ESTIMATION AND MAPPING OF SOIL ORGANIC CARBON STOCKS IN CROPLANDS OF THE BECHEM FOREST DISTRICT, GHANA

DIVINE MAKAFUI YAO AGBOADOH
MARCH, 2011

SUPERVISORS:
Professor E.M.A Smaling [ITC]
Professor S.K Oppong [KNUST]
Dr. Alfred Duker [KNUST]

ESTIMATION AND MAPPING OF SOIL ORGANIC CARBON STOCKS IN CROPLANDS OF THE BECHEM FOREST DISTRICT, GHANA

DIVINE MAKAFUI YAO AGBOADOH
Enschede, The Netherlands, March, 2011

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente and the Faculty of Renewable Natural Resources of the Kwame Nkrumah University of Science & Technology in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geo-Information Science and Natural Resources Management

SUPERVISORS:
Professor E.M.A Smaling [ITC]
Professor S.K Oppong [KNUST]
Dr. Alfred Duker [KNUST]

THESIS ASSESSMENT BOARD:
Prof. Dr. Ing.W. Verhoef (Chair), ITC, The Netherlands
F.K. Mensah M.Phil. (External examiner), CERGIS,
University of Ghana

Abstract

Global changes in climatic conditions due to human activities and efforts directed towards soils as an opportunity to both mitigate and adapt to climate change had gained much attention nowadays. This situation underscores the importance and adaption of sustainable land use management practises to enhance the potentials of soils as a carbon sink. Hence, the study aimed at (1) describing the various land use types in the Bechem Forest District, Ghana ;(2) to estimate and map soil organic carbon stocks in the different land use types; and (3) to recommend options to raise soil organic carbon stocks in the area. An ALOS satellite image was classified using a pixel based supervised approach. Field sampling was carried out based on random sampling and 78 soil samples per a layer (0-20cm and 20-50cm) were collected to a depth of 50cm. Soil organic carbon (SOC) concentrations were obtained using the modified Walkley-Black method. The spatial variability in the distribution of SOC was explored using Geographic Information Systems (Inverse Distance Weighted) and statistics (ANOVA). Farmers were interviewed on their various land use management practices. A classified land cover/land use map with an overall accuracy of 76% with six classes; Agroforestry, tree crops, mixed fields, tree plantations, forest and settlements; were obtained. The soil organic carbon content in each land use decreased with depth. Mean SOC in the entire top layer (1.4%) was higher than the bottom layer (0.79%) across the land use types. Therefore vertical variability in SOC distribution per land use/land cover type was statistically significant ($p<0.05$). However, for horizontal variability the SOC difference was not statistically significant for both top ($p=0.231$) and bottom ($p= 0.950$) layer respectively. The estimated average SOC stock range was 43(±2.6) t $SOCha^{-1}$ in forest to 35(±2) t $SOCha^{-1}$ in tree plantations for top layer and 41.7(±5.8) t $SOCha^{-1}$ in forest to 29.6(±3) t $SOCha^{-1}$ in tree crops for bottom layer. The total SOC stock for the study area was estimated as 8.78×10^5 t SOC.The order of SOC stock under different land uses for top layer is tree plantations<mixed fields<agroforestry<tree crops<forest and for bottom layer is tree crops<agroforestry<mixed fields<tree plantations<forest. 49-56% of the SOC stock resides in the top layer and makes this layer susceptible to land use change or management practices. Furthermore, there is approximately 20tons SOC loss per hectare when land use pattern changes from forest to any of the farm based systems. The spatial SOC distribution shows that higher values are associated with forests and tree plantation whilst the lower values are associated with farm based Land use. Residue retention is the most predominant land use practise (66%) but residue are poorly utilized, whilst fertilizer and manure applications are low (<4%).Therefore, adoption of viable and attainable options; residue retention as mulch, alley cropping, cover crops, guided use of fertilizers, socio-economic incentives, awareness creation; are required to reverse this trend in order to enhance the soil organic carbon status of the soils in the study area. Hence, awareness creation especially for farmers on the benefits of sustainable land use practices in terms of improving yields, soil fertility and the role of SOC in contributing to climate change mitigation as well as the potential financial benefits is pivotal. Therefore the need for more SOC research at the local level to provide an accurate baseline data for a national carbon inventory in readiness for the carbon trade cannot be over emphasized.

Keywords: soil organic carbon, spatial variability, land use/cover, land use management, Inverse Distance Weighted

Acknowledgements

I thank the Lord for His goodness, abundant grace and wonderful works in my life.

I acknowledge the Environmental Protection Agency, Ghana and ITC capacity fund for providing the funds for my study. I am grateful to my supervisors Professor Eric Smaling, Professor Samuel Kwabena Oppong and Dr. Alfred Duker for their constructive thoughts, criticisms and remarks during my research work. Thanks to the staff of ITC (NRM Department) and KNUST GISNATUREM for their varied contribution to the completion of this programme.

To my course mates it has been wonderful knowing you. I am also appreciative to all who in diverse ways contributed to the completion of this research.

Finally, I owe much to my family and my sweetheart Naanii for their patience and encouragement. When the next step was not clear you were there for me.

Table of contents

List of Figures

List of tables

List of acronyms

ALOS	Advanced Land Observation Satellite
BD	Bulk density
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
CV	Coefficient of variation
ERDAS	Earth Resources Data Analysis
FAO	Food and Agriculture Organization
IDW	Inverse Distance Weighted
IPCC	Inter-governmental Panel on Climate Change
MOFA	Ministry of Food and Agriculture
NUTMON	Nutrient Monitoring
REDD	Reduced Emission from Deforestation and Degradation
SOC	Soil organic carbon
SPSS	Statistical Package for Social Scientists
UTM	Universal Transverse Mercator
WGS	World Geodetic System

1. INTRODUCTION

The past 10 to 20 years have brought disturbing evidence that human activities contributes to high carbon dioxide(CO_2) concentrations and this might cause significant changes in future global climatic conditions(IPCC, 2007; Wallington *et al.*, 2004). These anticipated changes in climatic conditions have potential social, economic and environmental consequences worldwide (Robert, 2001). However, through the establishment of the Kyoto Protocol**,** global efforts are being directed towards biological systems(living biomass, forests and soils) for carbon sequestration(Dersch & Böhm, 2001; Freibauer *et al.,*2004). Furthermore, because soils hold more carbon than the atmosphere and vegetation combined, and can hold it longer, the focus has increasingly shifted to soil carbon as an opportunity to both mitigate and adapt to climate change, as well as the provision of ecosystem functions(Sheikh *et al.,*2009). Carbon sequestration refers to the removal of carbon dioxide from the atmosphere into a long-lived stable form that does not affect atmospheric chemistry(Miller *et al.,* 2004).

Agriculture is associated with the provision of food but at a cost to many ecosystem services including carbon sequestration(Tilman *et al.,* 2002; Tilman *et al.,* 2001). In addition, degraded ecosystem services also affect agricultural productivity(Albrecht & Kandji, 2003; Dale & Polasky, 2007).Agricultural activities such as forest harvesting, livestock related nitrogen and methane emissions, paddy rice-related methane emissions, and poor land management practises have become a major contributor to CO_2 emissions in the atmosphere(Lal & Bruce,1999; Miller *et al.,*2004; Oelbermann *et al.,* 2004). Consequently, agriculture contributes immensely to carbon induced climatic changes as well as inducing changes in soil properties(Yao *et al.*,2010).

