of land use was associated with quantitative analysis from participatory survey data with farmers and landowners. Results revealed, poor agricultural systems and cassava farming as major factors contributing to the alarming forest losses between 1985 and 2017. A significant net loss in forest cover of 23.6% and area losses under maize and cocoa agroforestry farming of 12.99% and 10.1% between 1985 and 2017 were observed, respectively. These significant losses are due to intensive cassava cropping (38.78%) and settlement expansion (7.87%). Based on participatory surveys, the majority of agricultural lands are threatened by erosion or physical deterioration (67.5%), land degradation and loss of micro/macro fauna and flora (56.7%), declines in soil fertility (32.5%) and soil water holding capacity (11.7%), and changes in soil texture (3.3%). Most farmers adhere to the proposed climate smart practices, with an emphasis on cost-effective drip irrigation systems (45.83%), soil mulching (35%), and the adoption of drought-resilient varieties (29.17%). Lastly, time series of land use transitions allowed for an assessment of soil organic carbon density (SOCD) gains, losses and emissions using matrix of land use change and point-based emission and removal estimators. Data were collected using land use transition experiment plots, slope gradient composite soil sampling methods across forest and agricultural lands within, the same soil unit and climatic zones. The analysis of variance ( $p=5\%$ ,  $F_{pr}<0.001$ ) revealed low SOCD ( $\text{MgCha}^{-1}$ ) under maize (54.33) and cassava (52.98) compared to cocoa agroforestry (169.52) and forest (189.34) plots. Based on land use change observed between 1985 and 2017, the transition of forest and cocoa agroforestry to cassava and maize depicted high carbon dioxide release of up to 100,059 and 74,192 for cassava and 5,342 and 5,227  $\text{MgCO}_2\text{eY}^{-1}$  for maize, respectively. Whereas the transition from maize to forest sequestered more carbon ( $1,423\text{MgCO}_2\text{eY}^{-1}$ ) compared to the transition from cocoa agroforestry and cassava to forest which, accounted for 626 and 404  $\text{MgCO}_2\text{eY}^{-1}$ , respectively. In terms of carbon release and sequestration over 32-year, results showed slightly higher carbon sequestration through the transition of cassava and maize to agroforestry than to forest. Significant losses were estimated for the transition from forest and cocoa agroforestry to maize and cassava mono-cropping. Results revealed mono-cropping of annual crops without residue return after forest or cocoa agroforestry transitions as main driver of soil carbon loss and  $\text{CO}_2\text{e}$  release. Consequently, site-specific integrated landscape management and dissemination of climate-smart agricultural practices like agroforestry are promising options to considerably reduce GHG emissions in Kloto District.

## TABLE OF CONTENTS

<b>DECLARATION</b>	ii
<b>ABSTRACT</b>	iii
<b>LIST OF TABLES</b>	vi
<b>LIST OF FIGURES</b>	vii
<b>LIST OF ABBREVIATIONS</b>	viii
<b>DEDICATION</b>	ix
<b>ACKNOWLEDGEMENTS</b>	x
<b>CHAPTER 1: GENERAL INTRODUCTION</b>	1
<b>1.1 Context and Justification</b>	1
<b>1.2 Problem Statement</b>	4
<b>1.3 Aims and Objectives</b>	6
<b>1.4 Study Area</b>	6
<b>1.5 Thesis Organization</b>	8
<b>CHAPTER 2: LITERATURE REVIEW</b>	9
<b>2.1 Review of Concepts</b>	9
2.1.1 Landmarks REDD+/ UNFCCC and REDD+ efforts in Togo	9
2.1.2 Climate Change, Forest Policies	14
2.1.3 Drivers of Deforestation and Forest Degradation	17
2.1.4 Land Use Land Use Change and Forestry	20
<b>2.2 Literature Review</b>	21
2.2.1 Land Use Transition and Intensity Analysis	21
2.2.2 Methods Used in Estimating Carbon-Stock Change	25
2.2.3 Soil Carbon Dynamics across Major Farming and Cropping Land Use System	33
2.2.4 Carbon Dioxide Emission and Removal from Forest Conversion	36
<b>CHAPTER 3: LAND USE AND ITS MANAGEMENT, INDIGENOUS AND CLIMATE SMART ADAPTATION STRATEGIES FROM FOREST SAVANNAH ZONES (TOGO)</b>	40
<b>3.1 Implications of some Major Human-Induced Activities on Forest Cover Using Extended Change Matrix Quantity and Intensity Analysis Based on Historical Landsat Data from the Klotu District, Togo</b>	40
Abstract	40

3.1.1	Introduction	41
3.1.2	Materials and Methods	43
3.1.3	Results and Discussion	47
3.1.4	Conclusion	55
<b>3.2</b>	<b>Remote Sensing-Based and Participatory Analysis of Forests, Agricultural Land Dynamics, and Potential Land Conservation Measures in Kloto District (Togo, West Africa)</b>	<b>57</b>
	Abstract	57
3.2.1	Introduction	58
3.2.2	Materials and Methods	61
3.2.3	Results and Discussion	64
3.2.4	Conclusion	71
<b>3.3</b>	<b>Land Use Change Matrix and Slope Gradient Soil Carbon and Carbon Dioxide Emission from Forest to Different Cropping Systems in Togo – West Africa</b>	<b>73</b>
	Abstract	73
3.3.1	Introduction	73
3.3.2	Materials and Methods	75
3.3.3	Results and Discussion	80
3.3.4	Conclusion	87
	<b>CHAPTER 4.0: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS</b>	<b>88</b>
4.1	Conclusion and Discussion	88
4.2	Conclusion and Recommendations	89
	<b>REFERENCES</b>	<b>91</b>

## LIST OF TABLES

Table 2. 1: Pertinent Land Use Intensity studies per agro ecological zones	24
Table 2. 2: Allometric models based on rainfall regimes	30
Table 2. 3: List of tested allometric models	31
Table 3. 1: Change matrix from 1985 to 2017 in the percentage of the map	47
Table 3. 2: Gain, loss, persistence, total change, net change and swap change per category	48
Table 3. 3: Definition of the land use/land cover types used in this study	62
Table 3. 4: Areal distribution of land use/land cover types in 1985, 2002, and 2017	64
Table 3. 5: Matrix of Land use land cover changes (ha) from 1985 to 2017	77

## LIST OF FIGURES

Figure 1. 1: Study Area	7
Figure 2. 1: Steps of REDD+ Implementation	11
Figure 2. 2: Flowchart of SOC study across LUS	27
Figure 2. 3: Sampling Unit from farming systems (A) and forested zones (B)	28
3. 1: Land use land cover map of the study area	45
Figure 3. 2: Quantity of land use transition	48
Figure 3. 3: Gain and Loss intensity per category in percentage	49
Figure 3. 4: Land use land cover intensity of transitions expressed as (a) Forest, (b) Cocoa agroforestry, (c) Maize, (d) Cassava and (e) Settlement	52
Figure 3. 5: Kloto district, with select villages marked	61
Figure 3. 6: Maps of historical land use/land cover types in 1985, 2002, and 2017	65
Figure 3. 7: Net land use/land cover changes during the periods 1985–2002 (A); 2002–2017 (B); and 1985–2017 (C)	66
Figure 3. 8: (a) Expressed willingness to adopt soil and water conservation practices. (b) Expressed willingness to adopt improved water management and harvesting techniques	69
Figure 3. 9: Study area with sampling locations	76
Figure 3. 10: Soil organic carbon density ( $\text{MgCha}^{-1}\text{y}^{-1}$ ) in 0-30 cm soil depth across land use systems	81
Figure 3. 11: Carbon emission/removal factors from land use/land cover changes assuming a period of 32 years to reach steady-state conditions	83
Figure 3. 12: Temporal land use land cover transition of carbon gain/loss takes 32 years to reach steady-state conditions	84
Figure 3. 13: Temporal land use land cover transition of carbon dioxide removal/emission equivalent takes 32 years to reach steady-state conditions	85

## LIST OF ABBREVIATIONS

Symbol	Definition
Pg	Pentagramme
C	Carbon
t	Tonnes
Mg	Megagramme
ha	Hectare
yr	Year
CO <sub>2e</sub>	Carbon dioxide equivalent
GHG	Greenhouse gas
Gt	Giga tonnes
Gg	Gigagramme
LULUC	Land Use Land Cover Change
LULUCF	Land Use Land Use Change and Forestry
LUS	Land Use System
EF	Emission Factor
AD	Activity Data

## DEDICATION

To my:

*Beloved, Afi D. Assogba and lovely kids.....*

*Father, Koglo K. A. Simon*

*Mother, Awuve Akuvi*

*Brothers, Koglo Komi Eric and Koglo Kossi Joseph*

*In-laws, Assogba K. H. and Nyawuame Yawavi*

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## CHAPTER 1: GENERAL INTRODUCTION

### 1.1 Context and Justification

Contribution of agriculture, forestry and other land use (AFOLU) to greenhouse gas emissions is significant in this era of climate change (Smith & Conen, 2004; Janzen, 2005; Smith *et al.*, 2008; IPCC, 2014). Land cover change from forest to mono-cropping (e.g., cereals or perennial cash crops) leads to land degradation with associated soil carbon losses, carbon dioxide emissions and productivity decline (Fearnside, 2000). Venterea *et al.* (2005); Ussiri *et al.* (2006) and Varughese (2011) reported that, slash and burn agriculture as well as the traditional fallow systems in Africa will negatively impact the climate system and experience huge decline in crop productivity due to land degradation. The traditional low-input agriculture is responsible for soil degradation, and depletion of carbon stocks, which is a key determinant of food security and environmental co-benefits (Lal, 2008a,b). According to available statistics and existing studies (e.g., Denman *et al.*, 2007; Lal, 2008a,b; Stockmann *et al.*, 2013) agriculture contributes 14% of global total GHG emission; and agriculture and deforestation together emit a third of global GHG.

In Togo, inventory of greenhouse gases from agriculture and other sectors started in 1995 as benchmark. Agriculture sector emissions in terms of global warming potential: CO<sub>2</sub>-equivalent (CO<sub>2</sub>-e) was 3278.87 Gg (1Gg = 1,000,000,000 g) equivalent to 13% total GHGs emitted (MERF, 2001). Methane emission measured in Gg recorded from enteric fermentation (15.53), savannah burning (8.23), compost management (1.63), crop residues burning (1.17) and rice cultivation (0.41). On the other hand, Nitrous Oxide measured Gg was significant from croplands management (8.62) with trace amounts recorded under compost management (0.0001), crop residue burning (0.034) and savannah burning (0.09) (MERF, 2001). A close analysis of direct

GHGs of each sector in 2005 revealed significant release from Land Use Change (i.e. forest to agriculture lands) and agriculture schemes followed by energy, industry and waste management sector: 8329.28 Gg CO<sub>2</sub>-e (62.88%), 2720.89 (20.54%), 1714.68 (12.94 %), 312.57 (2.36 %) and 169.9 (1.28%), respectively. Total emission was 13,249.76 Gg CO<sub>2</sub>-e with 68, 11.5 and 20.5 % carbon dioxide, methane and nitrous oxide, respectively.

High emissions (in Gg; %) have been documented from croplands (2107 Gg; 77.48%) due to an excessive use of chemicals and land mismanagement. Second source of emission was recorded from enteric fermentation (431; 15.86) followed by compost management (81.40; 2.99), residues burning (51.82; 1.91), grass savannah burning (38.08; 1.40) and finally rice fields (9.62; 0.35) (MERF, 2010; 2015). By simple analogy, forest conversion to agriculture and associated activities have had an important share in greenhouse gas emissions to the atmosphere since 1995. Relevant information exists regarding the emission level by main sectors. Meanwhile, some relevant questions still remain unanswered and necessitate rigorous scientific investigations. This crucial step is paramount for the implementation of precautionary measures to mitigate the emissions resulting from deforestation and degradation caused by human activities.

Questions such as: allocation of the change and emissions level across various land use and land cover (spatial distribution of the change and carbon losses); potential removal (sequestration) or release (emissions) of each category as well as the contribution of implemented and adopted smart climate change and land use practices effect on the native soil carbon dynamics and current and future crop production needs to be addressed. Compared to Malaysia, Indonesia, USA and some countries in Africa which, have undertaken scientific investigations on the distribution of soil carbon across land uses and the level of forests conversion into others land uses with their related carbon dioxide emissions (Villamor *et al.*, 2014; Aga Alo *et al.*, 2008; Aldwaik & Pontius, 2012)

little information exists regarding the quantity and allocation of the change in forest lands induced by human activities to agriculture expansions at local and national level in Togo. This is fundamental in laying out policies and measures to anticipate subsequent changes and also mitigate the changes. As mentioned earlier, literature is also replete on works related to quantity and allocation of the change as well as the speed of change of land use land types between the time intervals, categories which are active or dormant during the change and categories which are targeted or avoided during the transition. This kind of analysis is known as size and intensity analysis (e.g., Villamor *et al.*, 2014; Aga Alo *et al.*, 2008; Aldwaik & Pontius, 2012).

However, little is known on the contribution of each category at sub-stratum level. Simply put, conversion of forest land to plantations and agriculture lands is known in size and intensity that is concomitant to carbon emissions or removals at category level. Meanwhile, extent at sub category levels (e.g. for various cropping systems) with their related gains and losses in soil carbon are not well understood. Besides, carbon emissions/removals from rice field is likely to be different from another type of food crops (e.g., cassava, maize) similarly to cash crops (e.g. open and shaded cocoa plantations) due to the diversity in the cropping systems. From this foregoing analysis, wall-to-wall transition analyses are ways to explore and determine the contribution of systems and their implications on the carbon cycle regulations.

Moreover, estimation of carbon emissions/removals is either at global or national level due to the generic emission/removal factor developed by the Intergovernmental Panel on Climate Change (IPCC, 2006). Whereas, the level of carbon stock is climate, plant, soil and land management dependent, and using the default values for the computation of carbon emission or removal due to forest conversion and degradation, will create uncertainties and errors. This will therefore, lead to underestimating or overestimating carbon-stock change and gain-loss during monitoring reporting

and verification (MRV) for reducing emissions from deforestation and forests degradation (REDD<sup>+</sup>) projects. For recall, “+” aims at conservation of forest carbon stocks, sustainable management of forests and enhancement of forest carbon stock through afforestation, reforestation and monitoring of existing forest assets. Meaning that, measurements must be accurate, transparent, consistent and comparable.

As such, this study aims to bridge these gaps and draw a road map for policy actions regarding sustainable land use management and planning in Plateau region, Togo. The following questions will be addressed: To what extent do the changes of native forests to maize, cassava and cocoa plantations alter soil carbon dynamics (removal and release)? What is the speed of change (fast or slow) in land use transition (e.g., forest to maize farming)? What are the dormant or active categories? What group of categories are avoided or targeted? What are the causes of rampant deforestation and forest degradation in the study area? These questions lead to the following hypothesis: (i): changes in land use, over time may influence soil carbon gains or losses. (ii): Changes in cropping and farming systems after forest conversion may affect the speed of deforestation, SOC balance, CO<sub>2</sub> and yields.

## **1.2 Problem Statement**

In Togo, agriculture is the main primary economic activity. It provides about 40% of the gross domestic product (GDP) and employs 70% of the active rural population. The Plateau region (Forest area, zone IV) is the centre of agriculture activity in Togo and employs up to 1,161,580 persons, almost 31% of the rural active population (MAEP, 2014). In terms of households, 148,519 (32.62 %) and 170,867 (32.17 %) were involved in agriculture practices in 1995 and 2012, respectively. The percentage of rural population were 84.2 and 87.0% in 1995 and 2012, respectively.

However, land pressure (e.g., intensive mono-cropping, slash and burn agriculture, exponential urbanization) coupled with past and present climate extreme events (such as flood and drought) are some of the major constraints contributing to crop failure and poverty increase in the Region. According to Global facilities for Disaster Reduction and Recovery (GFDRR, 2011), over 61% of the population live below the poverty line. This situation is more acute in the Plateau (56%) compared to Lomé (24%) Administrative Region. Climate related hazards in terms of flood, drought and bush fire, are frequent in Plateau region. Referring to ISDR (2007), agriculture is affected by serious drought and flood events in this Region. Moreover, croplands are experiencing significant decline in fertility due to erosion and inappropriate soil fertility management. In the meantime, deliberate expansion of croplands results in significant degradation of native forestlands. The investigation also, the total conversion of forest areas to croplands mainly for cash (cocoa, teak, oil palm production) and food (rice, maize and cassava cropping) crops (MERF: Ministère de l'Environnement et des Ressources Forestière, MERF,2011) is on the increase.

Based on 2011 statistics (MERF, 2001), forest occupies 6.8 % (386,000 hectares) of the total land mass of Togo with an annual deforestation rate of 4.5% (Togo Forestry Policy: MERF, 2011). The main proximate cause underpins agriculture and population growth. In fact, land pressure coupled with unsustainable land management drive soil degradation and crop failure. On the other hand, population growth promotes more food demands and needs. Therefore, total absence of policies and measures to regulate the cohabitation of these entities (forest-population and population activities) will hammer forests existence with significant economic, social, and environmental negative impact.

Consequently, we need to understand this land use transition through scientific investigations by studying anthropogenic activities on forests losses and soil degradation with their related effects on the carbon cycle and crop productivity before implementing precautionary measures towards policies and actions and implementations of sustainable forests and agricultural management approaches.

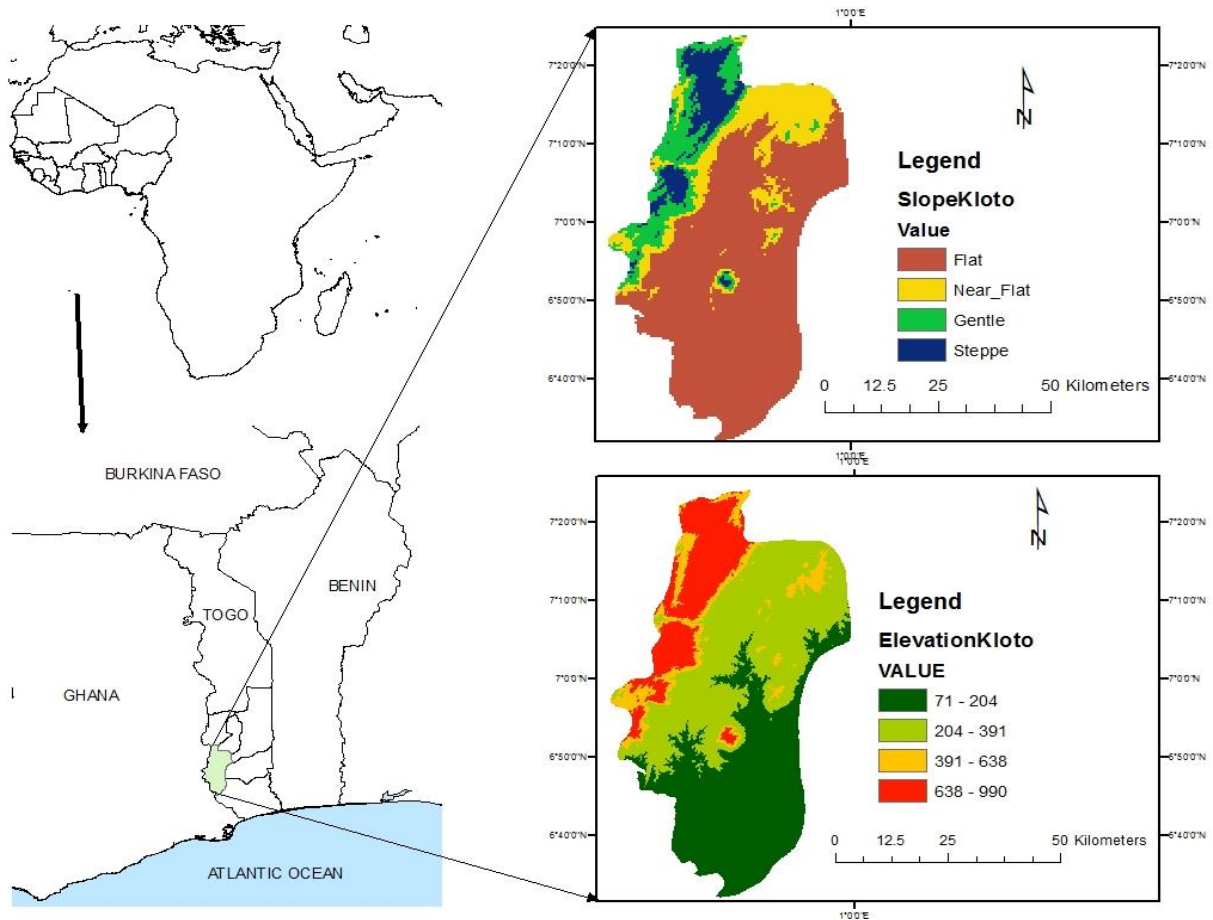
### **1.3 Aims and Objectives**

This study investigates agro and forest ecosystems carbon stock, carbon dioxide emissions and croplands degradation for priority and policy actions in the Plateau Region, Togo. Specific objectives are to:

- 1.3.1 Assess forest reference level over a 32-year (1985 to 2017) land use transition and intensity analysis
- 1.3.2 Analyse the spatio-temporal agro-forest system dynamics, implications on forest and land degradation, and potential land conservation measures.
- 1.3.3 Quantify potential Soil organic carbon stock and carbon dioxide emission resulting from forest conversion to food and cash crop farming.

### **1.4 Study Area**

This study was conducted in the Kloto District within the Plateau Region (Figure 1.1). The Plateau Region spans between 6° 44'30" to 7° 5' 30" Latitude North and 0° 30' to 0° 45'30" Longitude East. It is one of the largest region in terms of area with about 16,975 km<sup>2</sup> and encompasses twelve prefectures. It has two agrological zones viz: Plateau zone (V) and the meridional zone of the Mont Togo (IV) (Ern, 1979). Total population is about 1,375,165 with a density of 81 people/km<sup>2</sup> (DGSCN, 2011; MPDAT, 2010).



**Figure 1. 1: Study Area**

The Plateau Region is divided into two main agro ecological zone, namely: Plateau East (zone V) or Savannah area composed of Est and Moyen Mono, Haho, Anie and Ogou Prefectures; and Plateau West or Forest area encompassing: Agou, Kloto, Danyi, Kpele, Wawa, Amou and Akebou Districts also known as zone IV. In the Zone IV, oil palm, cocoa and coffee are mainly produced whiles Zone V is mainly covered with teak plantation. In both zones, annual continuous mono cropping with little or no rotational cropping systems is practiced. Soils are mainly loamy (70%). The annual temperature is between 16 and 26 °C. In terms of rainfall, the area experiences an annual of 1450 mm with two rainy seasons (March to July and September to October) interrupted by two dry seasons (August to September and November to March) (Ern, 1979).

## **1.5 Thesis Organization**

The thesis is organised into four chapters. CHAPTER 1 gives the background, problem statement, context and justification objectives of the study. In CHAPTER 2, concept, definition and literature review on the subject matter are presented. CHAPTER 3 focuses on objective 1 to 3. CHAPTER 4 brings out the general discussion, conclusion and recommendations based on the findings for policies and future scientific investigations.

## **CHAPTER 2: LITERATURE REVIEW**

### **2.1 Review of Concepts**

#### 2.1.1 Landmarks REDD+/ UNFCCC and REDD+ efforts in Togo

Forests have great potential to mitigate both anthropogenic and natural greenhouse gases, thus, tropical forests in developing countries have a significant role to play. As such, international negotiations and efforts to provide incentives for these countries to contribute to climate change mitigation through sustainable management of forests and land use activities sectors is paramount. Reducing emissions from deforestation and forest degradation and the role of sustainable forests management, conservation and enhancement of forest carbon stock, in acronym REDD+, was negotiated and ratified by all parties of the United Nations Framework Convention on Climate Change (UNFCCC) during a conference of parties (COPs) (UNFCCC, 2015).