However, the potential of agricultural soils to serve as carbon offsets has been seldom considered. Therefore the adoption of strategies and appropriate policies that make agricultural activities less detrimental are options that require consideration (Albrecht & Kandji, 2003; Herrick, 2000; Lal *et al.,* 2003; Robert, 2001). Changes in agricultural land use management can increase or decrease soil organic carbon (SOC)(West & Post, 2002).The promotion of tree based systems, agroforestry, cover crops, residue retention, manure application, irrigation, conservation, no/less tillage and other agrarian practises are options that may greatly reduce carbon loss and enhance soil organic carbon levels (Batjes & Dijkshoorn, 1999; Marland *et al.,*2004; Paustian *et al.,*1997). Enhanced soil organic carbon(SOC) has favourable effects on physical, chemical and biological activities of the soil for good crop yields(Ardö & Olsson, 2003). Soil Organic Carbon can be catalogued as an index of sustainable land management; hence SOC provides options for improving soil fertility and ensuring food security (Marks *et al.,* 2009; Nandwa, 2001). Additionally, it has been broadly used as a proxy to monitor land cover and land use change patterns (Khresat *et al.,*2008). This land use/cover change pattern therefore introduces spatial variability in the SOC content and an understanding of such variability is important for developing management practises for a particular land use(Wang *et al.,*2010).

Most agricultural practises in Africa are characterized by low-input technologies and the continuous cultivation of the soils depends largely on soil organic matter for productivity (Atsivor *et al.,* 2001; Braimoh & Vlek, 2005; So *et al.*,2001; Verma *et al.*,2010; Yao *et al.*,2010). Several studies assessing SOC dynamics with respect to different land use types have either adopted the routine indirect laboratory analysis procedure or the direct procedure of remote sensing or high-tech field methods(Batjes,2004; Brown *et al.,*2006; van Noordwijk *et al.,*1997; Viscarra *et al.*,2006). Conversely, there is a gradual shift from the routine soil chemical and physical laboratory analysis towards the development of more efficient methodologies for soil analysis as there is a great demand for good quality, inexpensive soil data to be used in environmental monitoring and agriculture. However, for this study the conventional method was adopted due to the unavailability of a field spectrometer, time constraint in collecting large amount of data for equipment calibration in order to obtain good results(Brown *et al.,*2006; McCarty *et al.,*2010).

In Ghana, the different farming systems, namely tree plantations or woodlots, tree crops, agroforestry (trees with food crops),alley farming (AL), conventional tillage (CT) or mixed fields and natural fallow (NF) could be characterized on their above ground and below ground carbon characteristics (Atsivor *et al.*, 2001; Benneh, 1972; Marks *et al.,*2009). These can be ideally considered as a function of the carbon stocks that are typical for these systems, but also a function of environment (soil type, rainfall, temperature) and management (Marks *et al.*, 2009; Paustian *et al.*,1997; Stewart *et al.,* 2007). However, despite the global recognition of agricultural land use management as a vital initiative towards removing carbon from the atmosphere, its inclusion in farming systems in Ghana have received little attention(Tiessen *et al.,* 1998). This trend is synonymous with research findings reported in other African countries (Bationo *et al.,* 2007; Smaling & Dixon,2006). Consequently, further insights would be needed to promote effective land use management practises in farming systems to enhance SOC stocks and improve agricultural productivity which is vital for the socio-economic development of Ghana(Woomer *et al.,* 2004).

Agro forestry or taungya systems have received a major boost in the Bechem Forest District and other Forest Districts in Ghana; as a Government initiative towards restoring degraded forest reserves; through maintenance of trees and production of food crops (Hapsari, 2010; Nguyen, 2010). Tree crops, tree plantation and mixed crop farming are also common within the District.These farming systems are supported mainly by nitosols(red clayey)soils; locally referred to as the susan series an intermediate between true Rubrisols and Ochrosols(FAO, 1998; Obeng, 2000). These soils are limited in extent in Ghana and are the most valuable within the Forest belt of Ghana(Obeng, 2000). They also have a better physical and chemical conditioning for the prolific growth of arable and tree cash crops than both the predominant forest Ochrosols and the Oxisols.The land use management practises to enhance this potential is seldom considered (Batjes, 2001; Batjes & Sombroek, 1997; Briggs & Twomlow, 2002;Smaling *et al.,*1996). More so, the subsistence farming practised deploys no regeneration periods to restore soil fertility due to unavailability of arable lands (Bationo *et al.,* 2007; Doraiswamy *et al.*, 2007). Such practises are associated with poor land management, low production levels, removal of crop residue and continuous tillage (Batjes & Sombroek, 1997). Therefore farmers are most likely to convert forestlands to increase food production rather than through enhanced soil management practises (FAO, 2003). This situation will expedite rate of deforestation, soil carbon depletion and impact ecosystem services negatively (Benefoh,2008; Dale & Polasky, 2007; Lal & Kimble,1997).

The current global effort to deal with CO_2 induced global warming to ensure atmospheric quality and the consideration of soils as a major carbon pool underscores the importance of sustainable land use management. The quality of agricultural soils in tropical regions including Ghana continues to decline due to poor land use and soil management practises(Marks *et al.,*2009). This trend affects soil organic carbon which plays the dual role of promoting soil fertility/yield and provision of ecosystem service (carbon sink) (Figure 1). Therefore adoptions of appropriate land use management practises are required to reverse this trend.

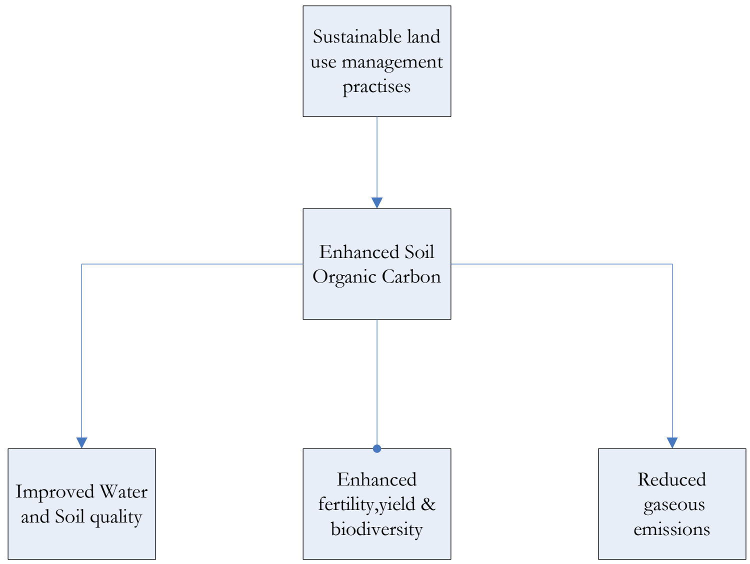

Figure 1: Diagram showing how management of soil organic carbon is key to soil, air and water quality. Modified from(Lal,2007)

Currently in Ghana, the Reduced Emissions from Deforestation and forest Degradation (REDD) initiatives considers carbon conversion in farming systems as one of two thematic areas for emission reduction(Nketia *et al.,* 2009). In addition, the potential consideration of soil carbon credit under the Kyoto Protocol underscores the need for an elaborate soil carbon data in Ghana (Batjes, 2001; Smith, 2005; Takimoto *et al.,* 2008). However, the evaluation of soil carbon sources and sinks is difficult because the dynamics of soil carbon storage and release is complex and still not well understood(Wang & Hsieh,2002). Furthermore, many studies have been conducted on the physico-chemical and biological changes on soil properties in humid regions of the world (Duiker & Lal, 1999; Oelbermann *et al*.,2005; Wang *et al*.,2008; Wang *et al*.,2010). However in Africa and more specifically in Ghana very little has been done with respect to soil organic carbon dynamics in various land use systems (Atsivor *et al*.,2001; Bellassen *et al*.,2010; Yao *et al*.,2010). Therefore it is important that the SOC estimates in the various land use systems are obtained and their potential for increase explored. This study aims to provide information on the soil carbon stocks in the Bechem Forest District and underscore the need for further assessment of soil organic carbon offset opportunities in Ghana. This will provide the country with a national SOC inventory for carbon sequestration projects. Additionally, agricultural practitioners will use the results to address land use change and adopt appropriate land use management practises to enhance soil organic carbon capacity and fertility of cropland soils. Furthermore, the Kyoto Protocol through the United Nations Framework Convention on Climate Change (UNFCCC) has created an economic opportunity for carbon credits in the near future(Bellassen *et al.,* 2010). Therefore, this can create opportunities for farmers to have an additional source of income and likely start a process that will consider carbon credit policy or incentives options for cropland soils in Ghana(Ringius, 2002; Vagen *et al*.,2005).