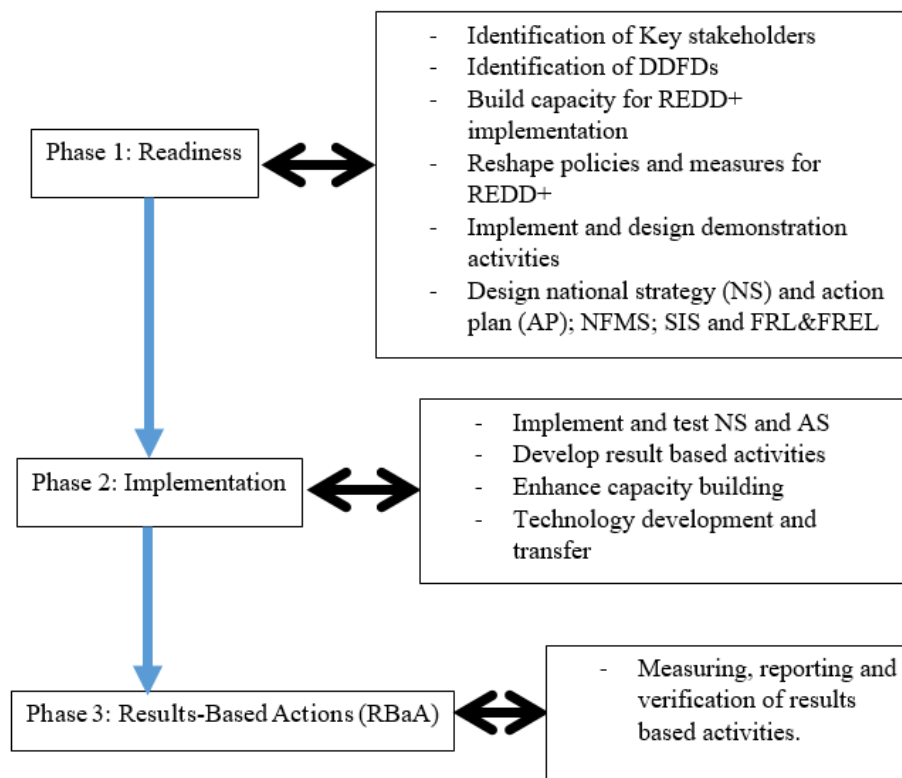
The genesis of REDD+ commenced with UN-REDD, which stands for United Nations collaborative programme on reducing emissions from deforestation and forest degradation in developing countries established in September 2008 for preparedness to the REDD+ mechanism and build these countries capacities to slow down and stabilize atmospheric greenhouse gas. It is a global partnership commitment which brings on board, the developing and developed countries to promote low carbon emissions and climate resilient activities, assist and provide predictable and significant funding as incentive measures to reduced forest-based carbon emissions (UNFCCC, 2015; UN-REDD, 2016a; 2016b; 2016c). The concept and understanding of UN-REDDs differ from one school of thought to another. While others stand for REDD+, we can also distinguish an additional plus (+) but, mechanisms and policies gathering them do not vary across countries. Each activity has its objective, benefits, and covers three main principles to tackle climate change, viz: reduction of emissions, enhancement of the rate of sequestration and repository of native carbon

stock. The first discussion on UN-REDD activities came out during the Montreal meeting, the eleventh conference of parties (COP 11) in 2005. During that meeting, focus was on substances that deplete the ozone layer, pioneer countries such as Papua (New Guinea) and Costa Rica asked for new agenda or approach for low carbon activities in developing countries. Consequently, before late 2007 and early 2008, the concept encompassed only Reducing Emissions from Deforestation and Forest Degradation known as REDD.

This laid a roadmap to further UNFCCC discussions to define the mechanisms of assessment of the efficacy of the programme, criteria and means of financial support from developed countries. As a result, in 2007 during the thirteenth conference of the parties (COP 13) in Bali, the action was provided in which the REDD concept was replaced with REDD+ (evolved from paragraph 70 of the Cancun Agreement; COP16). The additional (+) stands for (i) conservation of forest carbon stocks; (ii) sustainable management of forests and (iii) enhancement of forest carbon stocks. From some sources, we can find a second (+) which means (iv) low carbon losses and high biodiversity lands. Later all, the methodological guidance for REDD+ activities was adopted in 2009 during COP15 at Copenhagen (FAO, 2010, 2015; UNFCCC, 2015).

In 2010, COP16 at Cancun, i.e. the Cancun agreements were established, including policy approaches and positive incentives on issues relating to REDD+. In simple words, the vision defined for REDD+ during the conference can be summarized in two main points, notably: (i) Reducing GHG emissions produced by the forestry sector and (ii) enhancing the capacity of the forestry sector to act as a carbon sink, by storing and enhancing carbon in the five pools. In November 2013, COP19 at Warsaw, finalized and established REDD+ rulebook, comprising modalities and guidance (COP16, Cancun) for establishing national strategy/action plan (NS/AP); national forest monitoring systems (NFMS); measuring, reporting, and verification (MRV); forest

reference level (FRL); forest reference emissions level (FREL) and addressing safeguards and drivers for deforestation and forest degradation (DDFD). REDD+ is quite easy to understand, but complicated to implement due to the interactive complexities of the components that is involved. In the light of this, parties came to a consensus and defined REDD+ implementation in three core phases (Figure 2.1), notably: Readiness, Implementation and Results-Based Actions (RBaA) or Plans (AS or AP) with a specific objective and involved actions (Bassi, 2011; Holmgren and Marklund, 2007).



**Figure 2. 1: Steps of REDD+ Implementation**

**Source:** Adapted from (UN-REDD 2016a; 2016b; 2016c)

In summary, climate concerns are worldwide with likelihood significant impacts in developing countries due to their low and inadequate adaptation capabilities. Besides, West Africa is the most vulnerable to climate change due to its fragile ecology, extreme poverty and poor governance. For instance, in Togo, climate change manifests through variations in precipitation and temperature regimes causing fluctuations on the agricultural calendar from one year to another. Effects related to extreme events, notably floods and droughts spells have been recorded in both the southern and northern parts of the country, respectively (MERF 2001, 2010, 2015). Simulations of future temperature and precipitation regimes in the year 2025 and 2100 are very drastic.

The temperature is likely to increase from 0.6 to 4.5 °C with increase in precipitation from 3.26 to 39.7 mm. Using different IPCC representative concentration pathways scenarios (RCP2.6 and 8.5), temperature is projected to fluctuate between 0.63 and 0.71 °C under RCP2.6 and 0.78 and 0.88 °C under RCP8.5. Precipitation is likely to fluctuate between 3.26 and 7.6 mm, which equates to an increase from 0.36 to 0.47 % (MERF, 2015). For horizon 2100, the temperature will increase from 0.88 to 4.5 °C, with precipitation increase from 3.6 to 26.9 mm. This evidence on the likely future climate scenarios are some of the statistics to alert the population and policymakers to take a position to attenuate atmospheric greenhouse gas buildup through positive incentive measures and implementation of climate-friendly mitigation actions.

Review of available national communications on climate change and adaptation and mitigation documents shows that land use land use change and forestry (LULUCF) sector is on top of emissions and carbon removal. Also, it can be used as carbon dioxide removal and carbon sinker. To exemplify this, in 2001, the benchmark emission from the forestry sector mainly, through land use change was 22132 GgCO<sub>2</sub> in 1995. For the second National Communication on Climate Change (MERF, 2010), the benchmark emission level was 2000 with 10260.36 Gg and 9010 Gg

of carbon dioxide (CO<sub>2</sub>). Finally, the recent communication revealed a significant increase from LULUCF sector. Considering 2005 as baseline, which was 17743.42 Gg (72.93% progression compared to 2000 with 10260.36 Gg and 12569.42 GgCO<sub>2</sub>), LULUCF sector has emitted 11559.70 GgCO<sub>2e</sub>. It is against the above background that, policies and actions have been put in place to reinforce, halt forest shrinking and improve the ability of forest in mitigating climate change in Togo, where forests are defined in terms of minimum tree heights of 5 m with at least 10 % crown cover within minimal area of 0.5 ha.

These forests are experiencing rampant degradation and deforestation, and the rate of vegetation recovery is 24.24% referencing to the national forest inventory conducted for the starting of reducing emission from deforestation and forest degradation (REDD+) project. Based on the statistics of 2011, forest occupies 6.8 % (386,000 ha) of the total land mass with an annual deforestation rate of 4.5% (MERF, 2001). To date, up to 50% of these assets are lost due to human-induced activities. In terms of additional policies, promulgation of decree dated on 5<sup>th</sup> February 1938 related to forest sector (forest protection and reforestation) in Togo. This act aims to define rules and regulations to protect and monitor forests and natural resources utilizations and establishment of national tree celebration day (1<sup>st</sup> Jun., 1977) and environment by the Ministry of Environment and Forest Resources.

These measures were followed by the elaboration and adoption of the National Action Plan for Environment. Moreover, valuable actions are taken towards (i) reforestation (5000 ha/y) and promotion of agroforestry onto cultivated lands and (ii) sustainable management of remaining forestlands through enforcement of laws against deforestation and forests degradation. Unlike some neighbouring West African countries (e.g., Ghana, Nigeria) which are more advanced in REDD+ project and its mechanisms, Togo commenced its readiness proposal plan in 2015 with

ProREDD project. REDD+ readiness and rehabilitation of forests (ProREDD) project which was launched to meet these objectives. With financial support of donors (World Bank, BMBF) and strong political will of the government, national strategies and actions plans have been established to facilitate the start of the project. This step is very crucial to define forest monitoring and information systems as well as reference levels in terms of emissions and species distributions. It is in light of these achievements that, the national forest inventory was organised for qualitative and quantitative estimations of our national forests resources, as benchmark for monitoring and to mitigate climate change and deliver non-forest benefits (social, cultural and economic). This step also underlines proximate and underlying causes of deforestation and forest degradation through inclusive discussions of key stakeholders in order to develop, experience and implement incentive measures to surmount emissions from LULUCF sector in Togo. Moreover, it also focused on the timely and accurate evaluation of emissions resulting from forest conversion to other land use changes (e.g. agriculture, building, road, etc.) via remote sensing techniques combined with transition and intensity analysis.

#### 2.1.2 Climate Change, Forest Policies

The carbon cycle is a regulatory system of carbon equilibrium within the soil, plants, ocean and atmosphere systems, and any perturbation inducing harm to the climate system through significant fluxes of carbon, are the main drivers of climate change and global warming. It is a scientific consensus that soils and forests are the innate stock of carbon, which can also lead to carbon losses due to anthropogenic activities mainly through land use changes. Overall, 10% of net carbon dioxide is driven by land use change (IPCC, 2014). Every loss of 1 tonne of soil carbon equates to 3.67 tonnes of carbon dioxide and for 1 tonne of forest cleared results in an equivalent of 0.5 tonnes of carbon released into the atmosphere. These small statistics give light and understanding of the

relevance of the forest sector in adapting and mitigating climate change. Tropical forests are net sinks of soil carbon and repository of 195 Pg of above ground biomass carbon (Baker, 2005; Laurance, 2008; Liu *et al.*, 2015; Pan *et al.*, 2011; Saatchi *et al.*, 2011). However, the role of forests, especially tropical forests, which cover only 6% of the global land surface in climate change mitigation through the highly dense carbon stock has been compromised by humankind activities mainly through deforestation and forest degradation. Pertinent studies on tropical ecosystem carbon cycling are highly cited in literature (e.g., Bonan 2008; Alamgir *et al.*, 2016).

Meanwhile, the magnitude of sequestration is a function of multiple factors, notably: climate management, social barriers, and the period of monitoring. This throws more lights on the role of Land Use, Land Cover Change and Forestry (LULUCF) sector in the abatement of atmospheric greenhouse gas, most importantly carbon dioxide. In its special report on LULUCF, the Intergovernmental Panel on Climate Change (IPCC), cited by Watson *et al.* (2000) underlined the potential removal of 87 PgC by LULUCF at the global level by 2050. This role of climate cooler and regulator and stabilizer of atmospheric carbon dioxide has been emphasised by Forsell *et al.* (2016).

Simply put, forests can play a decisive role to meet the goal of Intended Nationally Determined Contributions (INDCs) of all the parties signatories of the UNFCCC agreements. To recall, parties of the UNFCCC have been asked to disclose their demarches to attenuate greenhouse gas emissions from their different sectors of activities in relation to UNFCCC post-vision 2020 to curb global warming and climate change. This recent study conducted by the authors above, given the credible evidence of LULUCF contributions in reducing carbon removal from terrestrial forest ecosystems considerably. Results have revealed a net LULUCF emissions increase with time up to 0.6 GtCO<sub>2e</sub>/yr in 2020 and 1.3 GtCO<sub>2e</sub>/yr in 2030 with a significant depletion through the

implementation of INDC's policies compared to the FAO (2015) benchmark emission (3 GtCO<sub>2e</sub>/yr). The significant reductions in net LULUCF emissions are likely to come from Indonesia, Brazil and Ethiopia, respectively under climate change policies. Previous and current statistics estimated that the implementation of INDCs would decrease worldwide LULUCF net emissions by 1.1 while others vowed for 11 GtCO<sub>2e</sub>/y by 2030 (UNFCCC, 2015).

Forests have the ability to mitigate climate changes, if well managed through enforced policy actions as previously mentioned. Forests have been given credit and privilege in climate talks and mitigation actions for their capability to absorb billions of tonnes of carbon dioxide at the global scale annually and for their remarkable co-benefits (social, economic and ecological). For example, studies have posited that forests nearly sink 3 PgC/y of anthropogenic carbon and absorb about 30% of carbon dioxide fluxes from fossil fuel burning and net deforestations (e.g., Canadell & Raupach, 2008; Gullison *et al.*, 2007).

The mainstream of forest contributions to climate change mitigation must emanate from activities dedicated not to jeopardize either its extension or ability to fight back carbon removal and sink in both soils and plants. Sustainable forests management practices to guarantee this eternal role are vividly required in the following ways: (i) increase forested land area through reforestation with new carbon dense species to avoid and reduce respiration from old growth plantations; (ii) increase carbon density of existing forests at both stand and landscape scales; (iii) expand the use of forest products that sustainably replace fossil-fuel CO<sub>2</sub> emissions; (iv) tackle main drivers of forest degradation and deforestation through diversification of source of income for the rural communities and promotion of clean energy sources for domestic needs and (v) enforce policies to reduce emissions from deforestation and degradation. Accordingly, the United Nations Framework Convention on Climate Change (UNFCCC) jointly with Food and Agricultural

Organization (FAO) and United Nations Environment Programme (UNEP) established a climate-friendly and socio-economic worthy international programme (REDD+), which aims to guarantee forest conservation, carbon stock, biodiversity with additional co-benefits.

### 2.1.3 Drivers of Deforestation and Forest Degradation

Deforestation and forest degradation are driven by a couple of forces which can be environmental (climate change), socioeconomic (poverty) and political (government interventions). These determinants can jeopardize the successful implementation of REDD+ projects and this must not be overlooked. The successive story of REDD+ is tightly correlated to how best we can identify, solve and draw valuable policies to mitigate these driving forces on forest resources in playing their essential role, notably carbon sequestration, mitigation of climate change and conservation and diversity of biodiversity. The intensity of deforestation and forest degradation driving forces varies across the globe with significant imprints in developing countries. Meanwhile, determinants, agents and institutions are quite similar. For instance, in Togo, expansion of croplands entails significant degradation of native forestlands in association with total conversion of forest areas to croplands mainly for cash (cocoa agroforestry, coffee, tea, palm oil production) and food crops (rice, maize and cassava cropping). Available statistics shows that forest occupies 24.24 % of the total land mass with an annual deforestation rate of 4.5 % will lead to a loss of up to 50 % of vegetation cover (MERF, 2011).

Among the causes mentioned above, agriculture and population growth are the key determinants endangering deforestation and forest degradation mainly in sub-Sahara African regions and other developing countries. Existing extensive literature and policies on this matter give clear evidence of the level of a hindrance; draw and proposes analytic frameworks to comprehend and analyse

them (FAO, 2010; 2015). According to UN-REDD (2016b), drivers in REDD+ context are direct or indirect actions, processes and factors that limit deforestation and forest degradation, through their accurate identification, understanding and analysis of their relevance and layout of frameworks on how to analyse them.

These measures are key to deepen the understanding of the main DDFD, critical for readiness phase (SBSTA, 2013). Besides, it helps in the development of national REDD+ strategies/action, plans and the formulation of policies and measures. Drivers of deforestation and forest degradation (DDFD) can be separated into direct and indirect. Direct drivers also called proximate causes are anthropogenic or immediate actions with impacts on forest cover and carbon losses, while indirect drivers, underlying causes, or driving forces are complex interactions of fundamental social, economic, political, cultural and technological factors. Agricultural expansion, infrastructure, legal or illegal mining and logging; and population growth, international markets, and national policies and measures are some of frontline direct and indirect drivers of forest depletion (Boucher, 2011; DeVries *et al.*, 2012), respectively.

A synthesis report on drivers of deforestation and forest degradation for REDD+ policymakers published by Kissinger *et al.* (2012) disclosed the contribution and areas affected by the five main drivers (urban expansion, infrastructure, mining, local/subsistence and commercial agriculture) of deforestation and three key drivers of degradation (Commercial timber extraction, fuelwood collection and charcoal production) from 2000 to 2010 across three continents viz: Africa, Latin America, sub and tropical Asia. Results revealed that, in terms of the proportion of deforestation, agriculture is driving 80% of worldwide deforestation with one third in Africa, sub and tropical Asia while large-scale commercial takes two third in Latin America. In the meantime, subsistence agriculture accounts for a similar proportion in each continent. On the other hand, statistics on

degradation show that fuelwood extraction and charcoal production are critical drivers in Africa while commercial timber harvesting accounts for 70% of forest degradation in the sub and Tropical Asia and Latin America. The context of deforestation and forest degradation in Bolivia also informed that, mechanized agriculture, cattle ranching and small-scale agriculture are the three vital direct drivers of deforestation up to 30 %, 50 % and 20 % between 2000 and 2010, respectively (Müller *et al.*, 2014) while, forest fires, selective logging (legal and illegal), grazing and fuelwood collection have been identified as frontline to forest degradation at different intensity (Hosonuma *et al.*, 2012; Müller *et al.*, 2014).

Additionally, studies on drivers of deforestation and forest degradation span across various countries (e.g., Chan & Sasaki, 2014; Sambou *et al.*, 2015; Salvini *et al.*, 2014; Tegegne *et al.*, 2016). For instance, Geist & Lambin (2002) analytical framework on DDFD identified ancillary factors (physical, climatic and land characteristics) as external to proximate and driving forces related to the forest depletion. These external factors serve as mediators between the direct and indirect forces and this can jeopardize the effectiveness of REDD+ scheme. On the other hand, Sulaiman *et al.* (2017) investigated the effect of poor institutions and bad governance as well as fuel consumption on forest degradation using cluster data from 2005 to 2013 of 45 sub-Saharan African countries. Results gave a valuable answer to this empirical question. In fact, wood fuel consumption, corruption and poor governance lead to forest degradation in the region. This suggests that effective control of corruption and poor governance, as well as instauration of policies and measures to promote domestic gas consumptions, can significantly curb forest degradation in sub-Saharan Africa. In summary, the factors of DD are complex and dynamic and they need to be well scrutinized. Besides, proper identification of drivers is vital for effective implementation of policies targeting carbon sequestration and greenhouse gas removal. As such,

linkage of spatial analyses of socioeconomic data as well as policies and measures can make drivers identification strong and accurate to establish reliable frameworks to analyse halt or combat them though, deforestation and forest degradation are growing at an alarming rate.

#### 2.1.4 Land Use Land Use Change and Forestry

Land Use Land Cover Change and Forestry regroups six land use and land cover categories defined by the Intergovernmental Panel on Climate Change and Adapted Land Use (IPCC, 2006; Paustian *et al.*, 2006). These six land use land cover categories include: Forest, Cropland, Grassland, Wetlands, Settlements and Others which are taking part of the agriculture, forestry and other land use (AFOLU) dynamic systems. To this end, the standard definition of forest as stipulated by FAO takes into consideration three main components namely: minimum land spanning (0.5 ha), tree height (5 m) and a crown cover of more than 10 %. Nonetheless, this definition is country and location dependent as we come across various agro ecological zones and inherent socio economic conditions worldwide (FAO, 2015).

Forests cover about 4 billion hectares globally approximating 31 % of the world's total land mass, and considered are redoubtable climate change negative multipliers through storage of carbon into the soils and plants biomes (Cramer *et al.*, 2004; Van der-Werf, 2009). However, increasing population growth, growing economy associated with various environmental hazards underpin changes of forest cover to other land use (e.g., agriculture, settlement) through degradation (partial conversion) or deforestation (total conversion) with tree canopy less than 10 % (FAO, 2010). Keenan *et al.* (2015) study on the dynamics of global forest area based on FAO global forest resources assessment revealed significant net depletion in forest areas from 4128 to 3999 Mha between 1990 to 2015 mainly in the tropics compared to temperate area with the highest rate of loss in low income countries. These conversions have on-site or direct effects (e.g. soil

degradation, loss of life and biodiversity, property destruction) and off-site or indirect impacts (e.g. greenhouse gas emissions, climate change and global warming). According to Houghton (2005) and Gibbs *et al.* (2007), 1 to 2 billion Mg of carbon per year and equivalent of 15 – 25 % of annual greenhouse gas emissions emanates from tropical deforestation and forest degradation. Accordingly, there is a crucial need to evaluate potential emission or release of agricultural land use practices resulting from forest conversion way of exploring mitigation and adaption options while increasing and sustaining crop productivity.

## **2.2 Literature Review**

### **2.2.1 Land Use Transition and Intensity Analysis**

Land Use Land Cover Change (LULCC) analyses are vital processes to identify drivers of degradation of natural land cover and explore possible policies and measures to curb their destructions. It refers to the change in the natural aspect of the land cover between at least two time periods over the same spatial extent and geographic location. It can be in terms of size (quantity of change) where only the percentage of overall annual change in LULC types are exposed based on the contingency tables or Markov Chain Analysis (e.g. Butt *et al.*, 2015; Han *et al.*, 2009; Munsu *et al.*, 2010; Pontius *et al.*, 2004; Rawat & Kumar, 2015); or in terms of size and intensity known as unify analysis (Interval, Category and Transition: ICT) introduced by Aldwaik & Pontius (2012) and Pontius & Santacruz (2014).

The first approach is based on a separate contingency tables of considered periods without accounting for the speed of the changes, the behaviours and transition levels of categories for the simultaneous periods. Moreover, it is also regardless of the uniformity of the annual rate of change that can occur. Besides, the quantity of changes in LULC types is less informative and explanatory

of possible actions to limit the damage on a specific land use type. The proportion of changes does not expose how and which of land use types. However, the intensity of conversion may vary from one point to the other, which generates information on the status of the land category. One category can be active or dormant while targeting or avoided, and the intensity can be uniform, and simultaneous consideration of all time points of a given land cover types over the same spatial extent enhances the understanding of land change processes.

The size and intensity analysis are carried out through three main phases, notably: interval, category and transition, which give valuable information about the speed (slow or fast) of change; categories regarding active or dormant and their gains and losses compared to the uniform annual rate changes, respectively. This method has been applied and tested across the globe in comparison with existing classical methods. It comes from the assumptions that: (i) annual rate of change in land use land cover types is not similar (increase or decrease) over the time.; (ii) gains and losses may vary across each land category for each time interval and (iii) some categories may be targeted or avoided and vice versa over each time interval (Aldwaik & Pontius, 2012; Aloô & Pontius, 2008; Manandhar *et al.*, 2010; Runfola & Pontius, 2013).

This approach aims to answer three main questions: (i) during which time interval is the overall annual change rate relatively slow versus fast? (ii) Which land use categories are relatively dormant versus active? Lastly, (iii) which transitions are targeting versus avoiding for each time interval? With regard to the uniform change (stationarity). According to Manandhar *et al.* (2010), reports based only on the net land use land cover change category are not accurate but misleading because, gross gains and losses in the land use category are overlooked. In the following, land use intensity analysis across various agroecology are duly summarized (Table 2.1). Land use intensity analysis and land classification go hand in hand in giving detailed information regarding the

characteristics of the transition. Net land use changes do not only expose or give information on how the transition behaves, and the type land use categories are targeted or avoided and active or dormant. It comes to reinforce the quantitative analysis, which gives information about the overall net change, categories that are persistent and those that are lost and/or gained. Many land use land cover change methods fail to account for these details. e.g., Markov Chain analysis is one of the most powerful land use algebra analysis but does not give information about the behaviour of the categories. Unlike intensity analysis, which is performed at three levels: interval, transition and category to assess the speed of change, dormant or active as well as targeted to lose and to be avoided; Markov chain just gives the net change of each interval, but its ability to explain the

**Table 2. 1: Pertinent Land Use Intensity studies per agro ecological zones**

Title	Climatic Zone/Country	Journal Information
Intensity analysis to unify measurements of size and stationarity of land changes by interval, category, and transition	northeastern Massachusetts, USA	<i>Landscape and Urban Planning</i> ./doi:10.1016/j.landurbplan.2012.02.010.
Identifying systematic land-cover transitions using remote sensing and GIS: the fate of forests inside and outside protected areas of Southwestern Ghana	Southwestern Ghana	<i>Environment and Planning B: Planning and Design</i> ./ doi:10.1068/b32091.
Agroforest's growing role in reducing carbon losses from Jambi (Sumatra), Indonesia	Bungo district, Jambi province, Sumatra, Indonesia	<i>Regional Environmental Change</i> ./doi:10.1007/s10113-013-0525-4
Evidence for deviations from uniform changes in a Portuguese watershed illustrated by CORINE maps: An Intensity Analysis approach	Portugal	<i>Ecological Indicators</i> ./ <a href="http://dx.doi.org/10.1016/j.ecolind.2016.01.018">http://dx.doi.org/10.1016/j.ecolind.2016.01.018</a> .
Land Classification and Change Intensity Analysis in a Coastal Watershed of Southeast China	Jiulong River watershed, Southeast China	<i>Sensors</i> ./ doi:10.3390/s140711640.
Use of intensity analysis to link patterns with processes of land change from 1986 to 2007 in a coastal watershed of southeast China	coastal watershed, Southeast China	<i>Applied Geography</i> ./doi:10.1016/j.apgeog.2012.01.001
Land Change Analysis from 2000 to 2004 in Peatland of Central Kalimantan, Indonesia Using GIS and an Extended Transition Matrix	Central Kalimantan, Indonesia	<i>Tropical Peatland Ecosystems</i> ./doi:10.1007/978-4-431-55681-7_29
Tree cover transition in Northern Vietnam from a gender-specific land use references perspective	Vietnam	<i>Land Use Policy</i> ./ <a href="http://dx.doi.org/10.1016/j.landusepol.2016.11.002">http://dx.doi.org/10.1016/j.landusepol.2016.11.002</a> .

changes is limited. Also, it is hard for a Markov approach to reveal information regarding the interval, category and transition level for the investigated periods. Moreover, the Markov approach compares the entries within each row of the transition matrix, since the Markov approach divides the area of each transition by the area of the losing category at the initial time. Thus, the Markov matrix is not adequate to scrutinize the process in terms of gains, while the process of gains is the primary focus in many analyses.