1.1. Research Objectives

1.1.1. Overall Objective

The overall objective of the study is to describe the Soil Organic Carbon (SOC) stocks within different farming systems and other land use types and discuss land use management options that could enhance SOC stocks within the Bechem Forest District, Ghana.

1.1.2. Specific objectives

- To describe farming systems and other land uses within the Bechem Forest District.
- To estimate and map SOC stocks within the different farming systems and other land use types.
- To recommend options to raise SOC stocks in the area

1.2. Research questions

- What are the land use types and their distribution in the study area?
- How is the soil organic carbon stock distributed across the land use types?
- What is the concentration of soil organic carbon stocks within the different land use types?
- Is the concentration of soil organic carbon stocks across the land use types significant?
- Which farming system and land use type has the highest Soil Organic carbon stock?
- What is/are the predominant land use management practises in the area?
- How can the SOC stocks be enhanced in the area?

1.3. Hypothesis

- SOC stocks in the different land use types are significantly different and overall SOC stocks can be increased by land use adaptations.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Site and Land use Characteristics

The study was conducted in Bomaa; a farming community with favourable agro-climatic conditions; located within the Bechem Forest District in the Brong Ahafo region of Ghana. The site lies between two Administrative Districts (Tano North and South) and located between latitudes 7˚00'N and 7˚25'N and longitudes 1˚45' W and 2˚15' W (Figures 2 & 3).

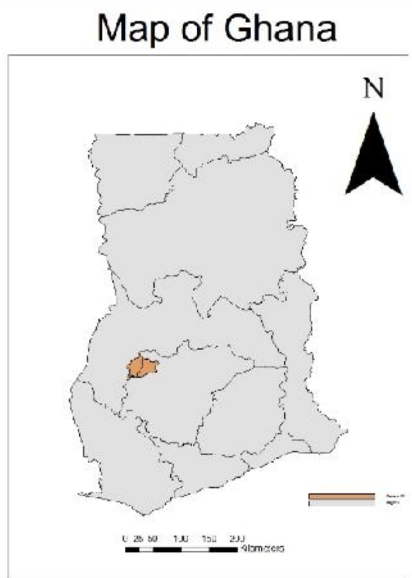

Figure 2: Location of study area in map of Ghana

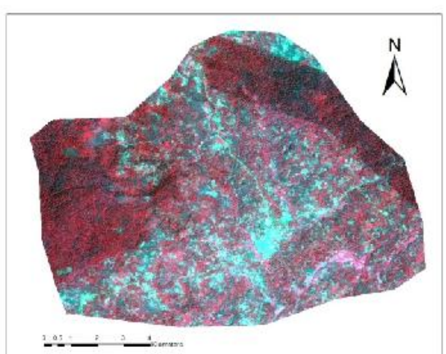

Figure 3: ALOS image (23 January 2008) for the study area

The area experiences double maxima rainfall patterns. The major rains starts from April to June and the minor from September to October. Annual rainfall ranges from 1250mm to 1800mm. Relative humidity is generally high throughout the year, ranging between 75-80% in the rainy season and 70-72% in the dry season. The dry season is quiet pronounced and occurs between the months of November and March each year. The monthly mean temperature range is between 26ºC in August and 30ºC in March(MOFA, 2009).

The District lies in the moist semi-deciduous forest zone of Ghana. There are two main forest reserves namely; the Bosomkese Forest Reserve which covers a total area of 138.41km² and Aparapi Forest Reserve with a total area of about 19.04km². Tree species found in the two reserves include Odum(*Milicia excelsa*),Wawa(*Triplochiton scleroxylon*),Ofram(*Terminalia superba*) Mahogany(*Khaya ivorensis*), Ceiba(*Ceiba pentandra*), Cassia(*Cassia sp*) and Esaa(*Celtis sp*). These trees are of economic importance as they are used for lumbering, timber, carving, chewing sticks, fuel wood and medicine.

The soils basically consist of forest ochrosols and the rubrisol - ochrosols intergrades(Obeng, 2000). They are alkaline and are more richly supplied with nutrients. Forest Rubrisols consist of dark red, firm or plastic, nutty to blocky clays developed over basic rocks. The soils are more clayey and therefore have greater capacity to maintain water for plant use. Therefore very ideal for the cultivation of forest crops like cocoa, coffee, oil palm and food crops like plantain, maize, rice, cassava and beans. Agriculture is the main economic activity in the district as in most districts in Ghana(Awanyo, 2009).

2.1.2. Image Data

A high spatial resolution ALOS image (23/01/2008) with no cloud cover was obtained for the study. The image was selected from the ITC database based on availability and suitability for the study area. The spatial and spectral characteristics of the image are shown in Table 1.

A shape file of the Bechem Forest District was used in the creation of the image of the study area. The shape file was used to clip the ALOS image to obtain an image of the Bechem Forest District. The Hawth tools in ArcGIS version 9.2 was used to generate random points on the Bechem Forest District image. The extent of the random points was digitized in ArcGIS version 9.2 to obtain the image for the study area. This image was uploaded onto an Hp214 iPAQ for the field work. The image was also used for land cover classification. Topographic, river and road maps of the Bechem forest District were acquired for geo-referencing.

Table 1: Characteristics of ALOS image used in the research

Subsystem	Band	Spectral range	Resolution
AVNIR-2	1	0.42 to 0.50 μm	10metres
	2	0.52 to 0.60 μm	
	3	0.61 to 0.69 μm	
	4	0.76 to 0.89 μm	

2.1.3. Software

The following softwares were used for the study:

- ERDAS Imagine 9.3 for image processing/analysis
- ArcGIS and Arc View 9.2 for database creation and geospatial analysis
- Microsoft Excel for field and laboratory data analysis
- Microsoft word 2003 and Microsoft Power point for report preparation and presentations
- IBM SPSS 19 for statistical analysis

2.1.4. Instruments

The following instruments were used for the study:

- Ipaq with GPS for navigation and location of sample plots.
- Digital camera for photographs of study area and fieldwork.
- Sample collecting bag and field knife for collection of soil samples
- Soil colour chart for the determination of colour of soil profile in samples
- Measuring tapes for the measurements of depth of soil profile in samples and for laying sample plots.
- Soil auger for digging holes for soil samples
- pH meter for measurement of soil pH
- Weighing scale for weighing collected soil clods/bulk density
- Metal core sampler/cylinder for collecting samples for bulk density determination
- Mallet for driving metal cylinder core into the soil
- Straight – edged knife for trimming soil samples in cylinder cores.

2.1.5. Research Approach

The study followed the outline as indicated in Figure 4. Literature on soil organic carbon as well as soil management practises was reviewed. Interpolation method was used in computing spatial soil organic carbon distribution.

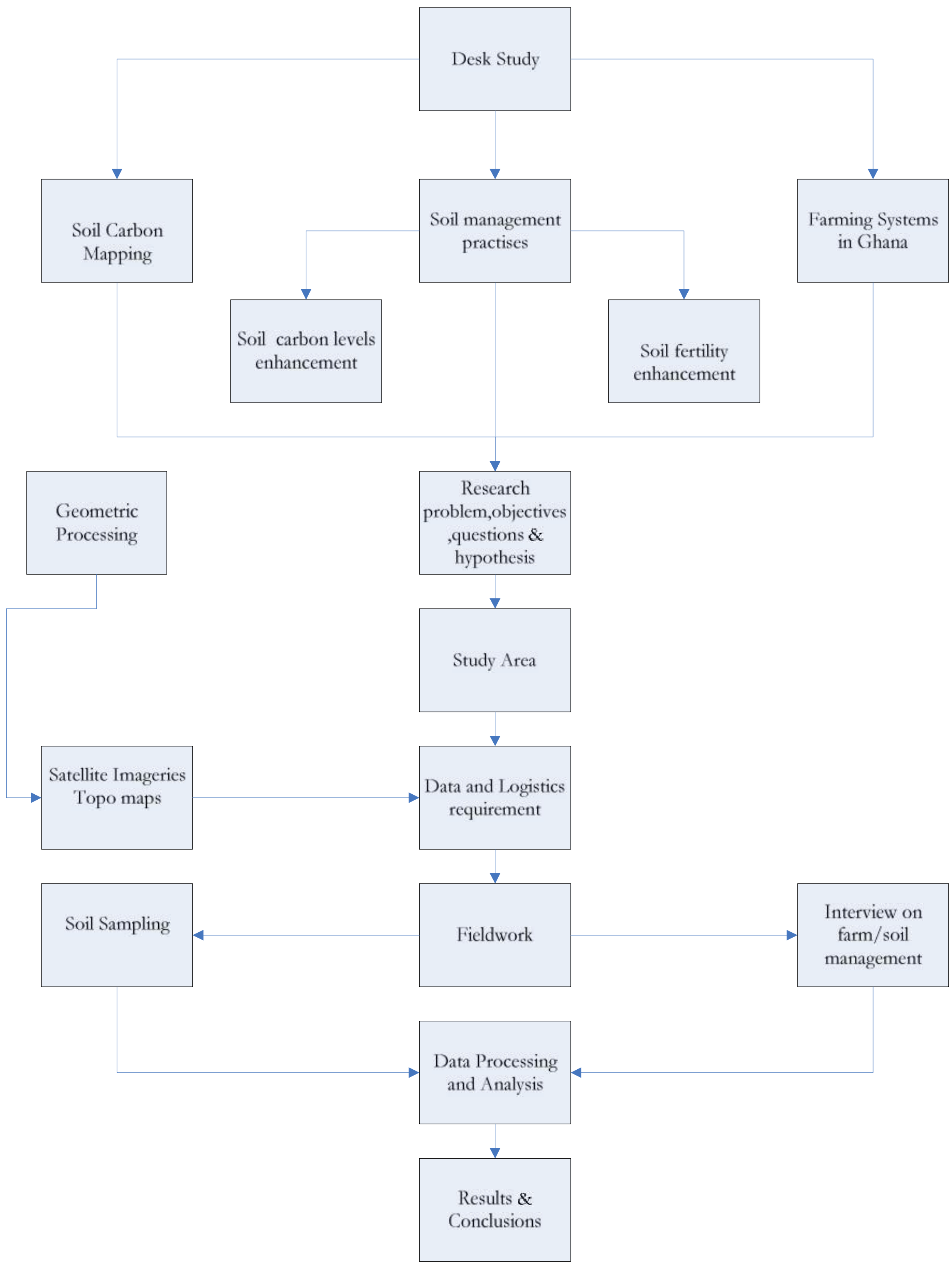

Figure 4: A flow chart of the Research Approach for the study

2.2. Methods

2.2.1. Flow chart of Research Methods in the study

The image of the study area was classified to obtain a land cover map. Soil samples were collected to 50cm depth at two layers (0-20cm and 20-50cm) and farmers were interviewed on land use management practices at each sampling field.

Soil samples collected were analysed for both chemical properties (Organic Carbon concentration and pH) and physical properties (Bulk density and texture). Carbon density was computed using the carbon concentration, depth thickness and bulk density. Land use management options to improve soil fertility and soil organic carbon in the study was obtained based on comparative analysis of SOC densities in the various land use types and the management practises deployed. Soil organic carbon distribution maps were created using inverse distance weighted (IDW) approach in ArcGIS version 9.2. The flow chart for the research is shown in Figure 5.

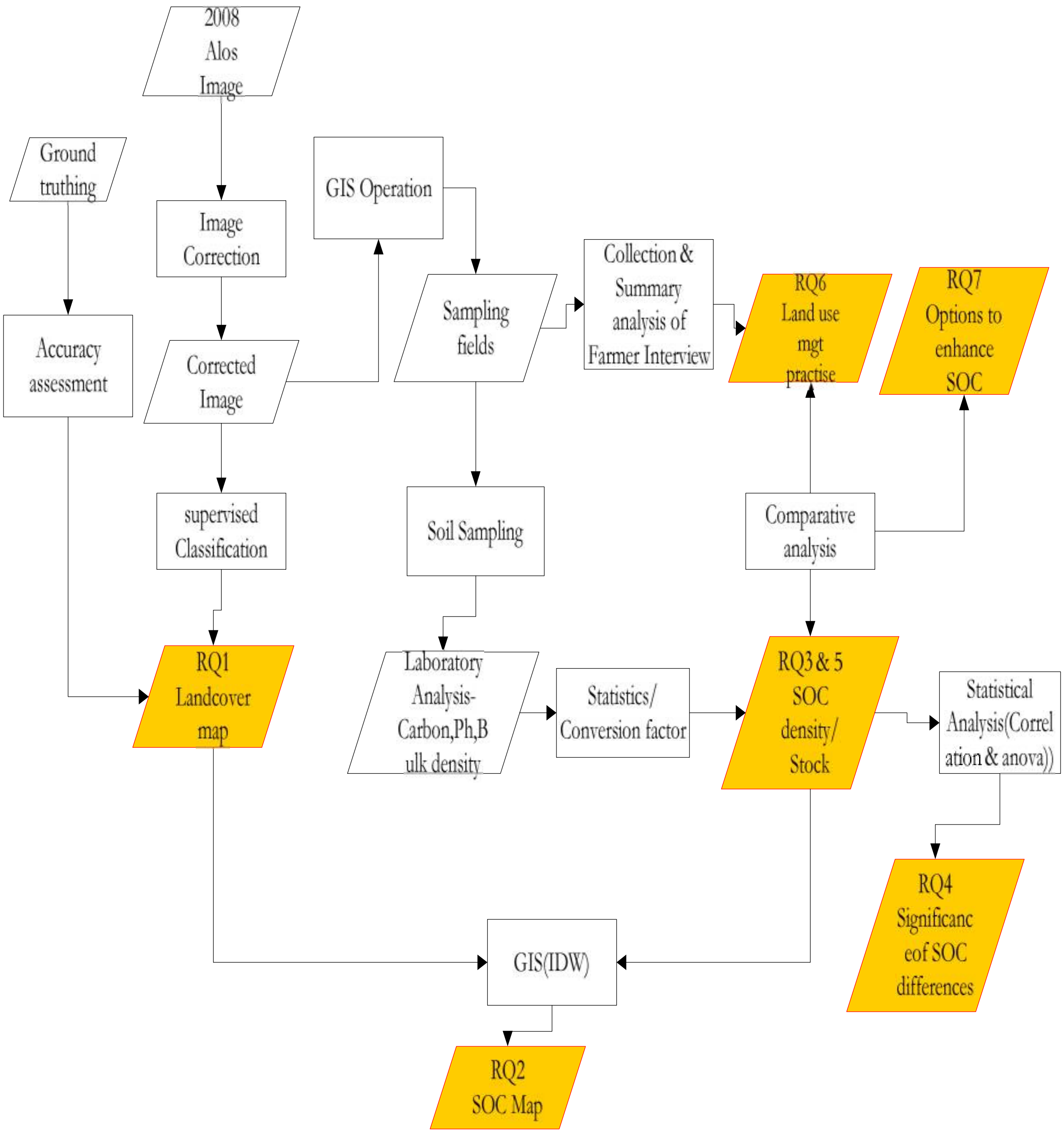

Figure 5: Flow chart of Research Methods in the study

2.2.2. Research Design

The following research design was adopted for the study. The research is divided into three components namely: Image Analysis, soil Sampling and Land use management interview.