### 2.2.2 Methods Used in Estimating Carbon-Stock Change

Carbon stock change assessment across terrestrial ecosystems is blueprint information for mitigation measures. Each country signatory of the United Nation Framework Convention on Climate Change (UNFCCC, 2015), must report on their emission and carbon level and their commitments to reduce these emissions through an Intended Nationally Determined Contribution (INDC's: COP 21 known as Paris Agreement) for policy actions. On top of that, measuring, reporting and verification of carbon stock and the emission levels of the forest sector is paramount in meeting REDD+ (Reducing Emission from Deforestation and Forest Degradation; conservation of forest carbon stocks, Sustainable management of forests and Enhancement of forest carbon stocks) requirements. The Intergovernmental Panel on Climate Change (IPCC, 2006) defines five major carbon pools: above and below ground (AG and BG), litter (L), dead wood (DW) and soil organic carbon (SOC) deterministic of the carbon cycle across different land use land cover change (LULCC).

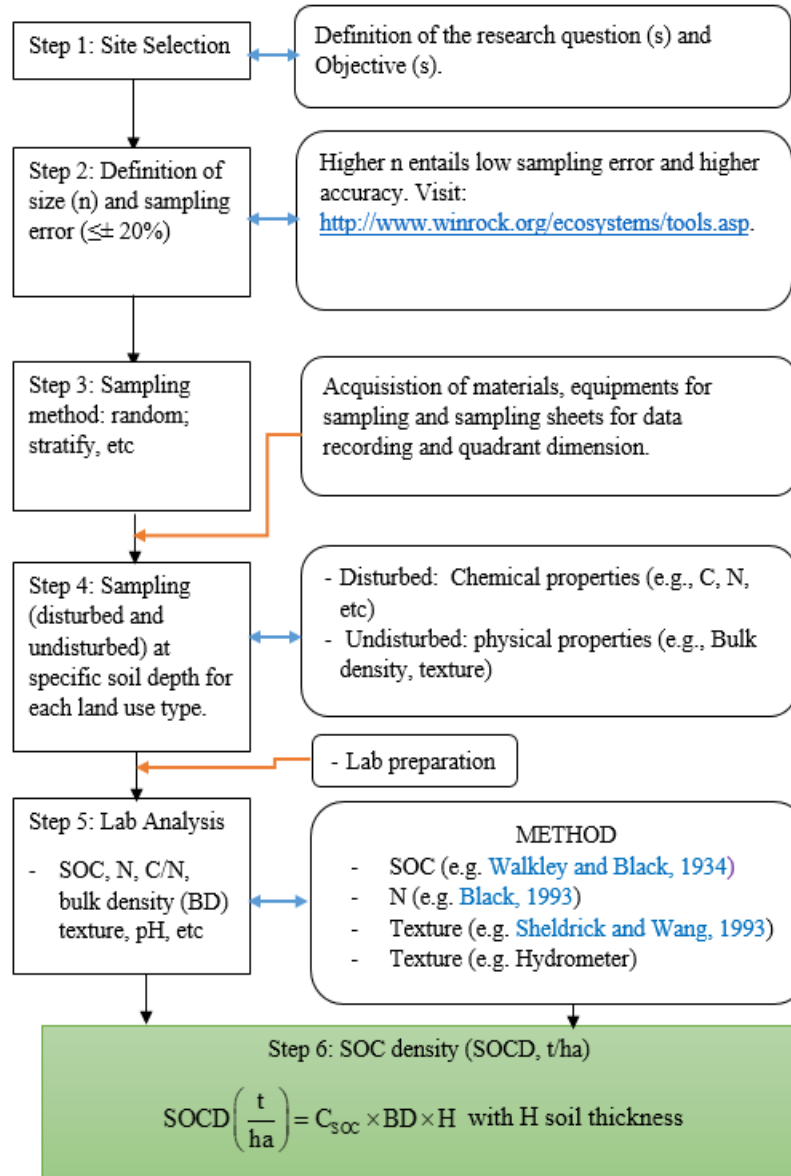
The quantity of carbon contained in biomass varies slightly between vegetation types but on average, a ton of biomass equates to half a ton of carbon (FAO, 2010). It is not mandatory to consider all carbon pools. The choice must tally with the research questions and the spirit that drives the investigation. For the sake of this study, we will focus on the methods used to estimate

AG, BG, L and SOC taken the proportion of 50% carbon content in biomass for the forestry sector. In the forestry sector, AG, BG, biomass estimation reposes on the allometric models e.g. (Chave *et al.*, 2005) whereas, in the agriculture sector (food crops) biomass (AG +BG) is derived from the annual crop yields based on empirical climate, soil and species conditioned existing equations (IPCC, 2006; FAO, 2015). In the following, we will underline approaches used for carbon estimation in soil and plants followed by methods used in estimating carbon stock or removal from terrestrial ecosystems.

Soil Organic Carbon (SOC) is one of the most sensitive carbon pools under land use change and requires more intention in carbon accounting schemes as deforestation can lead to 87 % release in the atmosphere. The stock of SOC (density/ha) estimation is also case sensitive if soil samples are not representative of the soil being assessed or of the intended decision. This can over or underestimates soil removal of emission factor for a particular system. SOC assessment is in accordance with the research questions and commences with soil sampling (disturbed and undisturbed), laboratory analysis of chemical and physical (bulk density) properties determination and ends with carbon stock calculation (Figure 2.2).

Once the stock of carbon for each LUS and soil types if applicable, they can be compared to the reference soil carbon (carbon under undisturbed land use system or indigenous forest) in order to derive the emission or removal factor. Compared to soil carbon determination, tree biomass is quite delicate and somehow tedious to perform. Therefore, sampling method and procedure are combined with the regression model (allometric model) to be used must match with the climate, species, soil types and the research questions. Plant Biomass Estimation (AGB) at plot level (field or site scale) comprises stem (truck), branches and fruits. Relevant parameters mostly considered

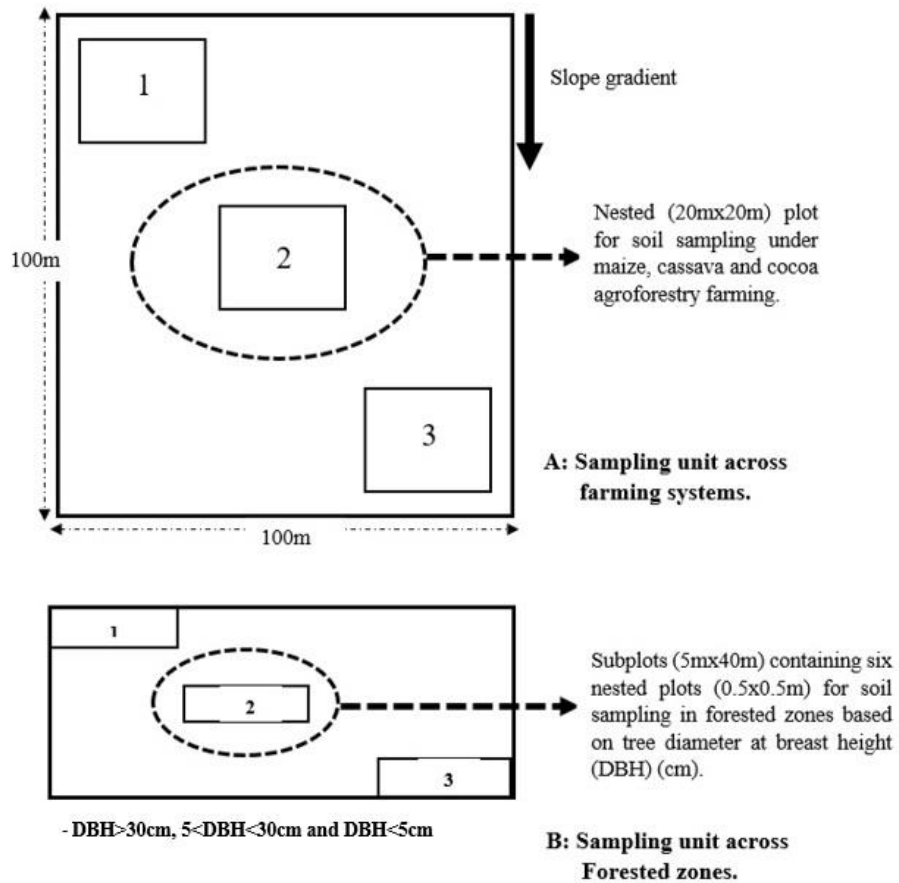
are tree diameter; height; wood density. The first step is to set out a nested plot (5 m × 40 m) per unit area (1 ha) within the land use system (LUS). The 200 m<sup>2</sup> quadrants are



**Figure 2. 2: Flowchart of SOC study across LUS**

commonly used, but are flexible depending on the LUS and subplots of 0.5 m × 0.5 m is established in the under storey and litter samples (Figure 2.3) (Hairiah *et al.*, 2011). When setting the main plots, information regarding the story, geographic location must be recorded for time-averaged

carbon (C) stock and matching field measurements with the spatial data. Plots must be randomly set out with equal chance of selection of densest and least vegetation and border effects must be avoided.



**Figure 2. 3: Sampling Unit from farming systems (A) and forested zones (B)**

Once the three components are calculated, the AGB can be estimated using appropriate allometric equation (Chave *et al.*, 2005). Thereafter, carbon content for a single tree resulting from the biomass can be estimated using a default conversion rate of 0.46 of tree biomass defined by IPCC (2006) and Hairiah *et al.* (2011). On the other hand, estimates of the BGB and carbon can be derived from AGB and carbon in accordance.

Studies have stated a clear relationship between diameter and root (ratio AGB/BGB) of trees taking into account forest ecosystem types e.g. Hairiah *et al.* (2011). This ratio equates to 4: 10 and 1 irrespectively in dry, very wet and mixed tropical forests. To date, we have a range of allometric models for the specific case of study, rainfall regimes, plants diameter, height, wood density and type of LUS.

Brown (1997) equation includes the Diameter at Breast Height (DBH) and the height (H) of trees for dry (<1500 mm); moist (1500 – 4000 mm) and wet (>4000 mm) annual rainfall excluding wood density. However, this model performed less when considering the wood density and overestimation of the AGB was reported for tropical forest biomass. Chave *et al.* (2005, 2014) reported forest types (climate regimes); total tree height (basal to last leaf); wood specific gravity and trunk diameter as best estimators of AGB in increasing order. Equations have then, been developed for forest types, tree species and LUS (e.g., agroforestry systems; and trees from monocotyle families: coconut and oil palm) for tree diameter ranging from 5 – 60 cm (Table 2.2). Summary (Table 2.3) is the different allometric models in use for carbon stock estimation across various climate regimes and LUS.

Conversely, estimation of above and below ground biomass and carbon estimation of food crops is quite different. Here, AGB is estimated using empirical equations (IPCC, 2006; FAO, 2015) based on crop yields and types. In addition, the estimation of the BGB is also crop dependent.

**Table 2. 2: Allometric models based on rainfall regimes**

Rainfall Regime (mm/year)	Corresponding Allometric Equation
Dry (<1500)	$AGB_{est} = 0.112 \times (\rho D^2 H)^{0.916}$
	$AGB_{est} = \rho \times \exp\left(-0.667 + 1.784 \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^2\right)$
Humid/Moist (1500 - 4000)	$AGB_{est} = 0.0509 \times \rho D^2 H$
	$AGB_{est} = \rho \times \exp\left(-1.499 + 2.148 \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^2\right)$
Wet (>4000)	$AGB_{est} = 0.0776 \times (\rho D^2 H)^{0.94}$
	$AGB_{est} = \rho \times \exp\left(-1.239 + 1.980 \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^2\right)$

**Source:** Adapted from Chave *et al.* (2005)

$AGB_{est}$  stands for estimated aboveground tree biomass (kg/tree);  $D$  = DBH: diameter at breast height (cm);  $H$  = tree height (m);  $r$  = wood density ( $g/cm^3$ ) and  $\rho$  = wood specific gravity ( $Mg/cm^3$ ). In addition, these equations are valid for broadleaf trees with stem diameters in the range 5–156 cm and tree biomass in the range 50 gram – 1 tonne Chave *et al.* (2014).

**Table 2. 3: List of tested allometric models**

Agro-forestry systems/Tree species	Allometric model	Source	Country
Coffee regularly pruned	$AGB=0.281D^{2.06}$	Arifin (2001)	Indonesia
Palm	$AGB=\rho \times \exp^{(-2.134 + 2.530 \times \ln(D))}$	Brown (1997)	Brazil (Cited in FAO report)
Oil Palm	$AGB=4.5 + 7.7 \times H$ $AGB=0.0976 \times H + 0.0706$	Frangi & Lugo (1985) ICRAF (2009)	Puerto Rico Nairobi (report)
Banana	$AGB=0.030D^{2.13}$	Arifin (2001)	Indonesia
Bamboo	$AGB=0.131D^{2.28}$	Priyadarsini (1998)	Indonesia
cocoa	$AGB=\exp^{(-2.134 + 2.530 \times \ln(D))}$ $AGB=\exp^{-2.977} + \ln(\rho \times D^2 \times H)$	Mohammed (2016) derived from FAO (1997) Chave et al. (2005) used by Dawoe <i>et al.</i> (2016)	Ghana Ghana
Secondary Tropical Forest	$AGB=0.1208D^{1.98}$ $AGB=0.0673 \times (\rho D^2 H)^{0.976}$	Yuliasmara (2009)	Indonesia
Fern	$AGB=1135.3D - 4814.5$	Mukul <i>et al.</i> (2016) adapted from Stanley <i>et al.</i> (2010)	Upland secondary forest, Philippines
Abaca	$AGB=5.1164 / (1 + 1343.0 \exp^{-0.1550D})$	Mukul <i>et al.</i> (2016) adapted from Armejin & Cosco (2012)	Upland secondary forest, Philippines
Agroforestry systems in West Africa		Moussa <i>et al.</i> (2015)	West African agro ecosystems

The rationale of carbon estimation for each pool or all of them is to estimate the emission or removal of carbon from terrestrial ecosystem due to anthropogenic activities, mainly deforestation and forest degradation. Two main methods exist regarding carbon dioxide emission estimation from LUS, viz: Stock-difference and Gain-loss methods (IPCC, 2006). Stock-difference method (Equation 2.1) requires two measurements in two different periods. Estimated carbon stocks between the two periods divided by the time difference between the two time periods is the estimated carbon stock change per unit area. This method is better suited for deforestation.

$$\Delta C = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)} \quad [2.1]$$

where,  $\Delta C$  is annual carbon stock change (tC/y),  $C_{t_1}$  and  $C_{t_2}$  is carbon stock at time  $t_1$  and  $t_2$  respectively.

However, whenever data of carbon loss/gain per unit area is known, so-called, activity data (tC/ha) (i.e. degradation information); then, Equation 2.2 is preferred. This way of calculation stands for a Gain-loss method of loss/ gain from small land use changes. It does not require two measurements; instead, it simply measures the rate of carbon change in a given period, i.e. mean annual increment or decrease of carbon. This method is better suited for forest degradation where the stock change can be measured in two time periods through the expected change in carbon stock.

$$C_t = \sum_{i=1}^n AD_i \times EF_i \quad [2.2]$$

where  $C_t$  is the carbon stock gained or lost in time  $t$ ,  $AD_i$  is the activity data or the area undergoing a specific type of land use change that emits or stores carbon (measured in ha), and  $EF_i$  the emission factor, which is the total loss or gain of the carbon stock per unit land area during the specific time and under specific land use change (measured in tC). Carbon stock or release by deforestation or forest degradation does not account for the emission level in terms of carbon dioxide equivalent. In doing so, the obtained values have to be multiplied by the carbon dioxide ( $CO_2$ ) emission factor (44/12) as recommended by IPCC (2006) and FAO (2015).

These methods have been widely used for the quantification of  $CO_2$  resulting from land use conversion across various land use and climate regimes. However, these estimations are questionable due to the generalized IPCC (2006) tiers (1, 2 and 3) to use. Emission factor or release/sink of carbon from soil depends on the soil type, land use management (size and intensity), topography and climate. Therefore, generic factor utilization may cause biases that may over or under estimate the values leading to poor and unrealistic greenhouse gas estimation. FAO (2010) reported that uncertainties in estimates of GHG emissions are due to uncertainties in emission factors, carbon stocks and activity data.

### 2.2.3 Soil Carbon Dynamics across Major Farming and Cropping Land Use System

Carbon stock across various agricultural systems are relevant to meet the triple win of food security, climate change mitigation and ecosystem management. As such, review of the potential of both perennial and annual farming systems in the context of soil carbon stock resulting from native forests and vegetation clearance must draw our attention to the ecosystem and climate wellbeing. Moreover, as the world is computerized over these recent decades, formulation of valuable scenarios in predicting future trends of crop yields, soil and climate behaviors using

process base and biophysical models; fair knowledge of each system soil carbon potential is paramount. The main question is that; how do we compensate the soil reference carbon under each agricultural system? Simulation of 30-years' field experiments under rotation, fertilizer and residue management in Sub-Saharan Africa, especially in the Central region of Togo clearly showed that, though residues were incorporated and fertilizer used at high rates, crop carbon were not able to compensate for native carbon.

Under continuous cultivation, baseline carbon (15 tC/ha) decreased by 20 % (3 tC loss per hectare) after vegetation conversion to farmlands Kintché *et al.* (2010). Likewise, similar studies, e.g. Balesdent and Balabane (1992), (Andriulo *et al.*, 1999; Koglo *et al.*, 2016), have modelled the behaviour of different agricultural systems on soil carbon stocks and crop yields. Koglo *et al.* (2016). investigated the integrated straw formulations on Soil Organic Carbon Density (SOC<sub>D</sub>) using both field experiments and modelling approach. Results indicated an increase of SOC<sub>D</sub> by 43 % with model estimation of about 44.4 % compared to the carbon sampled before the start of the experiment. Simply put, farming and cropping systems influence soil carbon dynamics. Kintche *et al.* (2010, 2014) investigated the soil fertility under continuous maize-cotton cropping which were altered by fallow systems of farming, in this case, there was no compensation of carbon loss but there is decrease in soil carbon under periodic fallow compared to continuous cultivation. Also, studies have been done across different pedo-climatic conditions under different agricultural land use practices either conventional or biological and different tillage practices coupled with different fertilizers and amendments applications worldwide with good results related to soil carbon dynamics e.g. (Koglo *et al.*, 2016; Mancinelli *et al.*, 2010; Varughese, 2011; Zhang *et al.*, 2013; Henderson *et al.*, 2015; Gaoussou, 2016).

Generally, the conversion of native or old-growth forests to agriculture lands or other types of land use, results in carbon losses that maybe small or significant depending on the type of system and its management. Kumar *et al.* (2010) assessed carbon stock (aboveground and soil carbon) for various land use system (forest, plantation and agriculture) in Aravalli Mountains, Western India. Results revealed significant total carbon stock under forests ( $533.64 \pm 37.54$  Mg/ha) followed by plantations ( $324.37 \pm 15.0$  Mg/ha) and agriculture ( $120.50 \pm 2.17$  Mg/ha). Soil carbon also followed the same trends with  $172.84 \pm 3.78$ ; ( $153.20 \pm 7.48$  and  $108.71 \pm 1.68$  Mg/ha, respectively). They have posited that these differences in carbon stocks across land use types might be induced by variations in the vegetation and soil types, which confirms the investigation of Ussiri *et al.* (2006) on the influence of soil properties on soil carbon sequestration when mine soils were reclaimed with afforested pasture in Ohio State, USA.

Carbon (organic and inorganic) stocks in major soil types and LUS in the semiarid tropical region in Southern India was also investigated by (Venkanna *et al.*, 2014). The findings clearly showed that soil organic carbon performed well in Alfisols compared to Inceptisols and Vertisols with 52.84; 51.26 and 49.33 Mg/ha, respectively. In contrast, Vertisols have the highest soil inorganic carbon (22.9 Mg/ha) followed by Inceptisols (17.5 Mg/ha) and Alfisols (12.4 Mg/ha). Regarding the investigated LUS, total carbon (Mg/ha) was highest in the forest system (87.29), ahead fodder (60.03), Paddy (57.12), maize (52.12), chilli (49.50), red gram (48.44), intercrop (45.69), cotton (44.98), permanent fallow (44.81) and Castor system with lowest carbon (36.86). Afforestation systems after forests conversions give also a specific response to soil carbon balance.

Relevant studies have been carried out in regards to the key implications of such systems in the soil carbon cycle. Contributions of savannah derived carbon to carbon dioxide effluxes decline rapidly after afforestation. A study carried out in the Congo on the dynamics of soil carbon after

afforestation with Eucalyptus showed positive implications in reversing back the labile carbon loss Epron *et al.* (2009). Likewise, studies related to carbon storage of agroforestry systems or in association with other cropping systems have been widely investigated. Referring to cocoa farming carbon ability, Mohammed *et al.* (2016) undertook an appraisal study on the potential of Ghanaian shaded and unshaded cocoa farming systems on carbon stock in Eastern and Western regions of Ghana. As a result, the total carbon stock difference was significant across region with highest carbon stock in Western ( $137\pm 8.6$  MgC/ha) than Eastern ( $95\pm 8.6$  MgC/ha) region. In all, total carbon (biomass + soil) for both ecosystems ranged from 81.8 to 153.9 MgC/ha. In conclusion, cocoa farming system is a potential focus for carbon sink and must be taken into account in the national carbon accounting emissions budget.

Agroforestry ability to redress greenhouse gas emission concentration, especially sink of carbon is well documented in existing literature (e.g. Dixon, 1995, Dawoe, 2009). Thus, agroforestry systems or tree-crop farming are likely to alleviate carbon removal with potential co-benefits. Dawoe *et al.* (2016) investigated the aboveground carbon stocks under shaded trees and cocoa farming systems in Ghana. Results revealed significant differences of carbon between shaded trees, but similar in cocoa trees. However, the amount of carbon was high in cocoa trees ( $8.32\pm 1.15$  MgC/ha) compared to shaded trees ( $7.45\pm 0.41$  MgC/ha).

#### 2.2.4 Carbon Dioxide Emission and Removal from Forest Conversion

Forests cover about 4 billion hectares globally approximating 31% of the world's total land mass, with climate change as a threat multiplier through the storage of carbon into the soils and plants biomes, e.g., deforestation is the second largest source of carbon emission (15%) projected to increase with regard to population growth (Cramer *et al.*, 2004; VanderWerf *et al.*, 2009), Deforestation and forest degradation account for 12 – 20% of worldwide anthropogenic

greenhouse gas emissions (Saatchi *et al.*, 2011). On a global scale, tropical forests are largest carbon sink (547.8 million tonnes of Carbon in tropical and subtropical forests) (FAO, 2010; UN-REED, 2016a; 2016b; 2016c). Tropical forests are carbon dense and highly productive, covering 7 – 10 % of the global land area with the ability to store up to 40 – 50% of all terrestrial carbon (Lewis, 2006;2013; Lewis *et al.*, 2009; Malhi & Grace, 2000). Lewis *et al.* (2009), investigated carbon stock potential of some tropical forests in ten countries across 79 plots (164 ha) under AfriTRON (African Tropical Rainforest Observation Network).