2.2.3. Image Analysis

2.2.3.1. Image Pre-processing

The ALOS satellite image was imported into ERDAS and geo-referenced with ground control points (GCP). These GCPs consisted of recognizable road intersections, building corners and river confluence. A second order polynomial was used for the geo-referencing. A root mean square error of 0.36 was obtained. This positional error margin is within the 0.5 acceptable margins. Furthermore, different levels of positional errors are accepted based on the spatial resolution of the image(Benefoh, 2008).

The geo-referencing process which is aimed at assigning each pixel to real world co-ordinates also increases the amount of information needed for improved image interpretation for classification.

The ALOS image was set in WGS 1984(UTM Zone 30°N) projection system. This was used for the study because that is the current projection system being used in Ghana.

The ALOS image obtained for this research had no cloud cover therefore no radiometric corrections were done on the image.

2.2.3.2. Image classification

The image classification process apportions the pixels of an image to exact spectral behaviour of the ground data. This process converts image data to thematic data. The land use/land cover of the study area was classified using the ALOS image of 2008. A pixel based approach (supervised classification) was used in classifying the image. The maximum likelihood algorithm was used in the classification process in order to obtain a good output(Braimoh & Vlek, 2005)..

Accuracy assessment was carried out by comparing samples of the pixel from the classification results/classified image with that of the ground truth data. The error matrix produced after the accuracy assessment has a column and a row which represents the reference data (ground-truth data) and the classification results respectively. One hundred and thirty two field data points were collected and 62 points were used as sample training whilst the rest were used as validation points. The image classification and accuracy assessment were performed in ERDAS Imagine version 9.2.

2.2.4. Soil Sampling

The following step was performed to identify the soil group unit of the study area. A digital soil map of the area obtained from the Soil Research Institute of Ghana was overlaid on the image of the study area. The soil map was re-projected in WGS 84 to match that of the image. This resulted in the identification of the soil types in the study area.

Two sets of soil samples were collected from randomly selected fields. This was to ensure that sample fields are well distributed over the study area and are representative of the various land use/land cover types of the area(Ololade *et al.*,2010). Soils from settlements were not sampled.

One set was used for Organic carbon and pH determination and the other set for the determination of bulk density. Since there was an interest in soil carbon management, regular monitoring of above ground conditions on each field was combined with the soil sampling. Field observations such as litter presence or accumulation, crop residue presence and signs of erosion and earth movements were noted where applicable because these factors might influence SOC accumulation.

2.2.4.1. Locating sampling fields

An Hp Ipaq and a portable Garmin GPS receiver were used to locate the sampling sites (Figure 6). On each field, a subsample of the field (12metre x 12 metres square) was delineated for sampling. Each field was sampled to a 50cm depth with two layers (0-20 cm and 20-50cm) through composite sampling "following the '5' on a dice procedure"(Velasquez *et al.,* 2007). At each sample point; 5 replicates of soil samples were collected; at the four extreme corners of the delineated field and one at the centre; using a soil auger. The 0-20cm soil depth was referred to as the top layer and the 20-50cm depth referred to as the bottom layer. According to (Baker *et al.,* 2007), soil sampled below 40cm depth introduces some bias in the determination of soil organic carbon . Therefore in this study, soils were sampled to a 50cm depth in order to remove bias.

All the five samples per field were combined to obtain a homogenized sample per field for analysis; each core was sliced laterally to include soil from all the depths but not the entire core. A bowl was used for mixing or combining samples to obtain homogenized samples. Hence, each sample was evenly representative of the entire layer sampled.

From each plot, soil samples were bagged for laboratory analysis (Anderson & Ingram, 1993). Each sample bag was well labeled with a clear and explicit identifier with a permanent marker. At each plot, the geographic co-ordinates, plot Id,vegetation,moisture status(Wet, dry, or moist),texture.(Sand, silt, clay, or a combination), rocks and roots(None, few, many.) were recorded.(Appendix A:Field Data sheet).

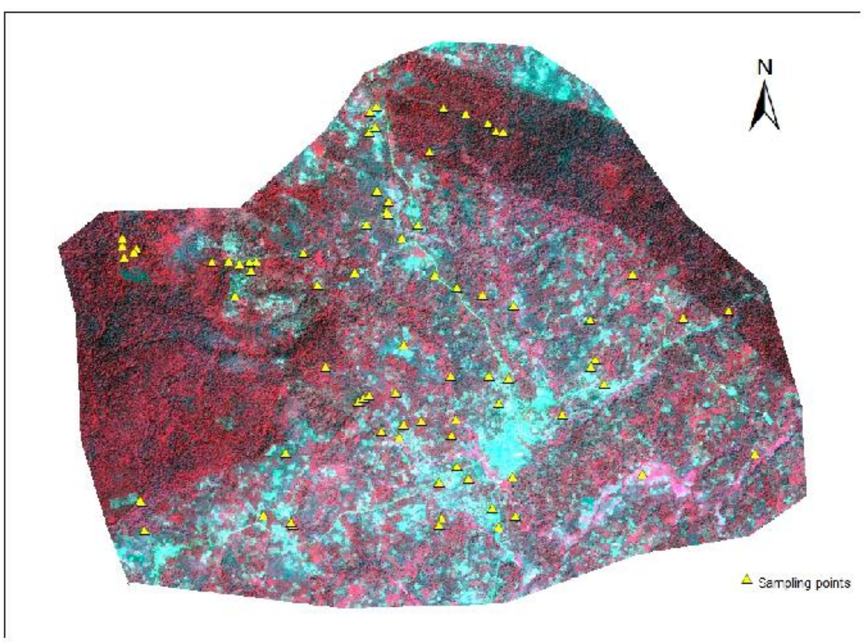

Figure 6: Location of sampling fields used in the study

2.2.4.2. Soil samples for soil organic carbon and pH determination

After soil surface observations, the soil samples were taken minimizing disturbance of the soil surface. The intention was to take a sample that is descriptive of the layer being sampled. The soil auger was driven to 20cm and 50cm into the soil for the top layer and bottom layer respectively. A calibrated meter stick was used for measuring the length of cores. In order to ensure consistency, crop residue, thatch, litter or any other material were removed from the soil surface by hands before a sample was taken(Chiti *et al.,* 2010).

As per standard practice in soil carbon determination, the litter layers were not sampled, but sampling begun at the upper surface of mineral soil. It was difficult to establish a boundary at the soil surface where abundant litter was present. A record of how each plot was handled with respect to litter removal was kept. Caution was exercised during sampling especially at locations where plot centres coincide with crops/plants. The soil samples at such locations were taken to avoid or minimize damage to the crop/plant. In some locations, the points were shifted away from the crops/plants. It was ensured that samples taken were contamination free. Soils from digging or auger work were piled and replaced before leaving each sampling site. Large samples were divided vertically to reduce the quantum of soil samples sent to the laboratory.

Photographs of the fieldwork are shown in Appendix B.

2.2.4.3. Soil samples for bulk density determination

Bulk density is a measure of the weight of the soil per unit volume expressed as grams per centimetre cube (g cm^{-3}) (usually given on an oven-dry (105 °C) basis. Most mineral soils have bulk densities between 1.0 and 2.0. Once the bulk density is known, measurement of soil mass, volume or percentages can be expressed interchangeably or in absolute terms.