Lewis *et al.* (2009) study indicated the increase aboveground carbon stock by 0.63 MgC/ha/y with carbon sink of 1.3 Pgc/y across all tropical forests during the recent decades when considering live trees with a diameter greater than 10 cm for the intact old growth forest. The total annual increase in tropical forest carbon stocks considering the same tree's diameter were 0.25, 0.44 and 0.62 Pg in Central and South America, and Asia, respectively. A similar study has been done in the Central Congo Basin in Yangambi, Democratic Republic of Congo with  $162 \pm$  MgC/ha aboveground carbon stock for virgin old-growth forest without considering tree height-diameter relationship, with 24% aboveground carbon overestimation (Kearsley *et al.*, 2013). Also, pantropical forests carbon storage and species richness across different biomes (Africa, Asia and South America) have been investigated.

Results indicated high, low carbon stock per unit area with low and high tree diversity in Africa and America, respectively. Forest in Asia, differed both with higher carbon and species abundance (Sullivan *et al.*, 2016). These results concur with Slik *et al.* (2010). Forest biomass carbon stocks variation for Tibet's forest in China from 2001 to 2050 have also been reported by (Sun *et al.*, 2016). Results indicated a likely forest biomass carbon stock increase from 831.1 to 969.4 TgC from 2001 to 2050, with a net gain of 3.6 TgC and 1.9TgC/y between 2001- 2010 and 2040 – 2050,

respectively. Even though tropical forests are under threats by human-induced actions, viz: deforestation due to agricultural activities, population growth and illegal logging activities, they still have high potential of carbon stock through regrowth and regeneration into tropical secondary forests. A case study conducted in Philippines provided a success story on the perpetual role of tropical secondary forests in storing carbon after some years of shifting cultivation. Mukul *et al.* (2016) measured the distribution and recovery of aboveground biomass carbon along a fallow gradient in *post-kaingin* secondary forests in an upland area of Philippines. Higher carbon was found in total aboveground biomass and living woody biomass in old-growth forest, while new fallows sites witnessed significant carbon from coarse dead wood biomass. Secondary forests are the dominant forest types in the tropical regions with more than half of the tropical forest area, and have rapid accumulation rates of carbon especially in the aboveground biomass (Malhi *et al.*, 2006; Pan *et al.*, 2011).

Despite the efforts in estimating tropical forest's potential in removing and sinking carbon, these results are still questionable for some reasons. Firstly, data scarcity at the level of deforestation and forest degradations, secondly a limited number of field studies per country and per ecosystem (Chave *et al.*, 2005; Malhi, 2010), and thirdly unknown amount of contribution of tropical forests to soil carbon sinks resulting from the conversion of forests to farming systems and vice versa. Some countries which have been doing well so far with tropical forests carbon estimations in the context of REDD+ programme, however, West African countries have to double their efforts and politics and invest in research in quantifying the level of carbon inputs of intact old-growth and artificial forest carbon stock.

Wall-to-wall carbon quantification must be a good start for policy actions and research prerogatives. It is likely that knowing the contribution of carbon removal and sink across different

carbon pools rather than carbon content in biomass is paramount for actions. Farming systems are proximate drivers of deforestation and forests degradation concomitant to anthropogenic greenhouse gas emissions. Nonetheless, they also have the potential to offset carbon cycle through implementation of sustainable and cost-effective practices (Koglo *et al.*, 2017). Accordingly, questions such as the contribution of each system on the amount of carbon inputs per pool must be primary to our research investigations. These studies gave credible evidence of the influence of farming activities on total carbon stocks. Also, this assessment must go beyond generalization to specific induced effects of each system. Knowing that soil carbon of each crop type, viz: annual and perennial crops in different agroecosystems are elusive and require more clarifications for judicious actions. Soil organic carbon is one of the five major carbon pool recognized by the Intergovernmental Panel on Climate Change (IPCC) with ability to sequester three times plants, carbon stock, and it is very sensitive to land changes, as up to 87% of soil carbon decline may occur due to deforestation (Totey *et al.*, 1986; Singh *et al.*, 1995; Post and Kwon, 2000). Therefore, accurate estimation of soil carbon across land uses and field scale emission factor is paramount to the identification of soil carbon booster practices in mitigating and adapting to climate change.

## **CHAPTER 3: LAND USE AND ITS MANAGEMENT, INDIGENOUS AND CLIMATE SMART ADAPTATION STRATEGIES FROM FOREST SAVANNAH ZONES (TOGO)**

### **3.1 Implications of some Major Human-Induced Activities on Forest Cover Using Extended Change Matrix Quantity and Intensity Analysis Based on Historical Landsat Data from the Kloto District, Togo**

#### **Abstract**

This study analyses forest reference level in terms of loss, gain and transitions among forest, cocoa agroforestry, cassava, maize, settlement and others in the Kloto district (Togo) for REDD+ and sustainable forest and agriculture. The pixel-based classification was adopted and combined with the extended change matrix quantity and intensity analysis using 32-year (1985 to 2017) Landsat data and land use information from land owners and farmers. Results indicate an active forest loss (19.5%) with dormant gain (0.8%). Forest is involved in most transitions as the most targeted category with the largest transition being a forest to cocoa agroforestry while the avoiding transition was from forest, cocoa agroforestry, maize, cassava and settlement to unclassified classes (e.g., road, water body) and vice versa. Other targeting categories were from forest to settlement, cassava and maize. Thus, both cash and food crops are major contributors of forest loss. The study concludes that cropland land degradation is the main reason that explains the significant conversion of forest lands to stable agricultural lands. Therefore, review of the existing cropping and farming systems by promoting agroecology systems (e.g., agroforestry, rotational cropping, mixing cropping with pulses) to sustain and restore soil degradation while mitigating climate change, forest degradation and provide food security for the rural communities is recommended. Economic measures such as: trade-off compensations for agroecology practices and afforestation and reforestation through farmer's association initiatives could be encouraged to limit forest extensions.

Keywords: Forest, REDD+, Extended Matrix, Intensity Analysis, Soil degradation, Agroecology

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### 3.1.1 Introduction

The deliberate conversion of tropical forests to agricultural lands, intensive deforestation, and forest degradation and inappropriate land management practices are the major impediments to forests and soil carbon sequestration potential (Denman *et al.*, 2007; Lal, 2008a,b; Stockmann *et al.*, 2013; Koglo *et al.*, 2016, 2017) in a changing climate. According to Valentine *et al.* (2000), forests have a remarkable ability to store carbon in both plants and soils and they are valuable natural break and sinkers of atmospheric carbon dioxide. The largest source of GHG emissions in most tropical countries is from deforestation and forest degradation. Fearnside & Laurance (2003) and Houghton (2005) investigation on tropical deforestation revealed that 1 to 2 billion tonnes (roughly 15 to 25 % annual global greenhouse) of carbon are being lost per year since 1990's. Lasco (2002) also posited that land use change and forest conversion are a significant source of CO<sub>2</sub> contributing to around  $1.7 \pm 0.6$  Pg C per year (e.g., Parks & Hardie, 1995; Plantinga & Birdsey, 1995; Callaway & Mccarl, 1996; Stavin, 1999; Kanime *et al.*, 2013).

Besides, land use change (e.g., forest to agricultural and non-agricultural lands) is one of the primary drivers of climate change and global warming (e.g., changes in albedo and radiative forces) with serious environmental and socioeconomic concerns. Following this background, in Togo, close analysis of available statistics on greenhouse gas emissions revealed significant released from land use change (forest to agriculture) compared to energy, industry, and waste management sector (MERF, 2001). This crucial step is paramount for the implementation of precautionary measures to mitigate the emissions resulting from forest conversion to agriculture lands. Thus, it is important to answer the following questions related to the changes, viz: when? (period and identification of the changes via remote sensing and GIS technology), how much? (referring to the significance of the changes), where? (locations) and moreover, what to do? (what

necessary and sustainable decision or measure to make). Knowing the initial time (time 1) and the transition time (time 2), change detection (pixel, area or percent of the map) analysis or transition matrix analysis can be performed to account for the net changes for each land use type from time 1 to time 2. However, this method fails to account for the likelihood gains and losses of a category from one location to the other. Moreover, it does not inform on the intensity of the changes (targeted/avoided and active/dormant categories) as well as the swap change (the difference between the total change and net change or spatial relocation), swap distance and persistent land use category (Pontius *et al.*, 2004). Thus, extended cross-tabulation matrix analysis combined with the intensity of gains and losses and transition intensity accounts for allocation changes based on land cover change signals. It is against this background that, scientific communities and policy makers have given credit to driven forces of deforestation and forest degradation projects and researchers to limit forest depletion and degradation.

The role of forests in a changing climate is of utmost importance to meet the requirements of sustainable development goals. Diminishing emission from deforestation and forest abasement; protection of timberland carbon stocks; sustainable management of forests and improvement of forest carbon stocks (REDD+) have turned into the major theme of environmental change discussion. For instance, the 2030 Agenda for Sustainable Development and the Development Goals and the United Nations Strategic Plan for Forest (UNSPF) 2017 – 3030 made and bold an ambitious commitment to halting deforestation in 2020 by reversing the loss of forest cover and increasing forest area by 3% ([www.cpfweb.org](http://www.cpfweb.org)). REDD+ does not only roll back climate change but also proffers additional co-benefit in response to food security, conservation of nature and improvement of socio-economic livelihoods of rural and poorest communities that are likely to experience the adverse effects of climate changes.

Accordingly, the main question to ask is how much forest changes and at which rates? and what are the impacts of anthropogenic activities on forest carbon loss or gain in Kloto district (Togo)? Several studies have been carried out on land use, land cover changes from one period to another (e.g., Han *et al.*, 2009; Munsi *et al.*, 2010; Badjana *et al.*, 2014; Folega *et al.*, 2014; Sambou *et al.*, 2015; Diwediga *et al.*, 2017), intensity analysis and its implications on carbon cycle (e.g., Pontius *et al.*, 2004; Manandhar *et al.*, 2010; Aldwaik & Pontius, 2012; Runfola & Pontius, 2013; Villamor *et al.*, 2014). However, little is known about the differentiation of food and cash crops extent (e.g., maize, cassava and cocoa agro-forestry) and the extent of urbanization (population growth). Moreover, these studies fail to integrate historical land occupation information and the extended quantity and intensity analysis. It is, therefore, a prerequisite to investigating long-term transitional dynamics of annual and perennial farming system expansions and population growth on the gain and loss of native forest extent at a local and national level in developing countries, notably Togo to facilitate forest reference levels (FRL) and forest emission reference level (FERL) assessment. It is a way to formulate solid arguments for the REDD+ establishment and accurate measuring, reporting, and verification of REDD+ to United Nations organs and Climate change donors.

From the foregoing introduction, this paper aims to assess 32 years transitional and intensity changes on the native forest extent due to maize, cassava, cocoa agroforestry cropping, and urbanization extent for establishing a logical framework model for sustainable forest management while increasing crop productivity and establishing recommended landscape programmes. Simply put it presents: (i) the quantity of changes in terms of gross gains, losses, persistence, net and swap changes; (ii) the intensity of gains and losses and (iii) the intensity of transition from forest to other land use type (maize, cassava, cocoa agro-forestry farming and settlements).

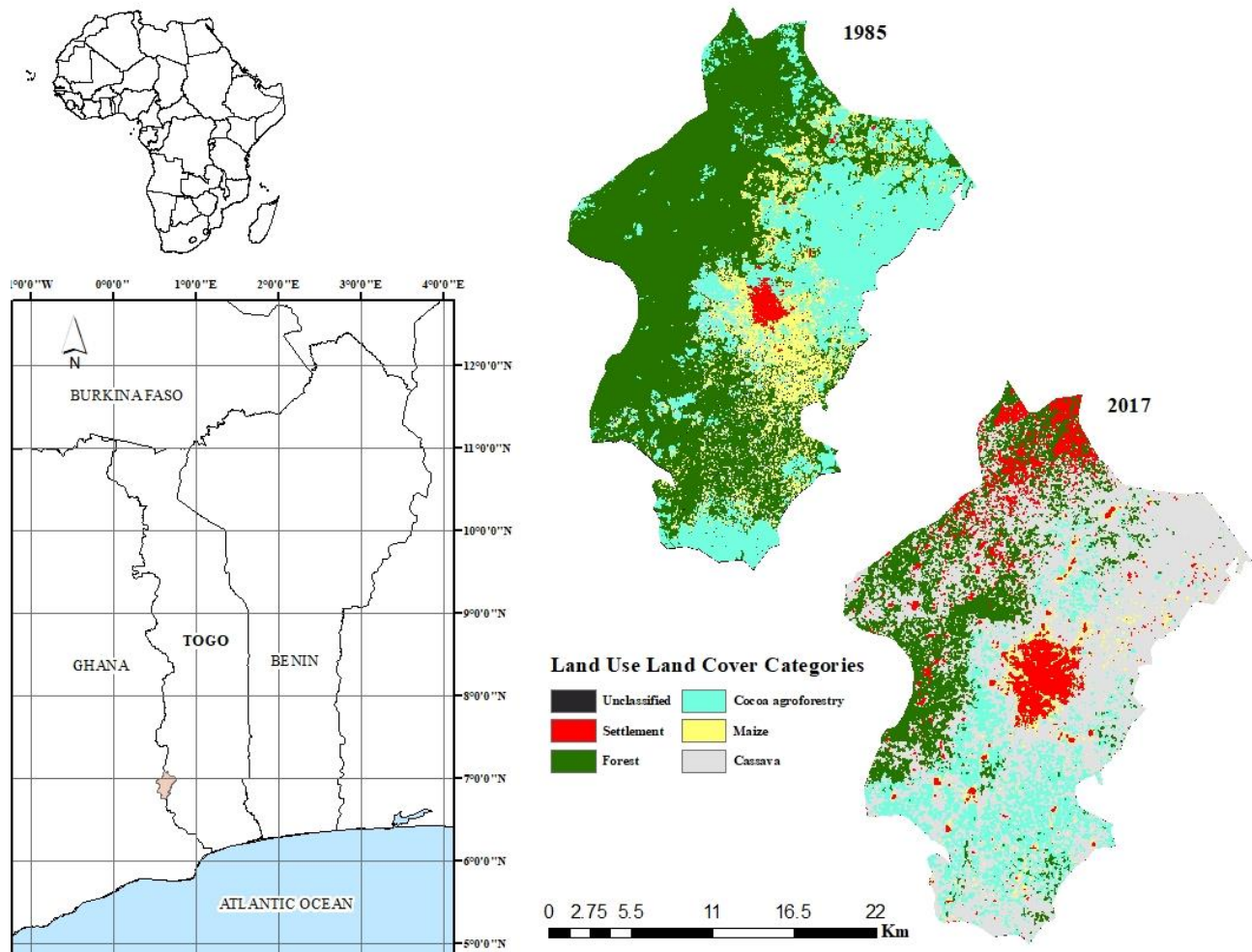
### **3.1.2 Materials and Methods**

### ➤ Study Area

The study was conducted in Kloto district, Togo and covers an approximate land area of 528.23 km<sup>2</sup>. It encompasses 13 sub-districts located in the northwest of the capital, Lomé (Figure 1.1). Kloto is located between 0.50° and 0.77° East and 6.75° and 7.0° North. The district covers a total area of 528.23 km<sup>2</sup>. The major economic activity is farming of food crops (e.g., maize, cassava) and cash crops (cocoa and coffee agroforestry). The average production of maize and cassava from 1990 to 2016 revealed an annual production of 10,928 and 19,498 tonnes for maize and cassava over an area of 8,291 and 3,080 hectares, respectively. From 2014 to 2016 cocoa agroforestry of 2,762 hectares produced 1,041 tonnes annually (Author, 2016).

### ➤ Data Collection and Analysis

Two Landsat data (5 and OLI) of March 1985 and April 2017 were downloaded from the USGS with cloud cover less than 10% using path (193) and row (055). We assumed same phenological conditions because of the bimodal climate . Acquired images were pre-processed for atmospheric (cloud and noise removal) and radiometric (brightness) corrections as well as layer stacking and sub-setting in ArcGIS. Thereafter, thematic analysis was performed in ENVI software based on six (06) Land Use, Land Cover types (Figure 3.1), viz: forest, cocoa agroforestry, maize, cassava farms, settlements and unclassified.



**3. 1: Land use land cover map of the study area**

A field campaign was organized from May to October 2017 for historical land occupational information via an interview with landowners and farmers and 40 random points of each land use type were collected to train and validate the classification. Image calibration of the two years was done using ground through and archive land occupational geo-referenced points (40 in total) of each land use type of the subsequent years of available statistics (Author, 2016) with the assistance of google earth historical data records, and classification was performed using a Maximum Likelihood Classifier. And the post-classification technique was initiated to derive the extended cross-tabulation matrix for land use change and intensity analysis.

➤ Quantity of Land Use Change

Change analysis of the thematic classes from time 1 (1985) to time 2 (2017) (Figure 3.1) as percent of map was assessed in terms of persistence (diagonal entries), total loss (total row of category  $i$  minus percentage map of the same category of final year), total gain (total column of category  $j$  minus category  $j$  of the initial year). The extended change matrix was also used to derive the total, net and swap changes of each land use category. The total change (TC) of a category is the sum of its gross gain and loss. At the main time, the net change (NC) of a category is the difference between its gross gain and loss while the swap change (SC) of a category is the difference of a total change and net change for the category.

➤ Intensity Analysis

The gain and loss intensity (GI, LI) were duly derived from the change matrix knowing that the uniform intensity (UI) of the transition is the total gain or loss of the four thematic classes. The gain and loss intensity help to identify dormant (GI or LI less than UI) or active (GI or LI greater than UI) categories. The LI and GI of a category were calculated by dividing the loss of a category in 1985 and a gain of a category in 2017 with the size of the categories in 1985 and 2017, respectively. Similarly, the loss and gain transition intensity of forest, cocoa agroforestry, maize and cassava farms were calculated from the extended matrix. In this case, the transition intensity (TI) denotes targeted (TI greater than UI) or avoided (TI smaller than UI) categories when a particular category changes into another category. Thus, the loss transition intensity (LTI) from forest to cocoa agroforestry, for instance, was obtained by dividing the loss of forest to cocoa agroforestry in 1985 with the gain of cocoa agro-forestry in 2017. Therefore, the LTI is compared to the hypothesized Uniform Loss/Gain Intensity (ULI/UGI) of forest loss to cocoa agroforestry, maize, and cassava. The ULI/UGI is the union of forest loss to cocoa agroforestry, maize and

cassava divided by the sum of cocoa agroforestry, maize and cassava and vice versa. Moreover, the gain transition intensity (GTI) of forest from cocoa agroforestry farms, for example, is computed by dividing the size of cocoa agroforestry in 1985 with the gain of forest from grassland.

### 3.1.3 Results and Discussion

➤ Quantity of Land Use Transition

Results (Table 3.1 and 3.2) revealed significant persistence (49.50%) of unclassified pixels (e.g. road, water bodies) with the marginal loss (0.04) and gain (0.00), respectively. The transition of other classes (settlement, Cassava, Maize, Cocoa Agroforestry, and forest) to such pixels is quite negligible (0%) over 32 years (1985 – 2017) land use and land cover transition analysis. In the meantime, Table 2 shows a total gain/loss of 38.29% with 61.71% persistence.

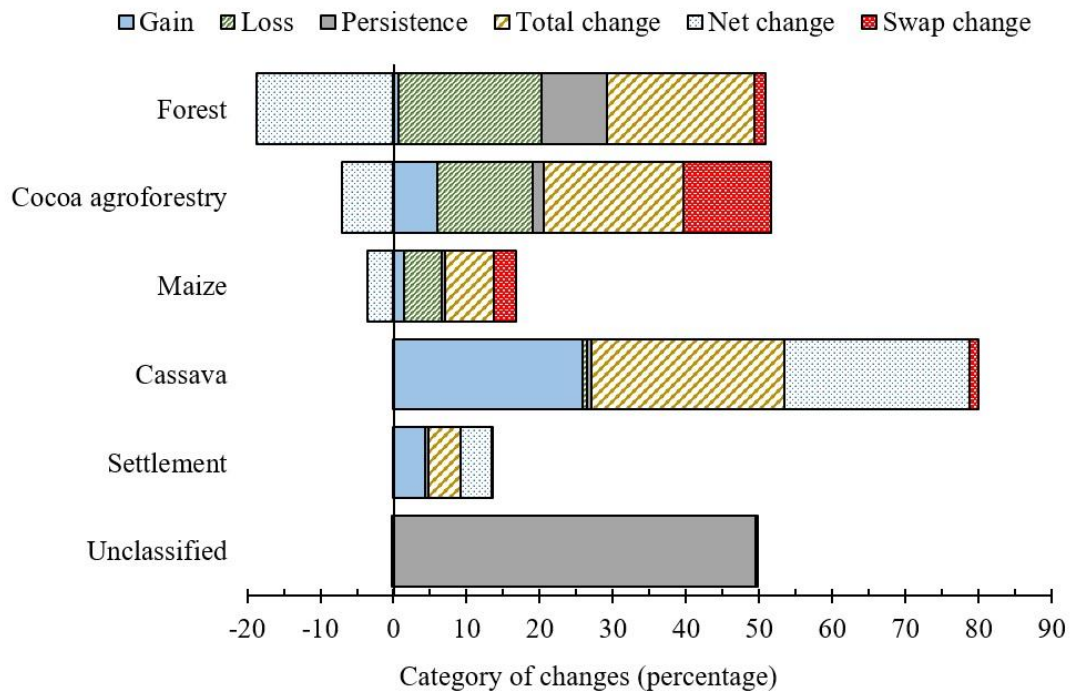
**Table 3. 1: Change matrix from 1985 to 2017 in the percentage of the map**

		2017							
		Unclassified	Settlement	Cassava	Maize	Cocoa agroforestry	Forest	Total 1985	Loss
<b>1985</b>	Unclassified	49.49	0.00	0.02	0.00	0.01	0.00	49.53	0.04
	Settlement	0.00	0.54	0.01	0.02	0.00	0.00	0.57	0.03
	Cassava	0.00	0.05	0.70	0.08	0.43	0.05	1.32	0.62
	Maize	0.00	0.71	3.14	0.51	1.04	0.17	5.58	5.06
	Cocoa agroforestry	0.00	1.29	10.51	0.75	1.56	0.52	14.63	13.07
	Forest	0.00	2.21	12.12	0.65	4.49	8.90	28.37	19.47
	Total 2017	49.50	4.80	26.49	2.03	7.54	9.65	1.00	38.291
	Gain	0.00	4.26	25.79	1.51	5.97	0.75	38.29	

**Table 3. 2: Gain, loss, persistence, total change, net change and swap change per category**

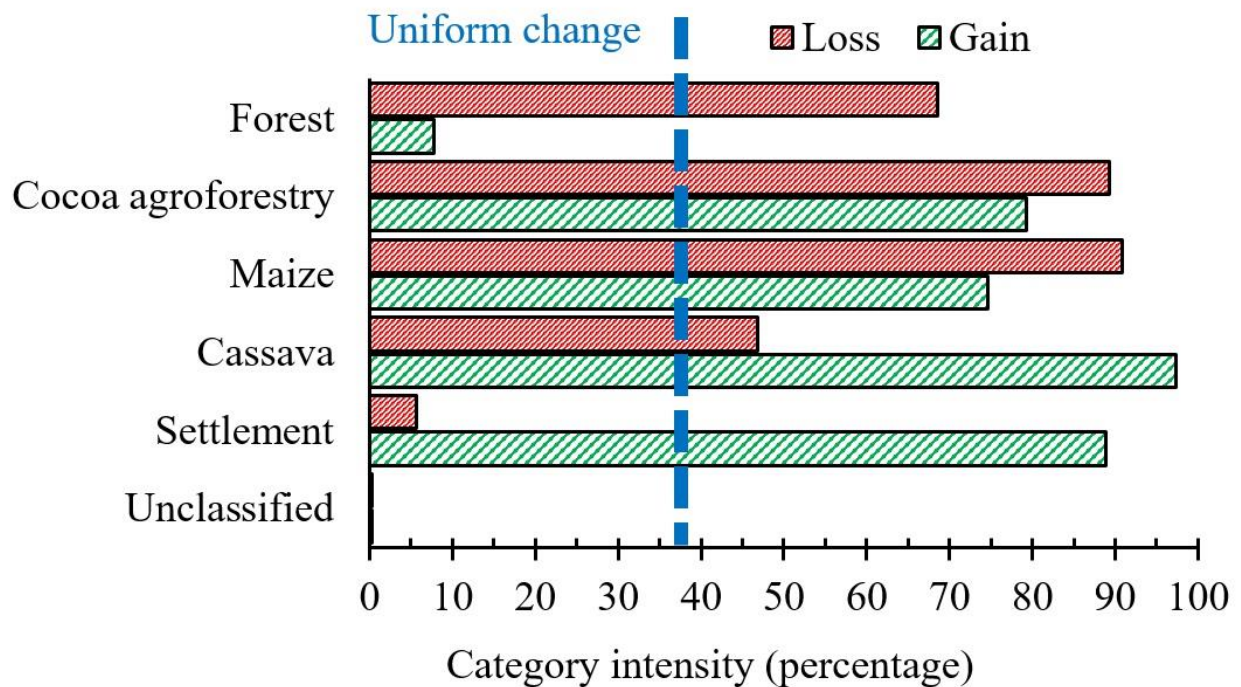
	Gain	Loss	Persistence	Total change	Net change	Swap change
Unclassified	0.00	0.04	49.49	0.04	-0.04	0.00
Settlement	4.26	0.03	0.54	4.29	4.23	0.06
Cassava	25.79	0.62	0.70	26.41	25.18	1.23
Maize	1.51	5.06	0.51	6.57	-3.55	3.02
Cocoa agroforestry	5.97	13.07	1.56	19.05	-7.10	11.95
Forest	0.75	19.47	8.90	20.22	-18.72	1.50
<b>Total</b>	<b>38.29</b>	<b>38.29</b>	<b>61.71</b>			

Very dynamic categories were distinguished in terms of total changes (Figure 3.2) namely cassava (26.41%), forest (20.22%) and cocoa agroforestry (19.05%); dynamic classes encompassing maize (6.57%) and settlement (4.29%) and unclassified pixels as a stable class (0.04%) in terms of loss-gain and vice versa over 32years period. The net change (Figure 3.2) reveals high forest land reduction (18.72%) follow by cocoa agroforestry (7.10%), maize (3.55%) and others (0.04%) to the detriment of cassava and settlement which are gaining 25.18 and 4.23%, respectively.

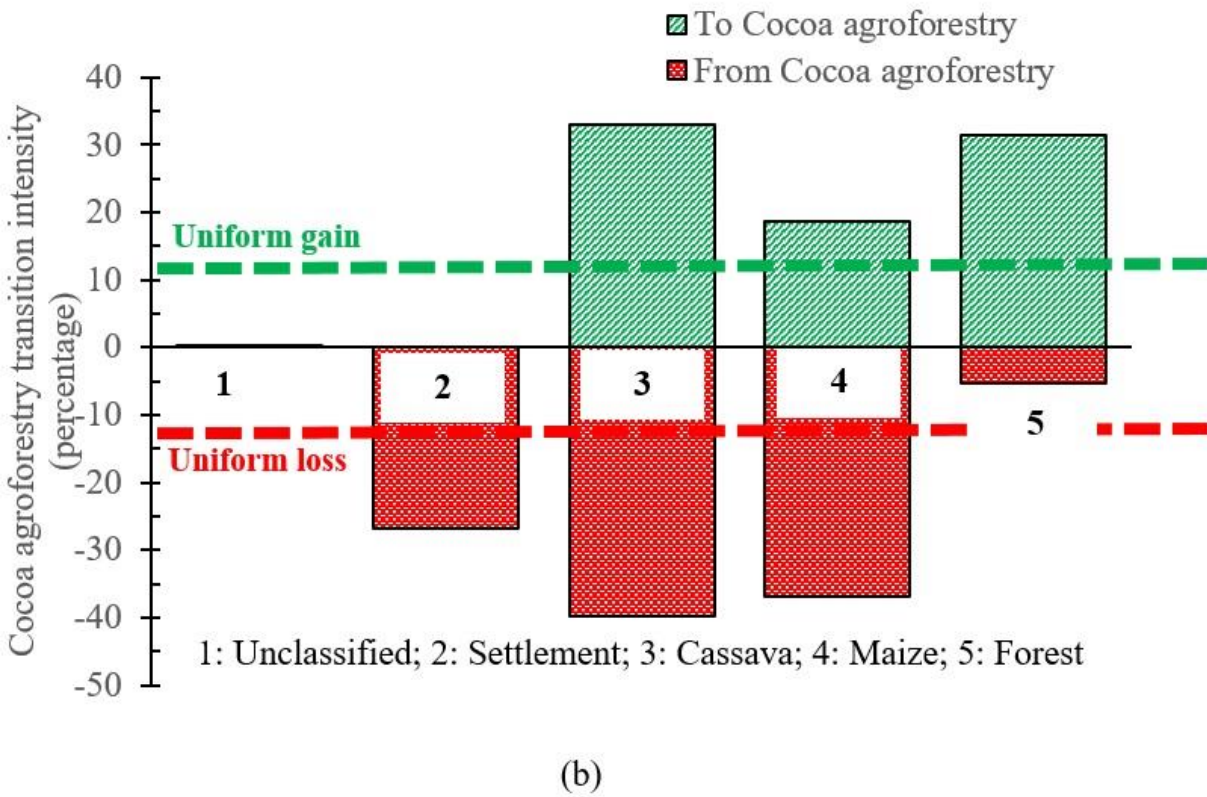
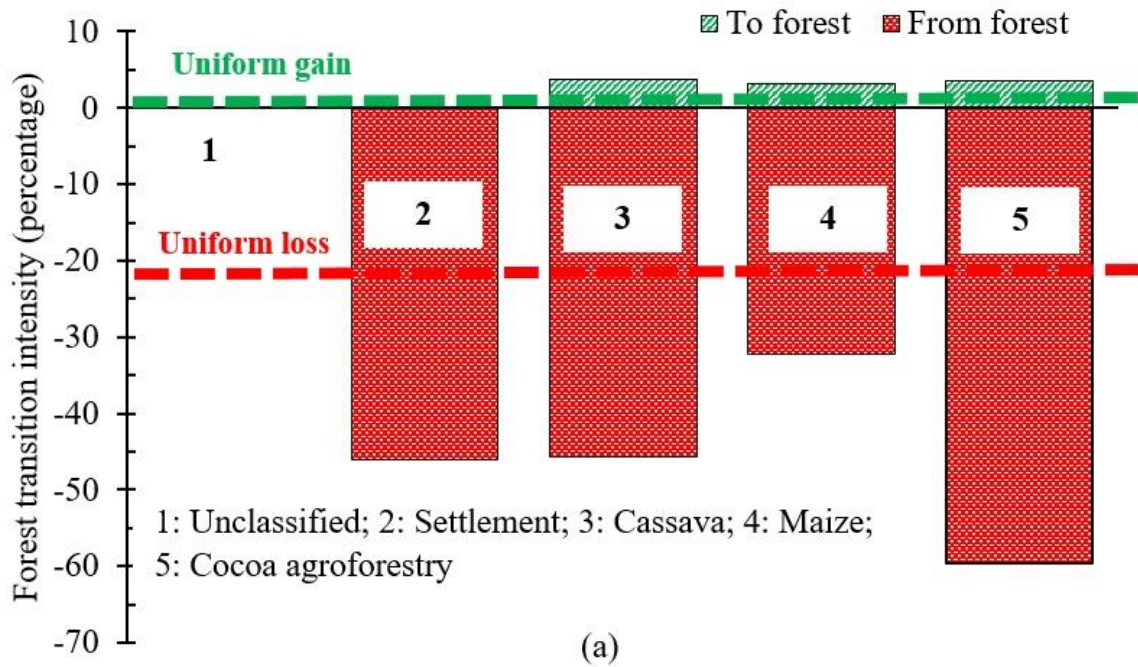


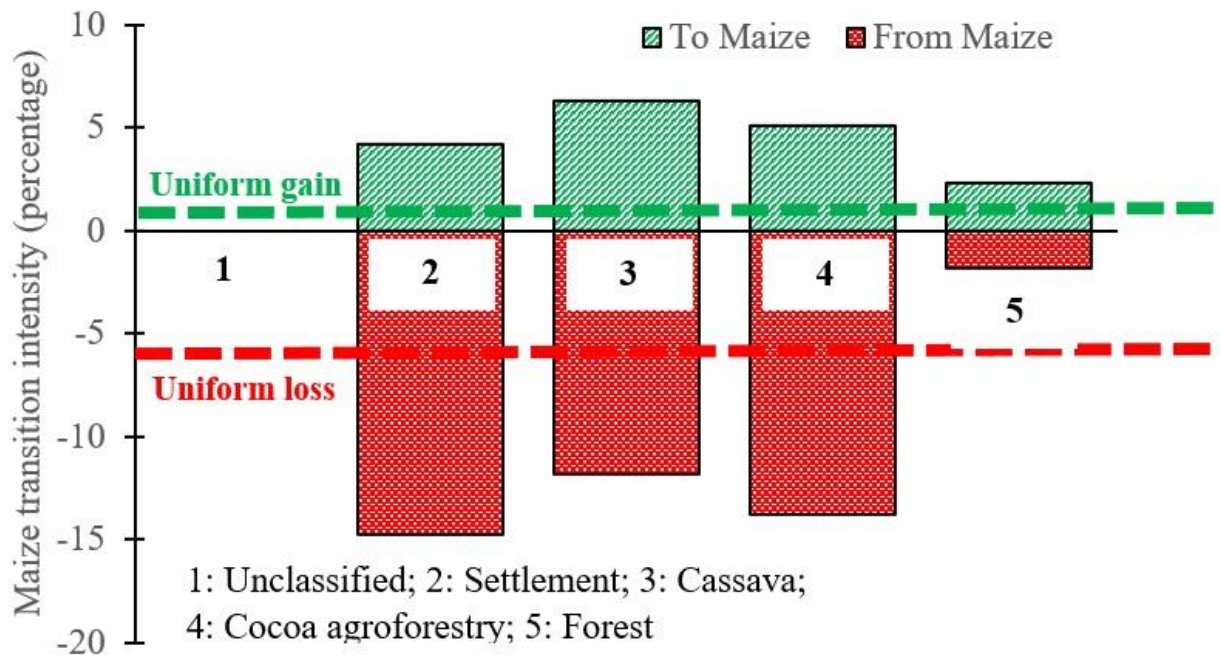
**Figure 3. 2: Quantity of land use transition**

The spatial relocation regarding loss or gain pixels shows a maximum distance change of 11.95 km for coca agroforestry and 1.50 km of forest lands. Cassava lands gain from others land use categories at a minimum distance of 1.23 km less than maize (3.02 km) and settlement (0.06 km). In sum, the quantitative analysis indicates that there are a change from forest to agricultural (cassava, maize, cocoa agro-forestry) and non-agricultural (settlement and unclassified) land use systems. However, it did not give the information about the speed of the change as well as the intensity at which the changes are occurring. In that line, intensity analysis was performed to determine dormant and active categories (Figure 3.3) of the transition as well as the targeted and avoided categories (Figure 3.4) of the 32 years' transition analysis.

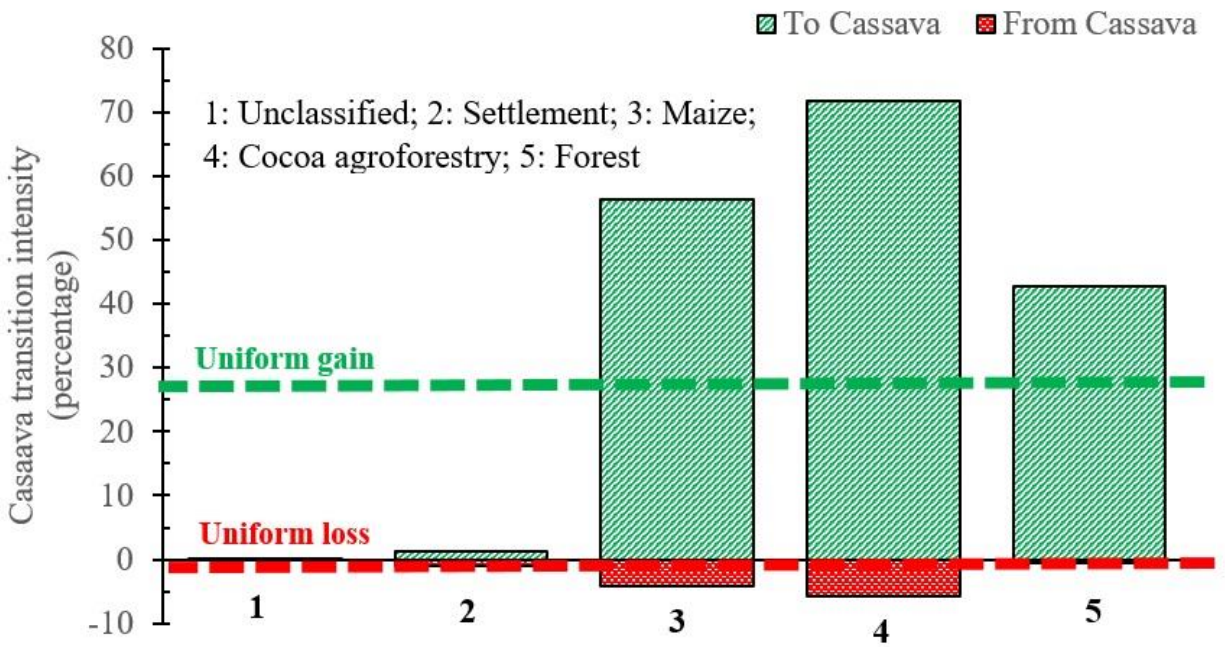


**Figure 3. 3: Gain and Loss intensity per category in percentage**

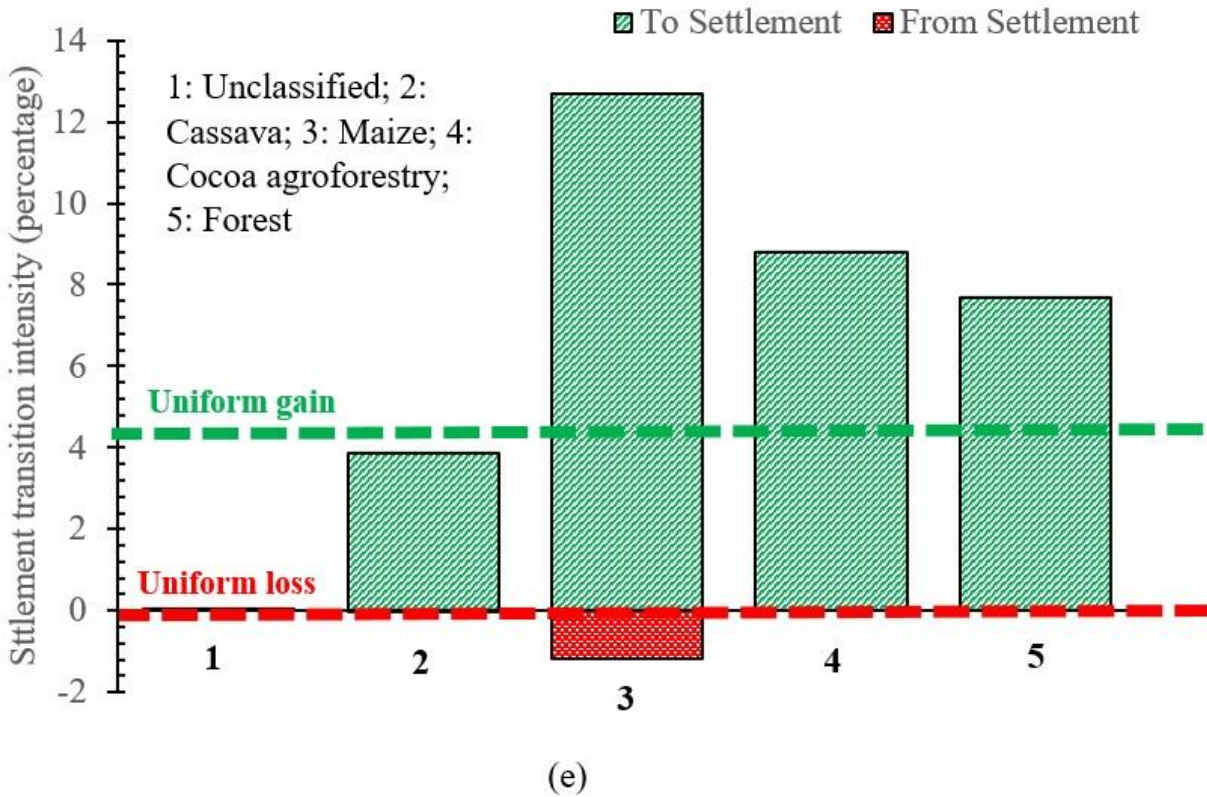




(c)



(d)



**Figure 3. 4: Land use land cover intensity of transitions expressed as (a) Forest, (b) Cocoa agroforestry, (c) Maize, (d) Cassava and (e) Settlement**

➤ Intensity Analysis

Results (Figure 3.3) depict the loss and gain intensity per category in percentage of map. Some categories, namely: unclassified and settlement is losing slowly while, cassava, maize, cocoa agroforestry, and forest are losing faster. Simply put, unclassified and settlement is dormant regarding area expansion, while, the remaining categories reduced significantly. In the meantime, some gain more sites compared to others (Figure 3.3). This is the case of forest which gains less than its losses. Forest gain is dormant ( $7.76 < 38.29$ ) while the conversion of forest to other land use, land cover types (e.g. settlement, cassava, cocoa agroforestry and maize) is active. This expansion of cultivated and non-cultivated areas is intense for cassava farms (97.36) followed by

settlement (88.80), cocoa agroforestry (79.28) and maize (74.63) farming systems. For the targeted and avoided categories of loss and gain transitions, Figure 3.4 (a-e) were used. The loss analysis (Figure 3.4a) revealed that deforestation and forest degradation is mainly targeted by cocoa agroforestry farms (59.60 %) followed by housing expansion (46.08 %), cassava (45.73 %) and maize (32.26 %) farms in 2017. In the meantime, the cocoa agroforestry loss (Figure 4b) is targeted by cassava (39.69 %) and maize (36.96 %) farming. In contrast, maize lost (Figure 4c) 14.75, 13.79 and 11.86 % to the detriment of the settlement, cocoa agroforestry, and cassava farm. The transition intensity of cassava, settlement, and unclassified categories (Figure 3.4d), Figure 3.4d depicts the high proportion of cassava loss to cocoa agroforestry (5.75 %) followed by maize (4.10 %) which also targeted settlement and others land use cover categories at 1.19 and 0.10 %, respectively. Transition to and from settlement is reciprocal with maize farming (Figure 3.4e), whereby, settlement losses and gains simultaneously from maize. Furthermore, the marginal gain of the forest came from cassava, cocoa agroforestry, and maize at 3.69, 3.56 and 3.13%, respectively while cocoa agroforestry took 32.89 and 31.37 % from cassava and forest rather than maize (18.64 %).

In the meantime, cassava targeted cocoa agroforestry farms (71.84 %) compared to maize (56.33 %) and forest (42.70 %). Results also revealed that settlement expansion is 12.70, 8.81 and 7.80 % due to maize and cocoa agroforestry farms and forest lands reduction respectively whereas, unclassified gain did not target any land use classes. From the analysis, it is quite an evident that deforestation and forest degradation transition intensity analysis in Kloto district is both agricultural (cocoa, agroforestry, cassava, and maize) and non-agricultural (settlement expansion) issues. The results present the role of agriculture and population growth on forest extinction. These results are consistent with similar studies in Indonesia (Villamor *et al.*, 2014; Gao *et al.*, 2016);

Ghana (Aloô and Pontius, 2008) and in China (Huang *et al.*, 2012; Zhou *et al.*, 2014) where, transition analysis revealed a systematic transition from either forest to croplands and from croplands to build-up. However, they failed to account for the part of individual systems for forest reference and emission level determination as a benchmark for REDD+ projects. Kloto district is a forest zone with the dominance of indigenous trees and cocoa agroforestry systems. These results could be explained by population growth, the market price of cash and food crops and farming and cropping systems in use. The perception of farmers and landowners bring to the conclusion that, population growth from 1985 to 2017 had implied a tremendous increase in food demand and expansion of residences. Recent population census (MPDAT, 2010) depicted a significant increase of rural population at national level to the rate of 25.2 % (1981) for 37.7 % (2010).

The population density of Kloto in 1981 was between 50 – 100 inhabitant/km<sup>2</sup> (Anipah *et al.*, 1989) against 263 inhabitants/km<sup>2</sup> in 2010 for a total population of 139,043 inhabitants (MPDAT, 2010). Moreover, economic incentives to cocoa and cassava prices in the market had promoted the conversion of many maize farms to cassava and cocoa agroforestry farms. Interview from farmers revealed that most of the farmers are adopting cocoa agroforestry farming systems (e.g. cocoa and coffee; cocoa, coffee, and cassava or cocoa, cassava and plantain) to increase and diversify their level of income. For others, the price of these cash and food crops are more stable at national and international markets compared to maize price. In addition to cocoa-cassava agroforestry systems, farmers also practice mono-cropping cassava systems with either indigenous or improved varieties while maize cultivation is mainly mono-crop. In some areas, maize is cultivated in association with cassava or as sequential cropping systems. The intensity of mono-cropping and the decline of soil fertility oblige farmers to clear more forests to the detriment of cocoa agroforestry, cassava and maize farms as revealed by the 32years land use transition analysis (Koglo *et al.*, 2018). These

analyses are similar to recent studies conducted in northern Togo by Diwediga *et al.* (2017). An evaluation of multifunctional landscapes progression in the mountainous basin of the Mo River (Togo, West Africa) from 1972 to 2014 uncovered an imperative anthropogenic land change prompting land degradation. This also explained part of the results of this study whereby, conventional agriculture intensifications and population growth are targeting native forest stability. The systematic land use transition was from forest to cocoa agroforestry followed by settlement expansion, cassava and maize farming with the total dormancy of forest gain and very active non-forest land cover types.

#### **3.1.4 Conclusion**

Land use transition analysis at sub certain level using extended matrix analysis, remote sensing and land occupational data information is scarce in developing countries for accurate REDD+ implementation, accountability and establishment of cost-effective sustainable land and forest sustainable management policies. This study uses this technique with pertinent results. Conclusions drawn revealed an intensive loss (19.47 %) of forest in the past 32years (1985 – 2017) to the detriment of cocoa agroforestry, maize, cassava farming and settlement expansion. In contrast, forest gain (0.75 %) slowly while, settlement, cocoa agroforestry, cassava, and maize are gaining faster. The systematic transition was from forest to cocoa agroforestry followed by cassava, settlement, and maize. These results are more explicit in formulating sustainable policies for each land use land cover type in forest management while promoting sustainable agriculture in forested zones (Kloto, Togo). This confirms the robustness of the land use transition analysis when combining satellite data with strong post classification analysis and historical land use information from landowners and/or farmers. In other words, it gives the exact effect of each land use type (e.g. food, cash crop or residential) on forest stability, loss or gain. This study recommends

demographic policies (e.g. family planning; incentive measures for small households), capacity building of land owners and farmers (e.g. sustainable forest management). As both cash and food crops are major impediments to forest loss, it urges to review the existing cropping and farming systems in the area by promoting agro-ecology systems (e.g. agroforestry, rotational cropping, mixing cropping with pulses) as natural fertilizers to regain and restore soil fertility while mitigating climate change, forest decline and providing more foods for the rural communities.

### 3.2 Remote Sensing-Based and Participatory Analysis of Forests, Agricultural Land Dynamics, and Potential Land Conservation Measures in Kloto District (Togo, West Africa)

#### Abstract

This study investigates proximate drivers of cropland and forest degradation in the Kloto district (Togo, West Africa) as a way of exploring integrated sustainable landscape approaches with respect to socioeconomic and environmental needs and requirements. Net change analysis of major cash and food crops based on Landsat data from three time steps (1985–2002, 2002–2017, and 1985–2017) and quantitative analysis from participatory survey data with farmers and landowners are used. The study underlines poor agricultural systems and cassava farming as major factors contributing to the alarming forest losses between 1985 and 2017. A significant net loss in forest cover of 23.6 % and areas under maize and cocoa agroforestry farming of 12.99 % and 10.1 % between 1985 and 2017, respectively, was noted. These significant losses are due to intensive cassava cropping (38.78 %) and settlement expansion (7.87 %). Meanwhile, the loss of forest cover between 2002 and 2017 was marginal (8.36 %) compared to the period 1985–2002, which had a considerable loss of 15.24 %. Based on participatory surveys, the majority of agricultural lands are threatened by erosion or physical deterioration (67.5 %), land degradation or salt deposits and loss of micro/macro fauna and flora (56.7 %), declines in soil fertility (32.5 %) and soil water holding capacity (11.7 %), and changes in soil texture (3.3 %). Most farmers adhere to the proposed climate smart practices, with an emphasis on cost-effective drip irrigation systems (45.83 %), soil mulching (35 %), and the adoption of drought-resilient varieties (29.17 %) to anticipate adverse spells. We conclude that low adoption of improved soil conservation, integrated water management, and harvesting systems and the use of less productive and adaptive cultivars entail extreme degradation of cropland and a decline in crop productivity. Consequently, farmers are forced to clear more forest in search of stable and healthy soil to meet their food demands and improve their livelihood. Capacity building on integrated pathways of soil and land management practices is therefore needed to ensure sustainable and viable socio-ecological systems at a local scale.