The bulk density sample was similar as much as practicable to the carbon samples. The core method was used for the collection of samples for the bulk density determination (Morisada *et al.*,2004). The core sampler was driven into the soil with the aid of a mallet. Soil at both ends of tube was trimmed and the end flushed with a straight – edged knife. .

2.2.5. Laboratory Analysis

2.2.5.1. Soil sample preparation

Soil samples were air dried ground and passed through a 2mm sieve before being used for analysis.

Photographs of the laboratory work are shown in Appendix C.

2.2.5.2. Soil organic carbon (SOC) determination

The organic carbon estimates in the soil samples from the top layer (0-20cm) and bottom layer (20-50cm) was determined using the wet combustion method (Walkely-Black, 1973). The modified version of method has been used by several researchers (Dutta *et al.*,2010; Gol *et al.*,2010; Ololade *et al.*,2010; Sheikh *et al.*,2009; Wang *et al.*,2010).

The Walkely and Black procedure adopted for this study is the modified version; wet oxidation method; based on the reduction of the $Cr_2O_7^{2-}$ (Dichromate solution) by organic matter. Oxidizable matter in the soil sample is oxidized by $Cr_2O_7^{2-}$, and the reaction is facilitated by the heat generated when two volumes of concentrated H_2SO_4(Sulphuric acid) are mixed with 1 volume of 1 N (0.1667 M) $K_2Cr_2O_7$ (potassium dichromate solution).

The excess $Cr_2O_7^{2-}$ is determined by titrating with standard ferrous sulphate solution. The quantity of substances oxidized is then calculated from the amount of $Cr_2O_7^{2-}$ reduced.

The procedure involved is as follows: 2.0 g of soil sample was weighed into a 500 ml Erlenmeyer flask. An exact 10 ml of 1.0 N; Potassium dichromate solution, is added from a burette followed by 20 ml of concentrated H_2SO_4. The mixture is swirled to ensure that the solution is in contact with all the particles of the soil. The flask with its content was allowed to cool on an asbestos sheet for 30 minutes. Then 200 ml of distilled water and 10 ml of orthorphosphoric acid were added to the mixture. A 2.0 ml (of 10 ml) of diphenylamine indicator was added. After which the mixture was titrated against 10 N ferrous sulphate solution until the colour changed to blue and then to a green end – point. The blank solution (> 10.5) was corrected through the steps outlined above but without any soil samples to standardize the Potassium dichromate solution. The percentage carbon was obtained from the following formula/equation 1:

$$\% \text{ organic C in soil} = \frac{(\text{Blank-Titre Value}) \times 0.003 \times 1.33 \times 100}{\text{Wt. of sample}} \quad \text{…. ……………Equation 1}$$

Where:

Milli equivalent weight of Carbon = 0.003

Correction factor (F) = 1. 33

The Wet combustion method is about 76 % efficient in estimating carbon value. Hence a factor (100/76 = 1. 33) is used to convert the Wet combustion Carbon value to the true Carbon value.

2.2.5.3. Soil pH

The soil water ratio method was adopted for the determination of hydrogen ion activity or pH of soil samples (Adigun *et al.,* 2008).

The procedure used for pH determination was as follows: 10g air dried soil was weighed into a 100 ml beaker. 25 ml distilled water was added and the suspension stirred vigorously for 20 minutes. The soil – water suspension was allowed to stand for about 30 minutes for most of the suspended clay to settle out from the suspension. A pH meter is then calibrated with a blank at pH of 4 and 7 respectively. The electrode of the pH meter is inserted partly into the settled suspension and the pH value is displayed on the screen of the metre. The pH value is read and recorded.

2.2.5.4. Bulk density

The procedure used for Bulk Density determination was as follows: The core sampler with its content was dried in the oven at 105 ^{0}C to a constant weight. The core sampler was removed from the oven after 48hours. The sampler with its content was allowed to cool. The weight of core sampler with content is recorded. The volume was determined by measuring the height and radius of the core sampler. The bulk density (BD) was calculated using the formula(equation 2) by (Anderson & Ingram, 1993):

$$BD = (W_1 - W_2) \times V^{-1} \quad \text{…………………………………Equation 2}$$

Where:

W_2 = Weight of core cylinder + oven – dried soil/grams

W_1 = Weight of empty core cylinder/grams

V = Volume of core cylinder ($\pi r^2 h$), cubic centimeters where: $\Pi = 3.142$, r = radius of the core cylinder and h = height of the core cylinder .The Bulk density is expressed in gcm^{-3}.

Soil particle size/texture was obtained by the hydrometer method(Bouyoucos, 1962).

2.2.6. Calculation of organic carbon density by depth

The organic carbon density represents the organic carbon held within each individual layer at corresponding depths (0-20cm and 20-50cm). The total organic carbon by volume (SOC, C kg m^{-2}) for individual profile layers was calculated using equation 3 adopted from (IPCC, 2003; Morisada *et al.,*2004) as follows:

$SOC_d = OC_i \times BD_i \times D_i \times (1\text{-}S_i)$…. …………………………………………………..……..Equation 3

Where SOC_d is the total amount of organic carbon (SOC, C kg m^{-2}) above depth *d,* BD_i(g cm^{-3}) is the dry bulk density of layer *i,* OC_i is the concentration of Organic carbon(C%) in layer *i,* D_i is the thickness of this layer (cm), and S_i is the volume of the fraction of fragments >2mm. Since the soil particles were mostly below 2mm, this fragment fraction was not calculated.

2.2.7. Calculation of soil organic carbon stock

The procedure used to estimate the organic carbon stock was adopted from (IPCC, 2003; Morisada *et al.,*2004). The steps involved the computation of the organic carbon density of soils to the depths of 20cm and 50cm respectively. The estimates were then grouped by land use types to give estimates of representative values. The representative values of the organic carbon density are averaged and converted to soil organic carbon stock in tons per hectare (t C ha^{-1}) for each land use type. The SOC storage per land use type was obtained by combining the estimated total SOC with the area estimates for the respective land use. The total SOC stock for the entire study area was computed by combining the average SOC stock for all the land use types with the total area estimate for the study area.

2.2.8. Mapping of soil organic carbon (SOC)

In ArcGIS version 9.2, the inverse distance weighted approach (IDW) was used to develop the spatial distribution map of the soil organic carbon content(Wang *et al.,*2009). Each sampling field was assigned the actual SOC value during the interpolation process.

The parameters of cell size 33.996 and a search radius of 12 nearest neighbour was used in the interpolation to produce the spatial distribution map of SOC density for the two soil layers (0-20cm and 20-50cm).

2.2.9. Land use management Interview

The farmers in each sampling field were interviewed on the land use management practises and the drivers for choosing these practises. A NUTMON Inventory forms/ questionnaires(Appendix D) was adopted, modified and administered to farmers to obtain information on nutrient/soil management practices(Smaling & Fresco,1993).

Information on farm size, crops grown, livestock and the redistribution strategies (garbage, manure heaps) were obtained. For each farm, inputs in terms of fertilizer and manure and the outputs in terms of crops/yields and residues were obtained. These are needed because they are major soil fertility factors that drive carbon storage.

A native of the town who works as an informant for the Forest Services Division, Ghana was hired as a research assistant. Where farmers are not located on their farms, they were traced to their homes for the interviews. The research assistant was very instrumental in this direction.

2.2.10. Statistical analysis

The data was checked and entered into a spreadsheet (Microsoft excel). The data was then imported into statistical software (SPSS Version 19, 2010), where general or summary statistics (mean, standard deviation, maximum and minimum values) were obtained. Coefficient of variation (CV) was obtained for the mean SOC, bulk density and pH to indicate the variation of each calculation for each soil profile/layer per each land use type. The CV which is a ratio of the standard deviation to the mean, measures the dispersion of a probability distribution (Wang *et al.,* 2009).