**Keywords:** forests; agricultural systems; land degradation; food security; climate change; remote sensing; survey datasets; Kloto district

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### 3.2.1 Introduction

One of the critical challenges facing humanity worldwide is land degradation and its negative effects, which translate directly into a decline in production, increase in poverty, diminished potential productivity, and climate change. Such effects of land degradation are more acute in regions with a high poverty rate where land use systems are threatening the sustainable maintenance and provision of land ecosystem functions and services and food security. In such conditions, integrated ecosystem management (IEM) and sustainable land management (SLM) are the most promising approaches to withstand soil degradation (Zhao, 2018). In the sectors of Agriculture, Forestry and Other Land Use (AFOLU), agriculture remains the main impediment to forest sustainability due to population growth and increasing human needs for food, energy, water, shelter, etc. With a global total area of nearly 4 billion hectares (30% of the Earth's surface cover), forests play a tremendous role when it comes to carbon cycling and ecosystem sustainability in a changing climate (Cramer *et al.*, 2004; Van derWerf *et al.*, 2009; Saatchi *et al.*, 2011; IPCC, 2014). However, population growth associated with increasing food demand, socioeconomic orientations of countries, and political situations underpin the alarming loss of forests and exacerbate land degradation in developing countries.

Several studies have focused on the various factors of land degradation (deforestation, forest degradation, and soil degradation). Moomen *et al.* (2016) underscored the relationships between mining and land degradation, with potential socioeconomic impacts in Upper West, Ghana. A case study in Cameroon and Congo also posited that institutional and policy factors are needed to combat deforestation, forest and land degradation (Tegegne *et al.*, 2016). Keenan *et al.* (2015) noted a significant net shrinkage in forest area, from 4128 to 3999 Mha, between 1990 and 2015, mainly in the tropics, with the highest rate of loss in low-income countries as a result of improper

land management practices and exponential urbanization. Consequently, it is estimated, according to Houghton (2005) and Gibbs *et al.*(2007), that 1 to 2 billion Mg of carbon are released per year as a direct consequence of forest conversion to agricultural land. Moreover, 15–25% of annual greenhouse gas emissions emanated from tropical deforestation, forest and land degradation. Globally, efforts towards climate mitigation and adaptation emphasize Integrated Ecosystem Management approaches through the implementation of land degradation neutrality projects and policies (Wunder *et al.*, 2018). In this regard, United Nations institutions (e.g., UNCCD, UNEP, UNFCCC, FAO) and affiliated research centers (e.g., CIFOR, WWF, ICRAF) have put forward an ambitious plan to halt deforestation and forest degradation, protect and promote forest reserves, restore degraded land and forest ecosystems, and improve capacity building on integrated forest and agriculture landscape management towards the achievement of land degradation neutrality (Wunder *et al.*, 2018).

In West Africa, and especially in Togo, deforestation and land degradation are acute environmental challenges occurring at an unprecedented rate due to exponential urbanization and unsustainable agricultural practices to meet the food demands of the growing population. Annual deforestation is alarming, occurring at a rate of up to 4.5% against a total forest cover of nearly 24.24% of national land ([www.reddtogo.tg](http://www.reddtogo.tg)). Deliberate expansion of cropland entails significant degradation of native forestland in association with total conversion of forest area to cropland, mainly for cash crops (cocoa, coffee, teak, and oil palm) and food crops (rice, maize, and cassava) in forest zones (Koglo *et al.*, 2018). These conversions drive on-site (e.g., soil degradation, loss of life and biodiversity, and property destruction) and off-site (e.g., greenhouse gas emissions, climate change, and global warming) drawbacks. Relevant studies on forest dynamics in a changing climate, its roles, drivers, policies, and reliable methods for their monitoring are duly undertaken

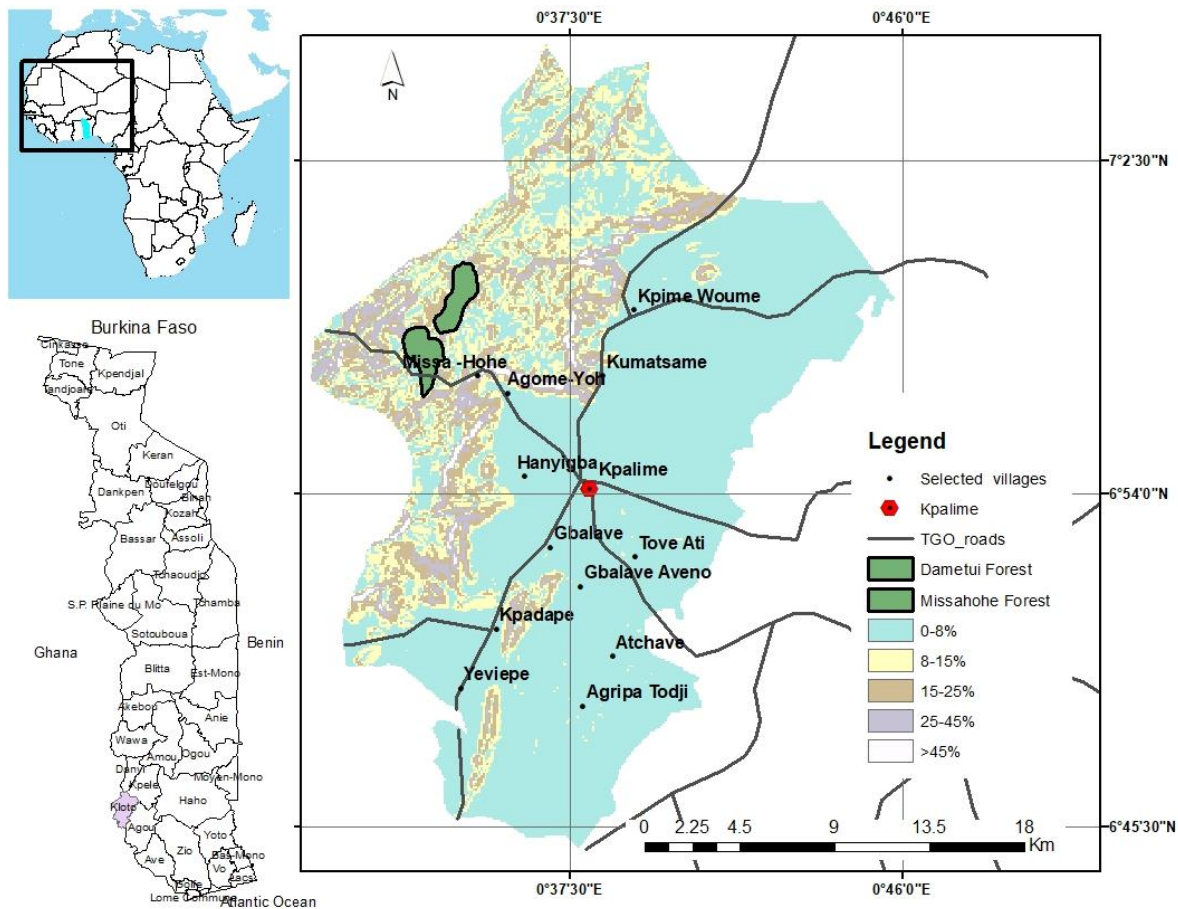
using different approaches. While some of them are based on simple remote sensing (e.g., Dewan & Yamaguchi, 2009; Rawat *et al.*, 2015; Folega *et al.*, 2014, Badjana *et al.*, 2014; Butt *et al.*, 2015; Dimobe *et al.*, 2015), others have investigated the intensity analysis (e.g., Pontius *et al.*, 2004; Aloô and Pontius, 2008; Gao *et al.*, 2016; Diwediga *et al.*, 2017). Though previous studies integrated remote sensing and household surveys to investigate landscape dynamics (e.g. Herrmann *et al.*, 2014; Liverman & Cuesta, 2008), little is known about the approach in Togo. In addition, a methodological gap exists with regard to integrating satellite data and household survey for the evaluation of existing farming and cropping systems and exploring willingness to adopt sustainable land management practices.

This avenue of research is essential for achieving sustainable socio-ecological landscapes through integrated and participatory assessment, opportunities and policies identification, and formulations to circumvent land degradation and forest cover shrinkage under climatic and anthropogenic threats in Togo, especially in Kloto district. Sustainable ecosystem management entails a coherent and integrated approach across all agricultural sectors and food systems through including farmers and rural people, who will adhere to the plans if they match up with their needs and interests. This paper aims to assess forest and agricultural land dynamics in terms of (i) forest conversion to agricultural and residential areas; (ii) farmers' perceptions of current farming and cropping systems and the potential causes of land degradation in a changing climate; and (iii) willingness to adopt integrated soil and water conservation measures to mitigate the degradation of cropland and forest in a changing climate.

### 3.2.2 Materials and Methods

#### ➤ Study Area

The study was conducted in Kloto district, which encompasses 13 sub-districts located in the northwest of the capital, Lomé (Figure 3.5). Kloto is located between 0.50° and 0.77° East and 6.75° and 7.0° North. The district covers a total area of 528.23 km<sup>2</sup>. The major economic activity is farming of food crops (e.g., maize and cassava) and cash crops (cocoa and coffee).



**Figure 3. 5: Kloto district, with select villages marked**

The average production of maize and cassava from 1990 to 2016 revealed an annual production of 10,928 and 19,498 tons for maize and cassava over an area of 8291 and 3080 hectares, respectively. From 2014 to 2016, cocoa agroforestry of 2762 hectares produced 1041 tons annually (Author, 2016). The average annual rainfall over a 16-year (2000–2016) total rainfall period is 1517.1 mm

(CI<sub>0.95</sub> = 1517.1 ± 108.1 mm). The highest and lowest annual rainfall of 1830 mm and 1063 mm were recorded in 2016 and 2005, respectively. The study area has 20.5 ± 0.11 °C and 28.9 ± 0.22 °C as the minimum and maximum 16-year mean temperature, respectively. The lowest minimum temperature (20.3 °C) was recorded in 2001, 2008, 2014, and 2015, with the highest (21.1 °C) in 2016. The hottest year was 2016 with a maximum mean temperature of 29.5 °C.

➤ Data Collection and Analysis

Three Landsat datasets (5, 7 and 8) from March 1985, 2002, and April 2017 were downloaded from the USGS website with cloud cover less than 10 % using path 193 and row 055. For the selected years, we assumed the same phenological conditions prevailed at the acquisition date because of the bimodal climate season in the study area. Thereafter, thematic analysis was performed in ENVI software based on six (06) land use land cover types, namely forest, cocoa agroforestry, maize, cassava farms, settlements, and unclassified (Table 3.3).

**Table 3. 3: Definition of the land use/land cover types used in this study**

Land Use Land Cover Type	Definition	Source
Forest	Areas covered with original vegetation of different tree species of a minimum height of 5 m at maturity and 30% maximum crown cover with 0.5 ha minimum area spanning.	IPCC (2006)
Cocoa agroforestry	Perennial arable and tillable land of mixing cocoa, trees and other crops (plantains) under conventional and family cropping systems.	Authors' definitions
Cassava	Annual/perennial arable and tillable land of local or improved cassava under conventional and family cropping systems.	
Maize	Annually tilled lands for cropping improved maize varieties (Ikenne or Obatanpa) under conventional family cropping systems.	
Settlement	Areas covered with human habitations where tree cover is negligible.	
Other	Places occupied by, e.g., road, water.	

Forty random points were collected for each land use type to train and validate the classification. Image calibration of the three years was done using ground truth (survey data), archived land occupational georeferenced points (40 in total) of each land use type of the subsequent years from available statistics (Author, 2016) and Google Earth historical data records. Supervised classification was done using Maximum Likelihood Classifier and a post-classification technique was initiated to derive the extended cross-tabulation matrix for land use change and intensity analysis. A field campaign was organized from May to October 2017 for historical land occupational information via interviews with land owners and farmers in 12 villages (Figure 3.5) at a rate of 16 respondents per village, selected randomly based on the following criteria: proximity to the original sampled forest (1 km to forest site), land occupational time frame (minimum five year) after deforestation, and spatial distributions in the same geomorphological soil unit and climate condition.

This aims to calibrate and validate land use land cover maps, to characterize actual farming and cropping systems and their related effects on cropland, and finally to appraise the will of farmers to adopt integrated soil fertility, conservation, and water management techniques in a changing climate. Images were classified with 95 % accuracy with a Kappa coefficient equal to 0.9 with 95 % producer and user accuracy. Classified maps were used to derive the net changes graphs of 1985–2002, 2002–2017, and 1985–2017 using the ArcGIS 10.3 raster calculator module. Descriptive statistics of net land use changes were performed at a 95 % confidence level using Microsoft Excel 2013. Questionnaire-based information was processed using SPHINX 4.5 software.

### 3.2.3 Results and Discussion

➤ Net Change Analysis

Land use land cover maps (Figure 3.6) and the statistical results (Table 3.4) depicted a significant decrease in forest area from 42.78 % in 1985 to 27.62 % and 19.26 % in 2002 and 2017, respectively. In the meantime, areas under cassava production and settlements increased up to 52.98 % and 9.44 % in 2017, respectively.

**Table 3. 4: Areal distribution of land use/land cover types in 1985, 2002, and 2017**

	1985		2002		2017	
	Km <sup>2</sup>	%	km <sup>2</sup>	%	km <sup>2</sup>	%
Unclassified	0.54	0.10	0.75	0.14	0.72	0.14
Settlement	8.29	1.57	11.24	2.13	49.89	9.44
Cassava	75.03	14.37	54.76	10.37	279.85	52.98
Maize	84.46	15.96	49.42	9.36	15.86	3.00
Cocoa agroforestry	133.52	25.23	266.14	50.38	80.16	15.18
Forest	226.37	42.78	145.92	27.62	101.74	19.26
Total	528.21	100.00	528.23	100.00	528.22	100.00

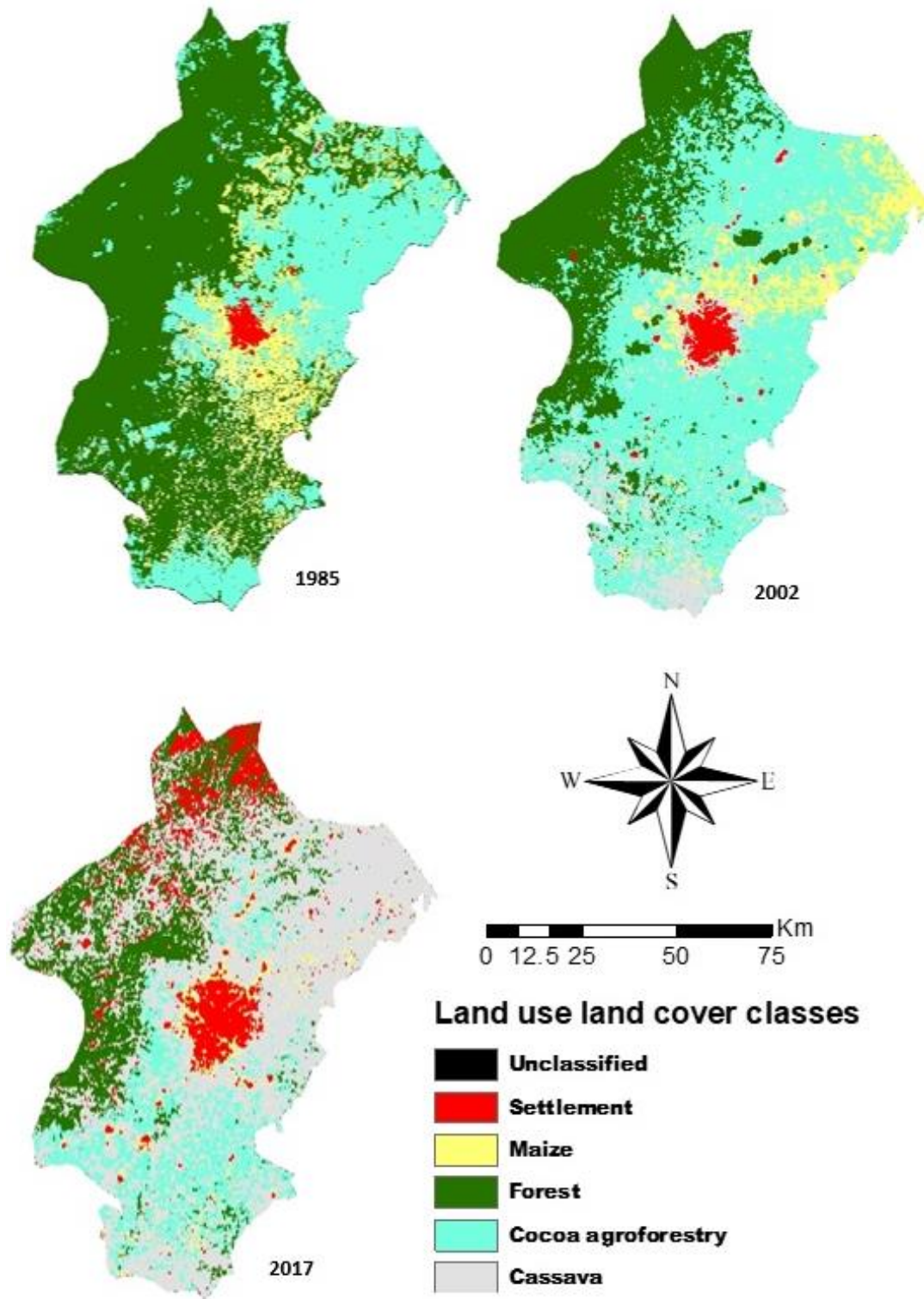
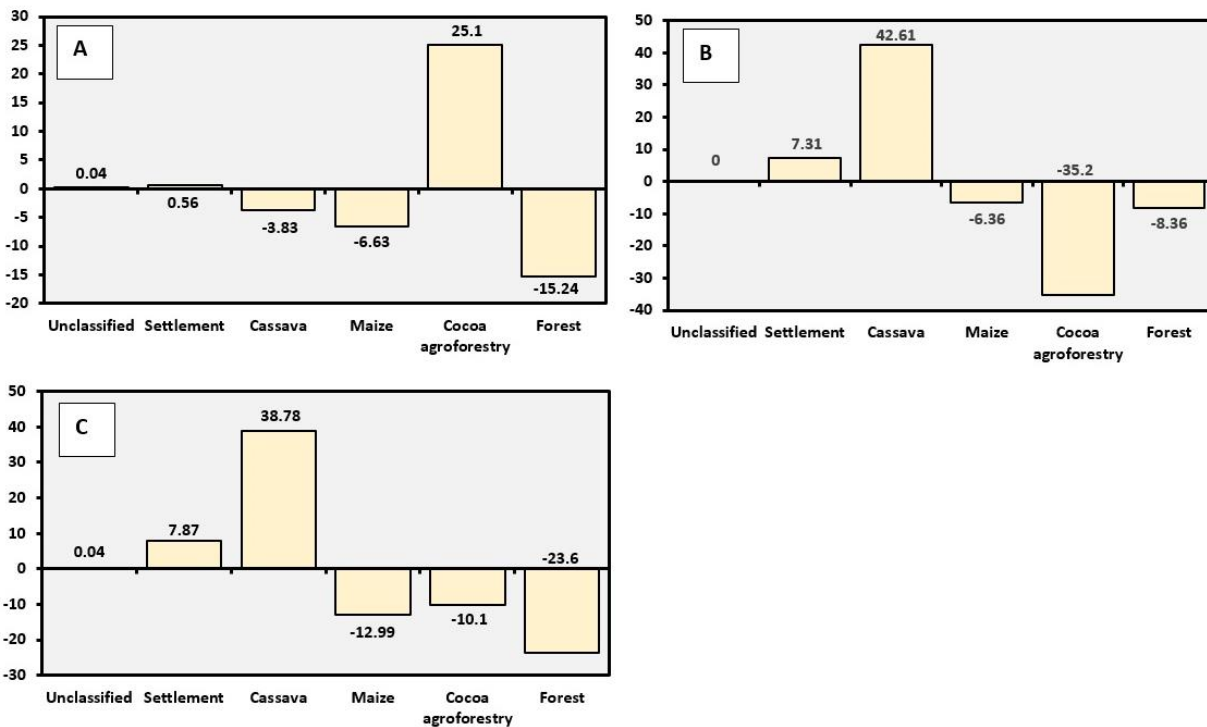


Figure 3. 6: Maps of historical land use/land cover types in 1985, 2002, and 2017

Maize and cocoa agroforestry farming was less intense. The proportion of areas under maize cultivation decreased from 15.96 % in 1985 to 9.36 % and 3 % in 2002 and 2017, respectively. Meanwhile, cocoa agroforestry expanded during the first period (1985–2002) from 25.23 to 50.38 % and decreased considerably during the second period (2002 to 2017) from 50.38 to 15.18 %. The net change analysis (Figure 3.7) results revealed a significant loss in forest cover by 23.6 % and surface areas under cultivation of cocoa agroforestry and maize by 12.99 and 10.1 % from 1985 to 2017 due to intensive cassava cropping (38.78 %) and settlement expansion (7.87%). Meanwhile, the loss of forest cover between 2002 and 2017 was marginal (8.36 %) compared to the earlier period (1985–2002), when the loss was considerable (15.24 %).



**Figure 3. 7: Net land use/land cover changes during the periods 1985–2002 (A); 2002–2017 (B); and 1985–2017 (C)**

Similarly, between 1985 and 2002, cassava and maize lost 3.83 % and 6.63 % of their area of cultivation to settlement expansion and cocoa agroforestry cultivation, which gained 0.56% and 25.1 %, respectively (Figure 3.7). During the following period (2002–2017), settlement and cassava areas expanded up to 7.31 % and 42.61 %, respectively. In the meantime, maize, cocoa agroforestry, and forests underwent negative changes of 6.36 %, 35.2 %, and 8.36 %. Cocoa production was low in some villages (e.g., Gbalave Volove and Kpime Woume). In the meantime, deforestation and forest degradation rates were also alarming in some areas, e.g., Kpime Woume and Atchave.

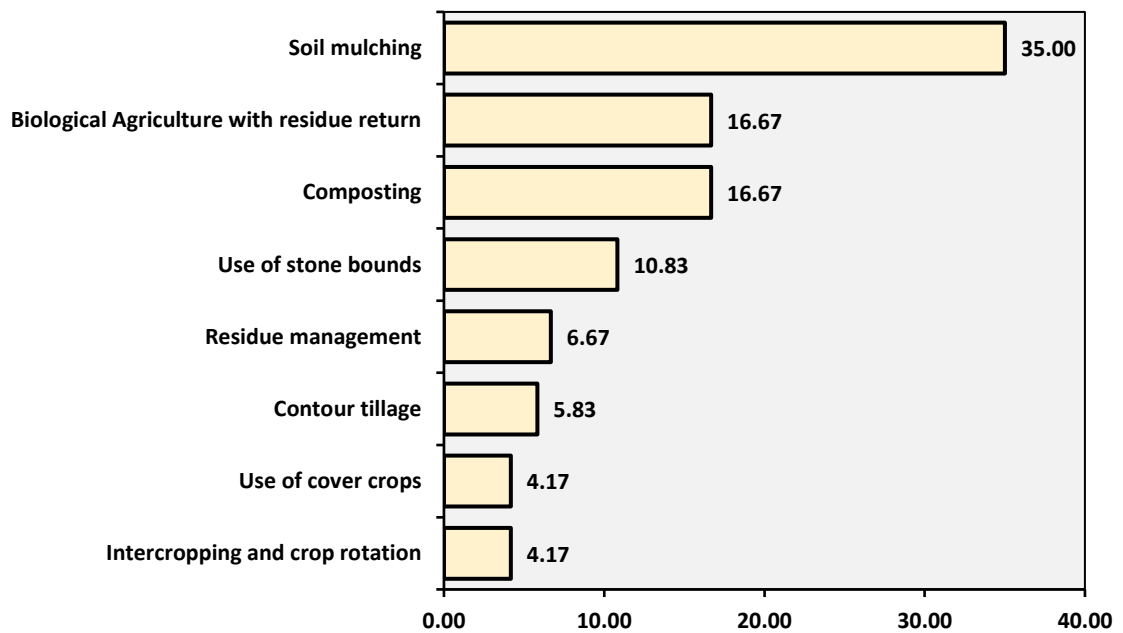
➤ Current Local Farming and Cropping Systems in a Changing Climate

Results from questionnaire data revealed an agricultural system largely dominated by men (104/120; 86.7 %). The age of the interviewed active farmers ranged between 19 and 56 years. Most farmers have reached secondary (47.6 %) and senior high (40 %) school, while 11.7 % have primary degrees. Among the respondents, only 0.6 % have an official degree and none has earned a university degree. The test of knowledge on climate change and related effects on the agroecosystems showed that most respondents (63.3 %) have not heard of or been educated about climate change issues; a minority (36.7 %) confirmed they have some knowledge of the subject matter. The majority of agricultural lands are threatened by erosion (67.5 %), followed by land degradation (56.7 %), soil fertility decline (32.5 %), a decline in soil water holding capacity (11.7 %), and changes in soil texture (3.3 %). In terms of farming activities, cassava, cocoa agroforestry (cocoa associated with plantain; trees and/or cassava at early stage), and maize are mainly produced at 34.2 %, 33.3 %, and 32.6 %, respectively, under various crop management systems. Land preparation and farm management are based on manual (75 %) and chemical tillage (70.8 %), followed by slash and burning (49.2 %). Meanwhile, 59.2 % are used to mixed cropping,

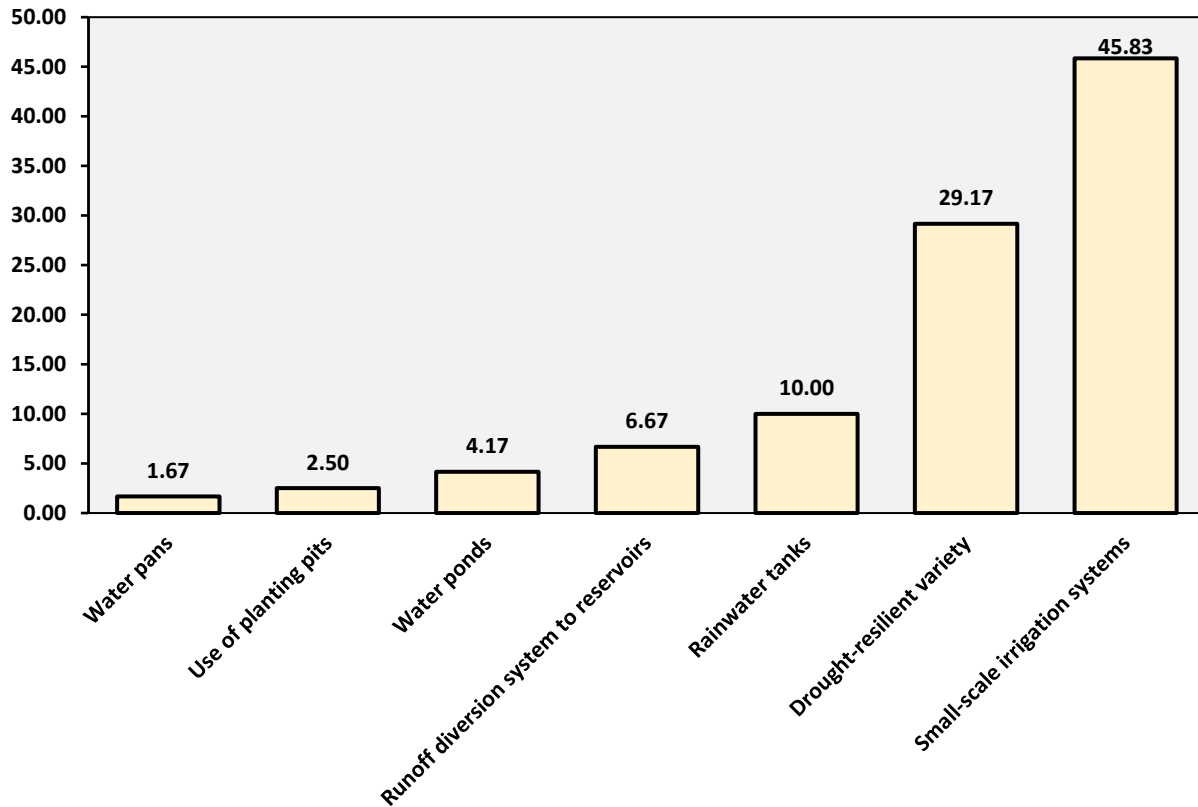
especially in cocoa production farming, while 29.2 % and 11.7 % are practicing monoculture and rotational cropping, respectively. However, none of the respondents used fallow and/or agroforestry farming systems. Monoculture is predominant under maize (55 %) compared to cassava (32.5 %), while all farmers (100 %) practiced mixed cropping under cocoa agroforestry compared to cassava (45 %) and maize (32.5 %) farming.

➤ **Local willingness to adopt integrated soil and water conservation (SWC) practices**

Analysis of questionnaire data on the adoption of improved agricultural SWC practices and rainwater harvesting systems showed positive responses from respondents (Figure 3.8 a, b). Regarding SWC measures, soil mulching (35 %) was given more attention compared to composting (16.67 %), biological agriculture with residue return (16.67 %), and contour tillage (5.83 %) (Figure 3.8a). In addition, some farmers expressed their willingness to use stone bounds (10.83 %) and other SWC measures such as intercropping, crop rotation, and the planting of cover crops.



(a)



(b)

**Figure 3. 8: (a) Expressed willingness to adopt soil and water conservation practices. (b) Expressed willingness to adopt improved water management and harvesting techniques**

Regarding integrated water management and harvesting (WMH) techniques, farmers pay more attention to small-scale irrigation systems (cost effective drip irrigation), at 45.83 % (Figure 3.8b). In the meantime, a relatively large proportion of farmers intend to adopt drought-resilient varieties (29.17 %) to anticipate the adverse effects of drought spells. Additionally, respondents showed a strong willingness to adopt other useful rainfall harvesting systems such as rainwater tanks (10 %), construction of runoff diversion systems to reservoirs (6.67 %), use of planting pits (2.50 %), water pans (1.67 %), and ponds (4.17 %).

The net deforestation rate (Figures 3.6 and 3.7) is a product of both agricultural activity and settlement expansion. Survey analysis revealed the weaknesses of the agricultural systems in terms of farming and cropping systems that deteriorate farmland. Indeed, in response to fertility decline and erosion problems, forests are cleared for fresh and stable lands for cropping to sustain food production. In this study, the majority of agricultural lands are threatened by erosion (67.5%), followed by land degradation (56.7 %), soil fertility decline (32.5 %), a decline in soil water holding capacity (11.7 %), and changes in soil texture (3.3 %) due to deliberate use of conventional practices (e.g., monoculture, tillage), non-adoption of climate-smart practices, and exponential population growth.

This study contributes to our understanding of the role of agricultural practices in the deforestation, forest, and land degradation processes in changing climate conditions (e.g. Tegegne *et al.*, 2016; Kissinger *et al.*, 2012; Moomen & Dewan, 2017). On the other hand, exponential shifting of maize production to cassava production and the overall expansion of cassava farming could be the result of cropland health status. Maize production requires a certain minimum soil fertility conditions, and when soil fertility declines, productivity is compromised. At this point, farmers find an alternative: growing crops with low input demand to restore soil fertility and derive benefits from crop leaves for food. Moreover, Kloto farmers associate cassava with cocoa agroforestry production, mixed with plantain and wild trees at early stages of cocoa planting. Some farmers also practice crop association and/or rotational cropping on soil with low fertility. It is evident that the land use systems, the adoption of cropping systems, and fertility management are responsive to various factors specific to the location. (Callo Concha *et al.*, 2013) showed that the major traits of farming and cropping systems in West Africa in a changing climate are mostly a result of their weaknesses vis-à-vis technical, environmental, and sociopolitical constraints.

Similarly, these findings confirm the results of existing studies on the potential drivers of forest and land degradation due to land misuse and agricultural activities in developing countries. In Upper West, Ghana Moomen & Dewan (2017) revealed that illegal mining is the major cause of land degradation. Additionally, land misuse not only affects agricultural productivity but also impacts negatively on household stability and security (Moomen *et al.*, 2016). Therefore, the formulation of strategies must be based on the assessment and understanding of the farming systems at a local level through a participatory approach with stakeholders. As African soils are poor in organic matter, improved soil fertility management, erosion control, and water management techniques are fundamental to guarantee the coexistence of agriculture and forest in the study area and developing countries in general. This study underlines the current poor agricultural systems and presents the need for the adoption of sustainable practices to achieve food security, forest sustainability, and climate change mitigation. It is therefore important to undertake awareness-raising and integrated land management for halting land degradation. Accordingly, (Zhao, 2018) estimated that environmental regulations to halt soil degradation could be effective when associated with integrated ecosystem management approaches.

### **3.2.4 Conclusion**

A better understanding of West African farming, cropping, and population dynamics is a prerequisite to developing measures and technologies promoting the coexistence of agriculture and forest sustainability schemes. In this light, this study, which combines remote sensing and survey data to analyze the historical net changes in forest and agricultural land, helped us to assess and understand the reasons for deforestation, forest and land degradation in Kloto district (Togo, West Africa). This approach enables us to better comprehend the proximate drivers of deforestation and land degradation by perceiving the weaknesses in existing farming and cropping systems, major

reasons for shifting from one farming system to another, and, most importantly, the reasons for the deliberate conversion of native forests and the willingness of farmers to adopt improved soil conservation and water management practices. Simply put, the participatory approach shows that pressure on cropland from actual farming and cropping systems entails severe land degradation. To circumvent these situations, farmers are obliged to shift from cereal mono-cropping (e.g., maize) to root crops (e.g., cassava) as an alternative to restore degraded soils, or clear existing adjacent forests in the search for more stable and healthy soil to sustain food production.

This study is useful for policy formulation towards appropriate cropland land management, land use planning strategies, and capacity building of smallholders. These are of the utmost relevance for slowing forest shrinkage and land degradation while sustaining food production and improving the livelihood of people residing in the poorest and most remote communities of Kloto district (Togo, West Africa), who depend on agriculture and forest products. Accordingly, joint efforts between governments, civil societies and farming collectives to evaluate actual and emerging problems in the agricultural sector and identify and implement sustainable solutions to promote agro- and forest ecosystems are imperative. We also believe that one of the optimal ways of achieving these goals is through the greater involvement of women in the decision-making process and in land management. Furthermore, adhering to governance principles of transparency, fair accountability, and inclusive sustainable agricultural land management (SALMP), along with advance crop breeding projects, will be critical.

### 3.3 Land use change matrix and slope gradient soil carbon and carbon dioxide emission assessment from forest to different cropping systems in Togo – West Africa

#### Abstract

This study analyses time series land use transition carbon gains, losses and emissions using matrix of land use change and point-based emission and removal estimators. Land use transition experiment plots, slope gradient composite soil sampling methods across forest and agricultural lands were used within the same soil unit and climatic zones. The analysis of variance ( $p=5\%$ ,  $F_{pr}<0.001$ ) revealed low SOCD ( $\text{MgCha}^{-1}$ ) under maize (54.33) and cassava (52.98) compared to cocoa agroforestry (169.52) and forest (189.34) plots. Based on land use change observed between 1985 and 2017, the transition of forest and cocoa agroforestry to cassava and maize depicted high carbon dioxide release of up to 100,059 and 74,192 for cassava and 5,342 and 5,227  $\text{MgCO}_2\text{eY}^{-1}$  for maize, respectively. Whereas the transition from maize to forest sequestered more carbon ( $1,423\text{MgCO}_2\text{eY}^{-1}$ ) compared to the transition from cocoa agroforestry and cassava to forest which, accounted for 626 and 404  $\text{MgCO}_2\text{eY}^{-1}$ , respectively. In terms of carbon release and sequestration over 32-year, results showed slightly higher carbon sequestration through the transition of cassava and maize to agroforestry than to forest. Significant losses were estimated for the transition from forest and cocoa agroforestry to maize and cassava mono-cropping. Results revealed mono-cropping of annual crops without residue return after forest or cocoa agroforestry transitions as main driver of soil carbon loss and  $\text{CO}_2\text{e}$  release. Consequently, site-specific integrated landscape management and dissemination of climate-smart agricultural practices like agroforestry are promising options to considerably reduce GHG emissions in the Southern Togo.

**Keywords:** Soil organic carbon density (SOCD), climate-smart agricultural systems,  $\text{CO}_2$  equivalent, carbon emission/removal factor, integrated landscape management, Togo

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#### 3.3.1 Introduction

Agriculture is the main source of income, food, and employment, but also the prime source of anthropogenic greenhouse gas (GHG) emission at global level (Smith and Conen, 2004; Janzen, 2005; Smith *et al.*, 2008; IPCC, 2014; Alvaisha *et al.*, 2019; IPCC, 2019). In developing countries, and across West African regions, forest transition to mono-cropping (e.g., cereals or perennial cash crops) leads to land degradation, soil nutrients and carbon losses, productivity decline and carbon dioxide ( $\text{CO}_2$ ) emissions (Fearnside, 2000; Koglo *et al.*, 2018; Alvaisha *et al.*,

2019; Dioha and Kumar, 2020). Besides, land use change mainly from forest to conventional agriculture expansion is a major source of GHG emissions (Pribyl *et al.*, 2010; Israel *et al.*, 2020; Petrescu *et al.*, 2020). According to IPCC (2019), agriculture, forestry and other land use (AFOLU) contributes about 23% of the global anthropogenic GHG. Koglo *et al.* (2018), study conducted in West Africa (Togo) posited that, forest lands are threatened due to improper agriculture activities and urbanization resulting from rapid population growth, increase for food needs and settlements. The 1995 benchmark emission statistics in Togo revealed tremendous carbon release from agricultural sector. Emission data in terms of CO<sub>2</sub> equivalence (CO<sub>2e</sub>) was 3278.87Gg equivalent to 13% of total GHGs emitted (MERF, 2001). Direct GHGs of each sector in 2005 revealed significant release from land use change (forest to agriculture lands) and agricultural land use systems followed by energy consumption, industry, and waste management sector: 8329.28GgCO<sub>2e</sub> (62.88%), 2720.89 (20.54%), 1714.68 (12.94%), 312.57 (2.36%) and 169.9 (1.28%) were recorded, respectively (MERF, 2001). Total mass (Gg) emitted was 13,249.76 Gg CO<sub>2e</sub> with 68% carbon dioxide emission. In the agricultural sector, huge emissions (Gg;% ) were inventoried from croplands (2107 Gg;77.48%) due to the use of chemicals and land mismanagement (MERF, 2001; 2015). From the aforesaid, forest conversion to conventional agriculture systems and land mismanagement are the primary source of greenhouse gas emissions to the atmosphere from 1995 to date. Therefore, carbon efficient and sustainable land and farming systems management practices are paramount to meet the Sustainable Development Goals (SDG) 1, 2 and 13 and the African Union (UA) agenda 2063 (Koglo *et al.*, 2018). Therefore, accurate estimation of emissions or removal components (emission factors and activity data) is becoming the main concern of the scientific community. Literature is replete on studies related to carbon dynamics across land use transition systems and their likelihood CO<sub>2</sub> emissions (Kumar *et al.*,

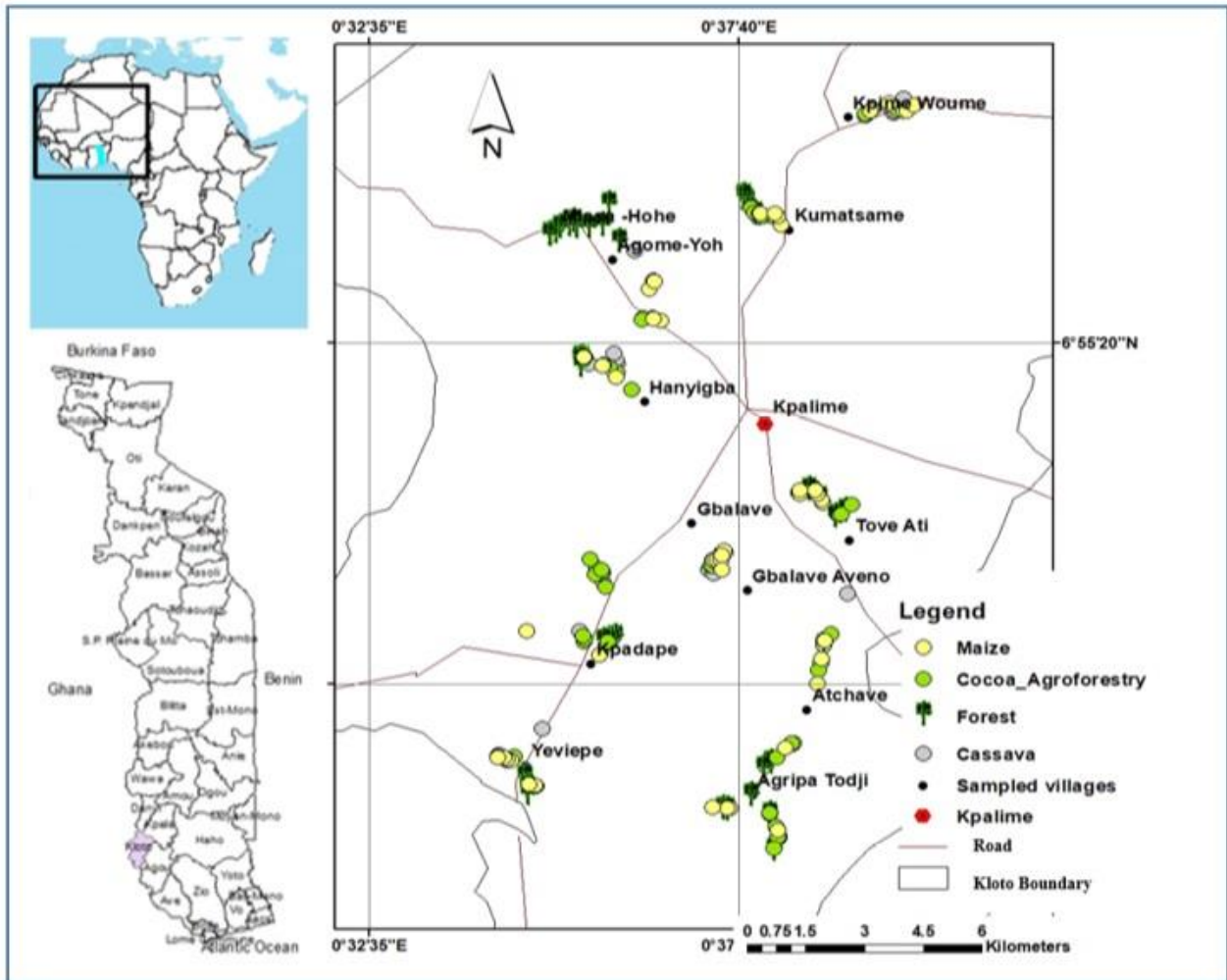
2010; Venkanna *et al.*,2014; Bhardwaj *et al.*,2013; Villamor *et al.*, 2014; Burton *et al.*, 2017; Carlson *et al.*, 2013; Diwediga *et al.*, 2017; Dioha and Kumar, 2020; Lam *et al.*, 2021).

However, little is known on the performance of the emission factor used for estimating the carbon gains/losses and CO<sub>2</sub> fluxes from different farming and cropping systems due to climate, soil, topography and farmland management variabilities. The emission factor is a determinant in estimating the level of emission/removal and must be calibrated locally due to its sensitivity to the soil, climate, and land use type. Additionally, the contribution of perennial and annual farming systems on each carbon fraction will be beneficial for the promotion of climate smart farming systems. This will facilitate emission-reduction and policy making towards sustainable land management. Therefore, this study aims in establishing locally validated soil emission factors for carbon dioxide resulting from forest conversion as well as the contributions of farming systems on soil organic carbon content and carbon dioxide emissions. Specific objectives are to (i) compute soil organic carbon density across agricultural and forest systems; (ii) generate locally validated emission/removal factors and subsequently calculate carbon loss/gain and carbon dioxide emission equivalents.

### **3.3.2 Materials and Methods**

#### **➤ Study Area**

The study was carried out in the Kloto district (Togo) which covers an approximate land area of 528.23km<sup>2</sup>. It encompasses 13 sub-districts located in the North West of the capital city, Lomé (Figure 3.9).



**Figure 3. 9: Study area with sampling locations**

Kloto lies between Longitude 0°30'0" and 0°46'30" East and Latitude 6°45'0" and 7°6'0" North. The major economic activity is farming of mainly food crops (e.g., maize, cassava) and cash crops (cocoa and coffee agroforestry). The average production of maize and cassava from 1990 to 2016 revealed an annual production of 1.32 and 6.33 tonnes for maize and cassava per hectare, respectively. From 2014 to 2016 cocoa agroforestry of 1 hectare produced 0.4 tonnes annually (Author, 2016). The average annual rainfall over 16-year total rainfall period (2000-2016) is 1517.1mm (CI<sub>0.95</sub> = 1517.1±108.1mm). The highest and lowest annual rainfall of 1830 mm and

1063mm were recorded in 2016 and 2005, respectively. The study area has  $20.5\pm 0.11^{\circ}\text{C}$  and  $28.9\pm 0.22^{\circ}\text{C}$  as minimum and maximum 16-year mean temperature, respectively. The lowest minimum temperature ( $20.3^{\circ}\text{C}$ ) was recorded in 2001, 2008, 2014 and 2015 with highest ( $21.1^{\circ}\text{C}$ ) in 2016. The hottest year was 2016 with  $29.5^{\circ}\text{C}$  maximum temperature.

➤ Data collection

This study investigated four (04) land use and land cover change (LULC) categories namely: forest, cocoa agroforestry, cassava and maize (Table 3.5).

**Table 3. 5: Matrix of Land use land cover changes (ha) from 1985 to 2017**

	Forest	Cocoa agroforestry	Cassava	Maize	Total
Forest	0	2,372.28	6,400.03	344.93	9,117.25
Cocoa agroforestry	275.21	0	5,553.81	395.64	6,224.66
Cassava	25.88	228.72	0	43.84	298.45
Maize	91.91	548.83	1,659.17	0	2,299.91
Total	393.00	3,149.84	13,613.02	784.42	17,940.28

Source: Koglo *et al.* (2018)

Data were collected from twelve (12) randomly selected villages (Figure 3.9) spatially well distributed based on the following criteria: proximity to original sampled forest (1 kilometre of a forest site), land occupational time frame (minimum five year) after deforestation and spatial distributions in the same geomorphological unit, soil, and climate conditions. Soil samples were taken from 0 – 30cm depth. A total of 160 samples (40 per LULC) for the four categories were collected. The Global Positioning System (GPS) was used to record the Longitude, Latitude, and Elevation in UTM (Universal Transversal Mercator) of each sampled location. Soil sampling was done with a ring 5.5cm diameter and 30cm in height. The experiment unit was one hectare (1ha), and three (03) plots of 20m x 20m spaced by 20m across the diagonal were used for composite soil sampling across agricultural land use types (maize, cassava, and cocoa agroforestry). For the forested zones, a main plot of 100mx20m was delineated within which, six nested plots (0.5x0.5m)

embedded in three subplots (40mx5m) were used across the diagonal of the main plot for composite soil sampling based on tree diameter at breast height (see Figure 2.3). This method was used because, the level of soil carbon stock may vary due to the amount of biomass produced by each vegetation type which, is a function of plant type and species. In this study, we did not account for woody (e.g., trees) and non woody (e.g., shrubs) carbon contents but the soil was sampled across each vegetation type using the delineated sub-plots and nested plots. Collected soil samples were analysed for soil organic carbon content (SOC,  $\text{gkg}^{-1}$ ) and one (01) undisturbed soil was sampled for bulk density (BD,  $\text{gcm}^{-3}$ ) for each LULC type.

- Laboratory analysis and soil organic carbon emission factor and stock computations

The dry bulk density was computed using the oven drying method. The dry weight of the soil was obtained by oven drying the sample at 105 °C for 48 hours or until a constant weight was obtained and then bulk density was computed (Equation 5.1). Collected disturbed soil samples were air-dried for 48 h and sieved with 2 mm mesh sieve and laboratory analysis was undertaken for carbon content using the black oxidation method (Walkley and Black, 1934; Schumacher, 2002). Thereafter, soil organic carbon density (Equation 5.2) of each land use category was done.

$$\rho_i = \frac{M_{di}}{V} \quad [5.1]$$

$$\text{SOCD}_i = \text{OC}_i \times \rho_i \times 0.3/10 \quad [5.2]$$

Where  $P_i$  is the dried soil bulk density ( $\text{g cm}^{-3}$ ),  $V$  is the volume of the cylinder core ( $\text{cm}^3$ ,  $d = 5.5$  cm and  $h = 30$  cm),  $\text{SOCD}_i$  is the soil organic carbon density ( $\text{MgC ha}^{-1}$ ),  $\text{OC}_i$  is the soil organic carbon content ( $\text{g kg}^{-1}$ ) and  $0.3\text{m}$  is soil thickness ( $30\text{cm}$ ) (Wang *et al.*, 2003; Pribyl, 2010). Once the carbon content is known for each land use type per zones, emission/removal factors ( $\text{EF}_{ij}$ , Equation 5.3) and related carbon loss/gain and net emission/ removal in terms of carbon dioxide equivalent ( $\text{CO}_{2e}$ ) (Equations 5.4 and 5.5) from forest conversion to other farming systems were estimated (IPCC, 2006; FAO, 2015).

$$\text{EF}_i = \text{SOCD}_f - \text{SOCD}_i \quad [5.3]$$

$$\text{CL}_i = \text{EF}_i \times \text{AD}_i \quad [5.4]$$

$$\text{CO}_{2ei} = \text{EF}_i \times \text{AD}_i \times 3.67 \quad [5.5]$$

Where  $\text{EF}_i$  is the emission/removal factor ( $\text{Mg C ha}^{-1} \text{y}^{-1}$ ) over the period ( $t_0 - t_f$ ),  $\text{SOCD}_{i,t1}$  and  $\text{SOCD}_{i,t0}$  are the soil organic carbon density ( $\text{MgCha}^{-1}$ ) of different land use classes ( $i$ ) from time  $t_0$  to  $t_f$ ,  $\text{CL}_i$  is the carbon loss ( $\text{MgCy}^{-1}$ ),  $\text{CO}_{2ei}$  is the carbon dioxide emission equivalent ( $\text{MgCO}_{2e}^{-1}\text{y}^{-1}$ ),  $\text{AD}_i$  is the activity data (ha) or total area converted from forest to other land use types (forest, cocoa agroforestry, cassava and maize) and vice versa of the study area obtained from land use land cover map (Koglo *et al.*, 2018) within the time period  $t_0 - t_f$  (Table 3.5) and using 3.67 as the coefficient for converting carbon to carbon dioxide equivalent.