Cv= Standard deviation/mean x 100%………………………..…………………..equation 4

A normality test (Kolmogorov-Smirnov and Shapiro-Wilk) was performed to check if the data was normally distributed before subjecting the data to a parametric test (simple One way ANOVA). The ANOVA was used to evaluate significant differences in the distribution of soil organic carbon across the different land use types. Correlation analysis was carried out to detect any useful relationships among soil variables (Carbon, pH, texture and bulk density) measured (Wang *et al.*,2010; Yao *et al.*,2010).

Descriptive statistical analysis like bar graphs, tables and pie charts were used to evaluate responses from farmers on land use management practises. Based on the analysis of the questionnaire and the SOC stocks from the different farming systems, management options to enhance SOC sequestration were identified.

3. RESULTS

3.1. Land use and Soil Unit/type

The overlay of the digital soil map on the study area resulted in a homogenous area of Nitosol (the susan series) soil type. In all 78 samples or observations were made and the total area was 12328 hectares (ha). These observations were separated into six land use types namely; settlements, forest, agroforestry, mixed cropping/fields, tree crops and tree plantations (Table 2). Out of the total area sampled, the distribution of each land use type was obtained (Table 2). Farm based systems (Agroforestry, Tree crops and mixed fields) formed a large portion (56%) of the fields sampled. This is an indicator that agriculture is the main occupation of the people in the study area. Photographs of the different land use types are shown in Appendix E.

Table 2 :Relative distribution of land use types in the study area

Land use type	Sample size(N)	Description	Area(ha)	Area coverage (%)
Agroforestry	15	Teak,plantain,cocoyam	2062	16.7
Tree crops	20	cocoa	3585	29.1
Mixed cropping/ fields	20	Plantain,cassava,cocoyam	1244	10.1
Tree plantations	13	Teak,Cedrella	1603	13
Forest	10	Wawa,mahogany,odum	3191	25.9
Settlements	None	Buildings, roads	643	5.2
Total	**78**		**12328**	**100**

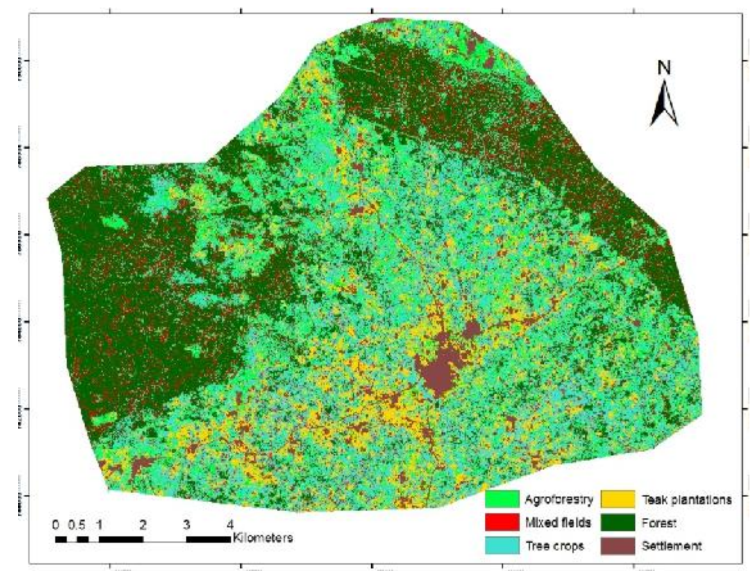

Figure 7 : A supervised classified ALOS image of the study area

3.1.1. Classified Image of the study area

The classified map was grouped into six classes based on land use types (Agroforestry, tree crops, mixed fields, tree plantations, forest and settlements (Figure 7). The overall accuracy was 75.71% with a kappa statistics of 0.6873(Appendix O).

3.2. Dry bulk density and soil texture

3.2.1. Dry bulk density

Table 3 summarizes the measured dry bulk density based on land use type for the top and bottom layers.

For the top layer, mean bulk densities across the different land use types increased from 1.29g/cm^3 in mixed fields to 1.51g/cm^3 in forest land use type. The variability in the measured dry bulk density for the land use types ranged from 12.83% to 18.34%. The farmers in mixed fields as per the interview data do not replenish nutrients but continually cultivate the land; mixed fields thereby recorded the highest variability of 18%.

With respect to the bottom layer, mean bulk densities across the different land use types increased from 1.36g/cm^3 in tree plantations to 1.50g/cm^3 in forest land use type. The variation in the measured dry bulk density for the land use type ranged from 11.27% to 17.91%. Again, mixed fields recorded the highest variability of 17.82%.

Depth wise, an increasing trend in dry bulk density was observed with increased depth in all land use types except for forest, where dry bulk density decreased by small margin. The maximum mean dry bulk density was present in forest for both depths. The largest variation was observed for mixed fields with CV of 18.34% for top layer and 17.82% for bottom layer respectively.

Table 3 : Mean and range for dry bulk density by land use type for two soil profiles

Land use type	Sample size (N)	0-20cm(top layer)				20-50cm(bottom layer)			
		Mean (gcm^{-3})	Max (gcm^{-3})	Min (gcm^{-3})	CV (%)	Mean (gcm^{-3})	Max (gcm^{-3})	Min (gcm^{-3})	CV (%)
Agroforestry	15	1.37	1.78	0.99	13.53	1.38	1.66	1.1	11.27
Tree Crops	20	1.36	1.69	1.08	12.83	1.47	1.79	1.03	15.10
Mixed cropping/fields	20	1.34	1.65	0.67	18.34	1.37	1.79	0.92	17.91
Tree plantations	13	1.29	1.54	1.02	13.34	1.36	1.75	0.97	17.82
Forest	10	1.51	1.86	1.2	14.37	1.51	1.83	1.21	16.39

CV: coefficient of variation, max: maximum, min: minimum

3.2.2. Soil texture analysis

Table 4 summarizes soil texture characteristics for selected top layers by land use type. Within the different land use types, clay content varied from 17% to 27%, while sand fractions ranged from 63% to 74 %. Clay contents were higher in tree plantations and forests as compared with soils from mixed fields, tree crops and agroforestry.

The soils were classified as sandy clay loam for tree plantations, forests land use types whilst agroforestry and mixed fields were classified as loamy sand and sandy loam respectively. The lowest clay content (17%) was recorded in agroforestry land use.

Soil clay and silt fractions showed a positive correlation (R=0.032, 0.065) with organic carbon whilst sand fraction recorded a negative correlation (R=0.184) with organic carbon (Appendix F). Since clay was positively correlated with SOC, it means that the lower the clay content the lower the SOC. Hence the agroforestry land use recorded a lower mean soil organic carbon content compared to other land use types that have relatively higher clay content (Figure 14).

Table 4 : Mean of soil texture in selected top layers by land use type

Land use type	Sand (%)	Silt (%)	Clay (%)	Class
Agroforestry	74.40±3.10	8.13±1.27	17.4±2.55	LS
Tree crops	70.73±7.49	9.83±3.00	19.43±4.88	SCL/LS
Mixed crops/fields	67.30±2.76	10.70±1.54	22.00±2.58	SL
Tree plantations	62.73±1.51	10.00±1.26	27.27±1.87	SCL
Forest	64.90±2.98	10.97±1.36	24.13±3.25	SCL

LS: Loamy Sand, SL: Sandy Loam, SCL: Sandy Clay Loam

3.3. Soil pH

Table 5 summarizes the measured pH by land use type for the two soil profiles. In the top profile, forest land use had the lowest mean pH value of 6.60 with a variation of 8.49% whilst agroforestry had the highest mean value of 7.21 with a variation of 9.97%. The low variability (8.49% - 9.97%) across the various land use types in this profile makes the profile a homogenous one.