#### ➤ Statistical Analysis

Descriptive and inferential statistics were performed and ANOVA analysis was done in GenStat 9v.2 for the significance variation of soil organic carbon stock and emission levels resulting from the conversion from forest to another land use type in the selected villages at 95% confidence level.

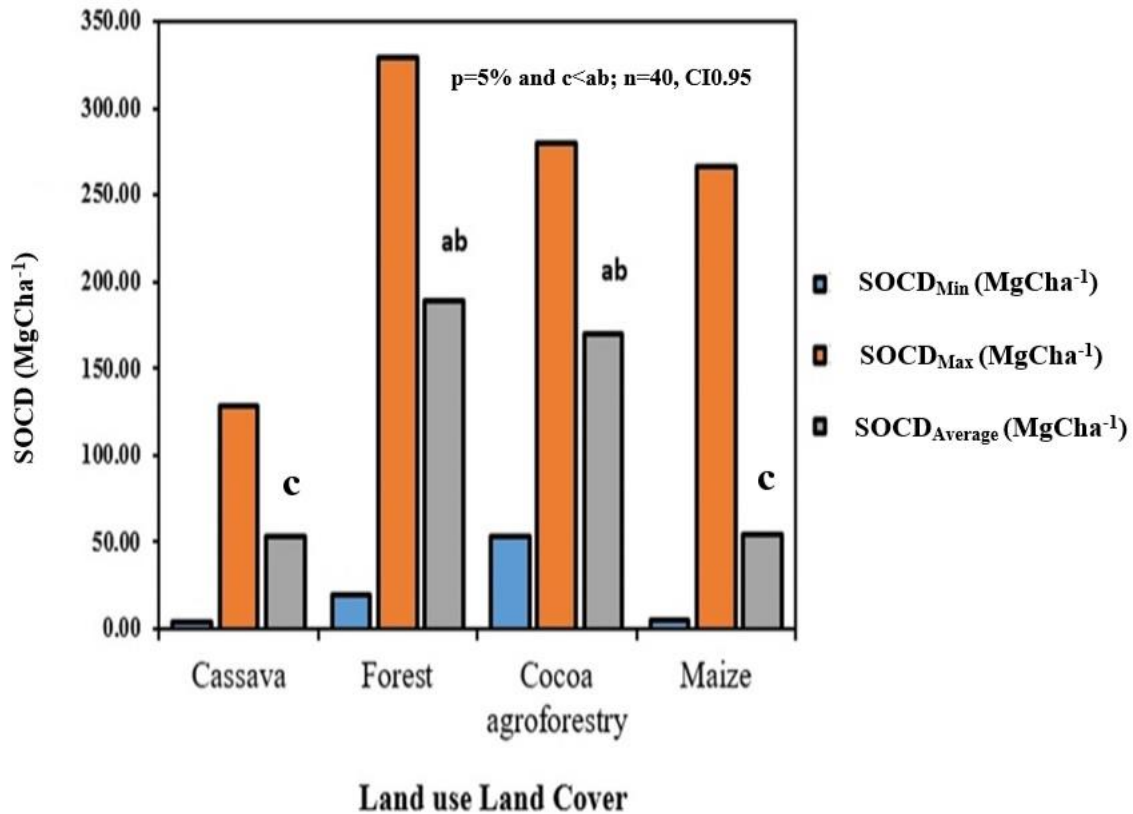
Duncan Multiple Range Test (DMRT) was used to discriminate each category for their related temporal soil organic carbon stock vs emissions, and emission or removal factor obtained.

### 3.3.3 Results and Discussion

#### ➤ Soil organic carbon density across agricultural and forest systems

The analysis of variance (Figure 3.10) depicts significant variation ( $p = 5\%$ ;  $F_{pr} < 0.001$ ) of soil organic carbon density (SOCD,  $\text{MgCha}^{-1}$ ) across cassava, maize mono-cropping, cocoa agroforestry and forest agricultural and forest systems in the Kloto district.

The amount of SOCD in 30cm topsoil was significantly higher for forest ( $189.34 \pm 19.18 \text{MgCha}^{-1}$ ) and cocoa agroforest ( $169.52 \pm 20.34 \text{MgCha}^{-1}$ ) compared to maize ( $54.33 \pm 18.11 \text{MgCha}^{-1}$ ) and cassava ( $52.98 \pm 10.71 \text{MgCha}^{-1}$ ). This could be the results of the quantity of residue returns and land management practices of the different farming systems. Indeed, cocoa agroforestry is a farming system with no or little soil tillage, high residue returns and high soil surface cover. This management enhances soil moisture content while limiting soil evapotranspiration. Moreover, it also reinforces and augments soil biological properties necessary for litter decomposition to stable organic matter and organic carbon. The selected forest areas were native forests which, explains the maximum accumulation of soil organic carbon (Figure 3) of the selected land use land cover type. These findings concur with Mohammed *et al.* (2016); Dawoe *et al.* (2016) and Epron *et al.* (2009) on the potential of cocoa carbon stock and dynamics via afforestation. Similarly, Nimo *et al.* (2021) and Assigbaase *et al.* (2021) posited a high soil carbon stock across cocoa agroforestry farming in Ghana.



**Figure 3. 10: Soil organic carbon density (MgCha<sup>-1</sup>y<sup>-1</sup>) in 0-30 cm soil depth across land use systems**

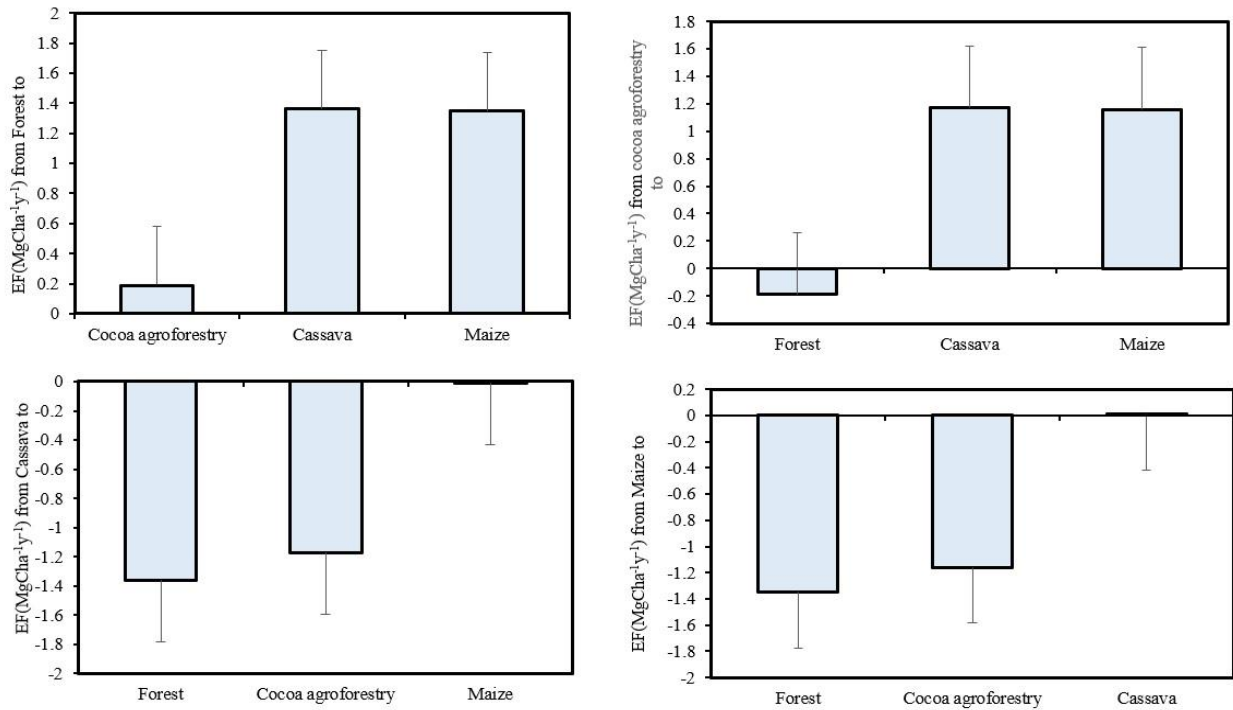
In contrast, the low soil organic carbon stock under maize and cassava is the result of five years of continuous mono-cropping systems adopted by farmers after converting forest to cassava or maize farms. In addition to mono-cropping systems, crop residue returns are low because, they are used either as firewood and or forage for livestock. In addition, applied fertilizer rates during the growing season do not compensate for nutrient uptake by plants. This condition associated with annual soil disturbance deteriorates soil health leading to low biomass production, excessive loss of nutrients and soil organic carbon stock in the maize and cassava systems. Related studies on soil organic carbon (SOCD) dynamics across different agricultural and forest ecosystems in Africa

indicated significant SOCD under forests compared to different cropping systems. For instance, in South-eastern Nigeria, Anikwe (2010) investigation on soil carbon storage under different management practices depicted about 70 % of losses under continuously cropped and conventionally tilled soils compared to natural and artificial forests as well as grassland ecosystems. Likewise, in Ethiopia, Solomon *et al.* (2017) evaluated the potential of carbon stocks under community managed dry forest and recommended the promotion of community-based forest management projects. Similarly, Kassa *et al.* (2017) evaluated the impact of deforestation on soil carbon in the Gacheb catchment in the White Nile Basin (Ethiopia) across forest and agricultural systems. The study revealed higher soil organic carbon stock (SOC) under forest and agroforestry against lower SOC content under maize farmlands. Accordingly, authors concluded that agroforestry is essential in sustaining soil health status while mitigating carbon dioxide losses from agro ecosystems (Mbow *et al.*, 2014a, 2014b, 2014c). Recent studies also showed that, soil carbon losses from conventional farming systems are time and land management related. Besides, Long- or short-time conversion with adequate soil management practices, e.g., no-till, crop residue return, rotational cropping with leguminous plants, efficient irrigation and water management practices reduces the level of CO<sub>2</sub> and enhance soil carbon pool (Alavaisha *et al.*, 2019; Abbas *et al.*, 2020; De Souza Medeiros *et al.*, 2020; Rigon *et al.*, 2020).

➤ Land Use Transition Carbon Balance

The estimation of soil organic carbon emission/removal factors related to land cover changes over 32-years (1985 to 2017) revealed highly dynamic soil organic carbon turnover (Figure 3.11) in Southern Togo.

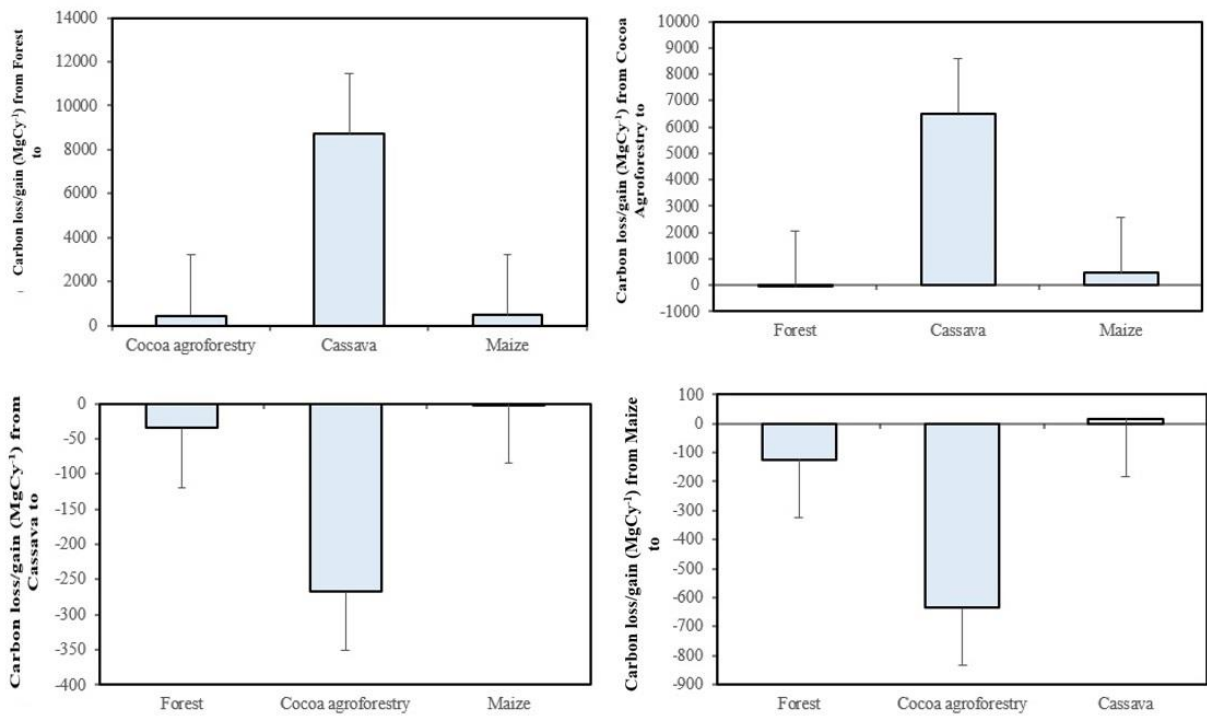
The transition from forest to cassava, maize mono-cropping or cocoa agroforestry released carbon from soil organic matter decomposition amounting to 4.26, 4.22 and 0.62MgCha<sup>-1</sup>y<sup>-1</sup>, respectively. On the other hand, results also revealed that, transition from cassava and maize to forest as well as to cocoa agroforestry systems is increasing the carbon stock in soils.



**Figure 3. 11: Carbon emission/removal factors from land use/land cover changes assuming a period of 32 years to reach steady-state conditions**

In terms of a regional assessment across Kloto district (Figure 3.12), the transition from maize to cocoa agroforestry showed highest yearly SOC changes ( $1975\text{MgCy}^{-1}$ ), followed by cassava to cocoa agroforestry ( $832\text{MgCy}^{-1}$ ).

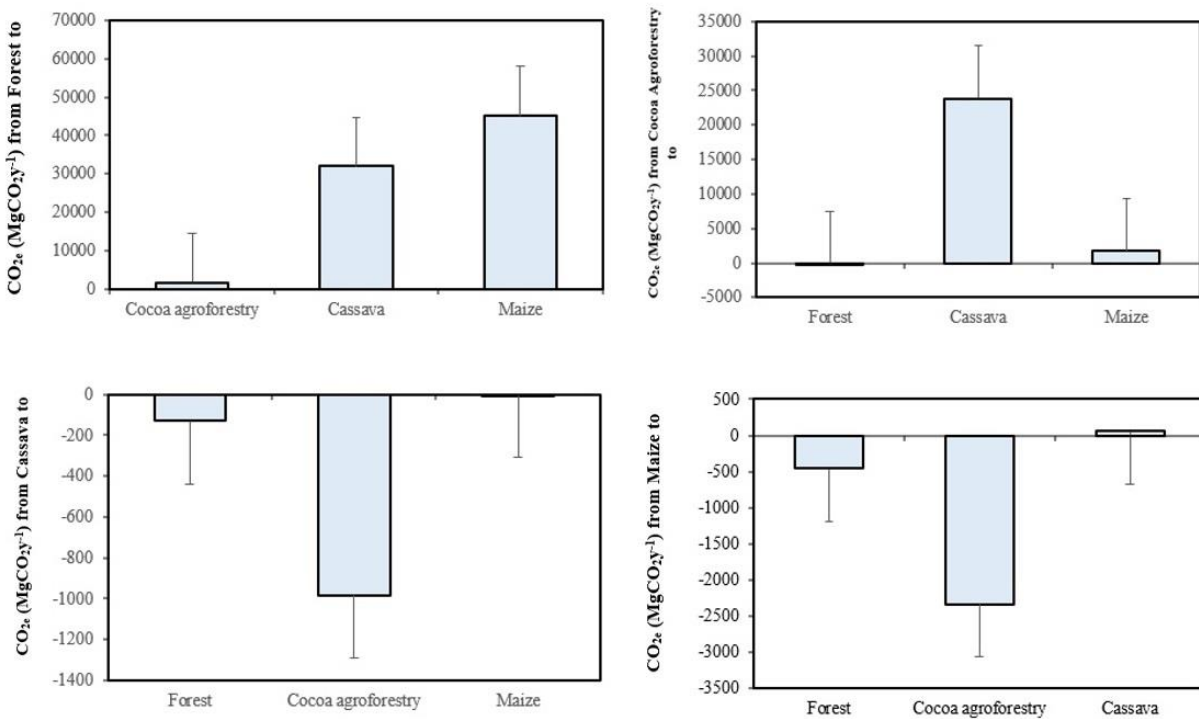
In the meantime, transition from cassava to forest is likely to store  $110\text{MgCy}^{-1}$  compared to maize and cocoa agroforestry transition to forest which gained 387 and  $170\text{MgCy}^{-1}$ , respectively. Conversely, the loss of carbon is tremendous for the transitions from forest and cocoa agroforestry to cassava,  $27,264$  and  $20,215\text{MgCy}^{-1}$ , respectively. The loss was also important for the transition from forest and cocoa agroforestry to maize and forest to cocoa agroforestry to the extent of  $1,455$ ;  $1,424$  and  $1,470\text{MgCy}^{-1}$ , respectively.



**Figure 3. 12: Temporal land use land cover transition of carbon gain/loss takes 32 years to reach steady-state conditions**

The carbon dioxide removal/emission equivalent from 1985 to 2017 (Figure 3.13) depicted the highest carbon dioxide emissions through transition from forest and cocoa agroforestry to cassava and maize mono-cropping systems.

However, analysis revealed significant carbon dioxide sequestration for the transition from maize to cocoa agroforestry ( $7,251\text{MgCO}_2\text{e}^{-1}$ ) and cassava to cocoa agroforestry ( $3,055\text{MgCO}_2\text{e}^{-1}$ ). In fact, the total regional carbon dioxide emissions were closely related to the extent of agricultural land between 1985 and 2017 and the type of crop management by the farmers.



**Figure 3. 13: Temporal land use land cover transition of carbon dioxide removal/emission equivalent takes 32 years to reach steady-state conditions**

Conventional practices under annual cassava and maize crops are the total removal of residue to domestic usage and animal feeding, which contributed tremendously to soil carbon losses over time. In addition, poor or no nutrient applications and inadequate soil amendment practices by smallholder's farmers keep carbon dioxide assimilation by the crops low and prevent the annual crops to restore more soil organic carbon. In contrast, different situation is observed under native forest and cocoa agroforestry because, they are undisturbed natural or man-made agroforestry ecosystems, where residues are maintained on the soil leading to a permanent and total soil cover. This condition favours continuous inputs of organic residues as litter and creates a favourable microclimate for soil micro and macro-organisms while preventing from soil water loss through evaporation.

Carbon dioxide emissions from tropical agriculture are a function of the potential of soil carbon stock by different crop management systems. Manjaiah *et al.* (2000) study revealed that, soil organic carbon stocks, the level of storage and microbial activities varies from different crop management systems in a tropical ecosystem. Similar investigations also point to the fact that, cropping system conversions and land use dynamics lead to soil organic carbon changes (Sainepo *et al.*, 2018; Tong *et al.*, 2017; Trimble *et al.*, 2018; IPCC, 2019; Cooper *et al.*, 2020; Lam, 2021). However, these studies did not quantify carbon gains and losses through land use transitions over long-term periods. Additionally, most of them overlooked the likely biases when computing the carbon dioxide emissions using the average emission or removal factors published by IPCC. Results from this study revealed the importance of locally estimated emission factors, that fit the pedoclimatic conditions of a given region, to estimate carbon dioxide emissions when converting forest to particular cropping systems with annual crops. This study revealed that, analysis of soil carbon balance in agricultural and forest ecosystems in tropical, humid regions necessitates local

emission and removal factors for an accurate estimation of the carbon dioxide over time. This leads to robust local adaptation and mitigation strategies when combined with remote sensing and terrain datasets.

### **3.3.4 Conclusion**

This study revealed that, combination of point based geospatial, topographic, soil type and climate data is very key in developing more reliable carbon emission and activity data for carbon balance assessment from forest lands transition to different farming systems. From these findings, the level of emission or sequestration depends on the adopted farming system technics that follows forest conversion. It also underpinned time, soil, plant, and climate as key factors likelihood to affect cash and food crops farming systems soil carbon balance. This is unique for identifying point-based cost-effective climate smart agricultural and agroforestry systems to meet the need of the population (e.g., food on table, economic independency) and efficient in addressing current and future global warming threats.

## **CHAPTER 4.0: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS**

### **4.1 Discussion**

This study reveals significant land use dynamics and land degradation due to urbanization and agricultural expansion in the study area resulting in significant carbon dioxide emission when converting native forest to mono cash and food farming. The use of both Geospatial tools (Remote sensing and GIS) associated with socio economic and survey dataset is tremendous in determining, firstly, farmer's perception regarding climate change and anthropogenic pressure on forest resources and land degradation, causes and consequences of such degradation and the willingness for sustainable soil erosion and conservation measure adoption. Secondly, it enables in establishing local carbon emission and removal factor to best estimate soil organic carbon balance in agro-forest ecosystems of the study area. It ascertains that, land occupational time frame and its management affect the soil carbon balance.

This study brought out three key scientific knowledge to the existing land use transition analysis studies available in the current literature. The time series intensity analysis (objective one) depicted not only the amount of change but how the changes occur over each time period. The intensity of each period associated with the amount of gains and losses are very key in evaluating the effectiveness of existing land use policies and measures over time in the study area. This analysis is quite relevant in point based adaptation strategy evaluation. In contrast, the conventional land use land cover changes only focuses on the mean quantity of change. This, is very limited when it comes to appreciate how best a specific adaptation strategy works over time. Additionally, it also presents weaknesses in terms of the dominant land use land cover in terms of loss and gain, respectively.

Integrating remote sensing and socio economic data analysis (Objective 2) provides better quantification and evaluation of the level of soil degradation and its main drivers on one hand. The second relevance was to evaluate the existing indigenous conservation measures and appraise the need and willingness of introducing most robust sustainable soil conservation measures. Compared to many studies, this dual approach is effective for cost benefit analysis of the best practices. It also helps to understand the real need of the farmers and evaluate the local resources available in testing and promoting the most suitable practices.

The Objective 3, which was related to the evaluation of emission and removal from a specific land use transition to another gave satisfactory results. Emission and removal evaluation must be unique and based on local estimators. The use of generic coefficient can be biased and compromised by several local factors viz, climate, topography, anthropogenic land management. The method used in this study took into consideration these external factors for point based accurate analysis and policy recommendation. It is therefore, necessary to incorporate these aspects. Additional studies are vividly encouraged for validation. Though the data collection and sampling methods could affect the emission and/or removal from a specific land use to the other, this method is promising for calculating local carbon foot print initiatives and researches.

#### **4.2 Conclusion and Recommendations**

Results from this study underline two major concerns in the study area such as: significant changes of forested area to agricultural activities both cash and food crops, and the negative implications of conventional practices on croplands degradation resulting in loss of native forest lands. Besides, monocropping and residue removal from croplands result in soil degradation, loss of fertility, greenhouse gas emission and more importantly yield failure. Consequently, farmers are forced to clear virgin forests for significant agricultural benefits. Therefore, there is a need to:

- evaluate, experiment and implement cost effective and sustainable point based agricultural systems and forest management.
- establish point specific greenhouse gas emission estimators at local and national scale for accurate emission and sequestration estimation. This is important in evaluating climate change and agricultural resilience projects for adaptation and mitigation strategies.
- promote field based farmer technical and business schools. These approaches will help to collect and evaluate perception of smallholders on a specific sustainable land management strategy; understand reasons for their non-adoption and limits; document and evaluate available local resources; evaluate their costs, coping, adaptation and mitigation benefits and establish ways of improvement.
- participatory community-based climate change and food security projects are relevant in identifying direct and indirect causes of agricultural systems vulnerability to climate change; evaluate the proximate consequences; define priority areas and required actions needed to sustain and overcome the changes.

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