For the bottom profile, mixed fields land use had the lowest mean pH value of 6.01 with a variation of 12.14% whilst agroforestry had the highest mean pH value of 6.61 with a variation of 16.52%. Again, the variability (12.14%-16.52%) across the land use types is low.

Generally, a decreasing trend in soil pH was observed with increased soil depth in all the land use types. Soil pH is significantly negatively($R=-0.481$, $p<0.01$) correlated with clay content (Appendix F). This means the lower the clay content the higher the pH values. Therefore, the relatively high pH values for agroforestry could be attributed to the fact that it is practised on degraded areas which have low clay content. The same reason could be assigned to the high variability in agroforestry pH values.

Table 5 : Mean and range of pH by land use type for two soil layers

Land use type	Sample size (N)	0-20cm(top layer)				20-50cm(bottom layer)			
		Mean	Max	Min	CV (%)	Mean	Max	Min	CV (%)
Agroforestry	15	7.21	8.21	6.03	9.97	6.61	8.19	5.08	16.52
Tree Crops	20	6.82	8.02	5.32	10.74	6.17	7.98	5.06	13.81
Mixed cropping/fields	20	6.56	7.77	5.26	10.10	6.01	7.62	4.55	12.14
Tree plantations	13	6.86	7.8	5.84	8.91	6.49	7.5	5.39	9.24
Forest	10	6.60	7.63	5.55	8.49	6.37	7.6	5.22	13.44

CV: coefficient of variation, max: maximum, min: minimum

3.4. Soil organic carbon content

The distribution of soil organic content for the top and bottom layers is shown in the line graphs (Figures 8-12). Amongst the farm based systems, the top soil in tree crops had the highest litter accumulation and also some heterogeneity in land use management as observed during data collection. Tree crops recorded the highest SOC content of 1.96% but with decreasing depth records the lowest SOC content of 0.44 %(Table 6). It was also observed that the top soil was less disturbed compared to the other farm based systems.

The tree crops, agroforestry and mixed fields that receive much soil disturbance by way of cultivation recorded high degrees of variability (22.20-33.84%) in the top layer. The tree based systems (forest and tree plantations) with less disturbance recorded low variability (15.35-16.98%).

In the bottom layer amongst the farm based systems, mixed fields and tree crops recorded the highest SOC content of 1.4% whilst the lowest SOC content of 0.18% was observed in tree crops(table 6). A high variability range of 39- 54% was recorded amongst the farms.

The horizontal variability (land use aggregate) of SOC as depicted by the mean value of the two layers per land use is displayed by the box plots (Figure 14). The box plot per land use depicts the mean, standard error and standard deviation. The displayed box plot shows that the mean SOC content decreases from forests to tree crops to mixed crops. Comparatively, variability in SOC content is large amongst the tree crops, mixed fields and agroforestry. This can be attributed to human influence especially with the tree crops which displays the highest variability. The tree crops land use from the interview data have the most diverse of land use management practises.

A trend observed in all the land use types is that the top layer exhibited a higher SOC content than the bottom layer. This means that for the vertical variability (mean of respective layer aggregates from all the sampling fields), SOC content decreased with increasing depth across the five land use types (Figure 13). Therefore, average SOC was 1.36% and 0.79% for the top layer and bottom layer respectively. A test of significance indicated a significant difference in vertical SOC distribution in each land use type ($p<0.05$) (Appendix P).

There is large variation within the farming systems and these also recorded much lower SOC values than the other land use types. However, grouping the sites according to land cover/land use patterns, a statistical test at 95% confidence interval (ANOVA) indicated no significant difference among the land use types($p=0.231$ for top layer and $p=0.950$ for bottom layer) (Appendix G).

A normality test (Kolmogorov-Smirnov and Shapiro-Wilk) indicated that the distribution of SOC in mixed fields and tree crops were not normally distributed (Appendix H). However, data transformation and removal of outliers did not improve the normality of the data; therefore the two were excluded from the statistical test.

Pooling all the measured soil properties, SOC content showed the highest variability especially within the farm based systems where human disturbance via cultivation is high.

SOC content was negatively correlated with soil water pH at both top layer ($R= 0.079$) and bottom layer ($R=0.002$) respectively.

SOC content was significantly negatively correlated ($R=0.382$, $p<0.05$) with bulk density for the bottom layer but the top layer had a weak negative correlation($R=0.039$) (Appendix I). This indicates that the higher the bulk density the lower the SOC content especially for the bottom layer.

Table 6 : Mean and range of soil organic carbon content by land use types for two soil layers

Land use type	Sample size (N)	0-20cm(top layer)				20-50cm(bottom layer)			
		Mean (%)	Max (%)	Min (%)	CV (%)	Mean (%)	Max (%)	Min (%)	CV (%)
Agroforestry	15	1.33	1.90	0.48	33.42	0.75	1.42	0.42	39.36
Tree Crops	20	1.37	1.96	0.44	32.84	0.71	1.42	0.18	53.80
Mixed cropping/fields	20	1.34	1.70	0.86	22.20	0.77	1.34	0.32	41.47
Tree plantations	13	1.36	1.84	1.04	16.98	0.90	1.34	0.26	34.32
Forest	10	1.44	1.90	0.48	15.35	0.92	1.40	0.52	37.97

CV: coefficient of variation, max: maximum, min

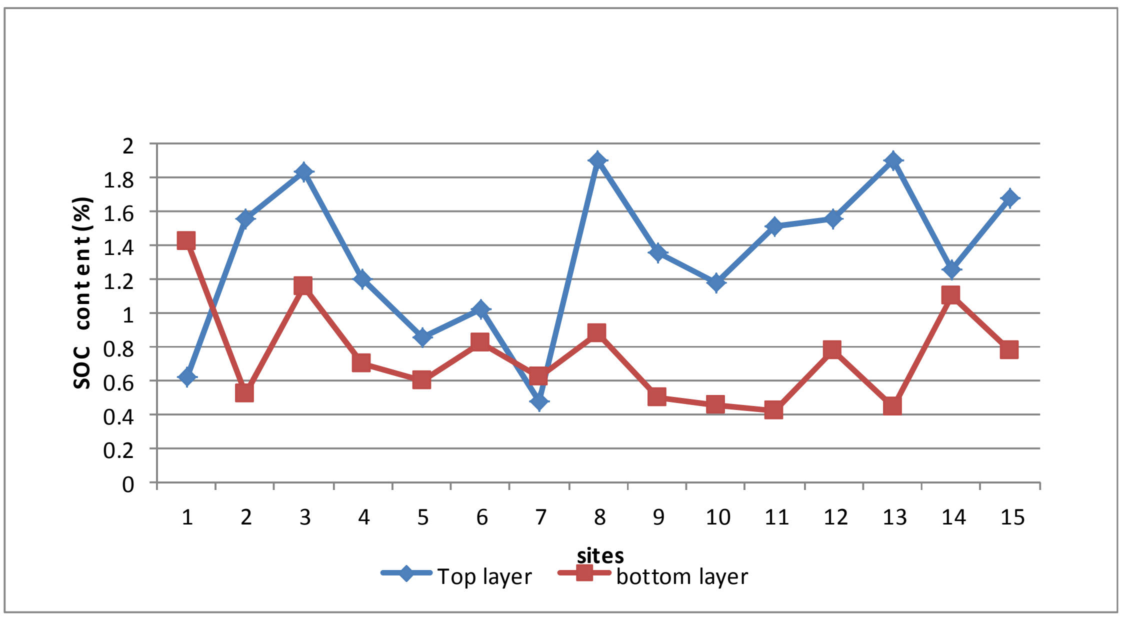

Figure 8 : Soil organic carbon for two layers across 15 sites in agroforestry land use

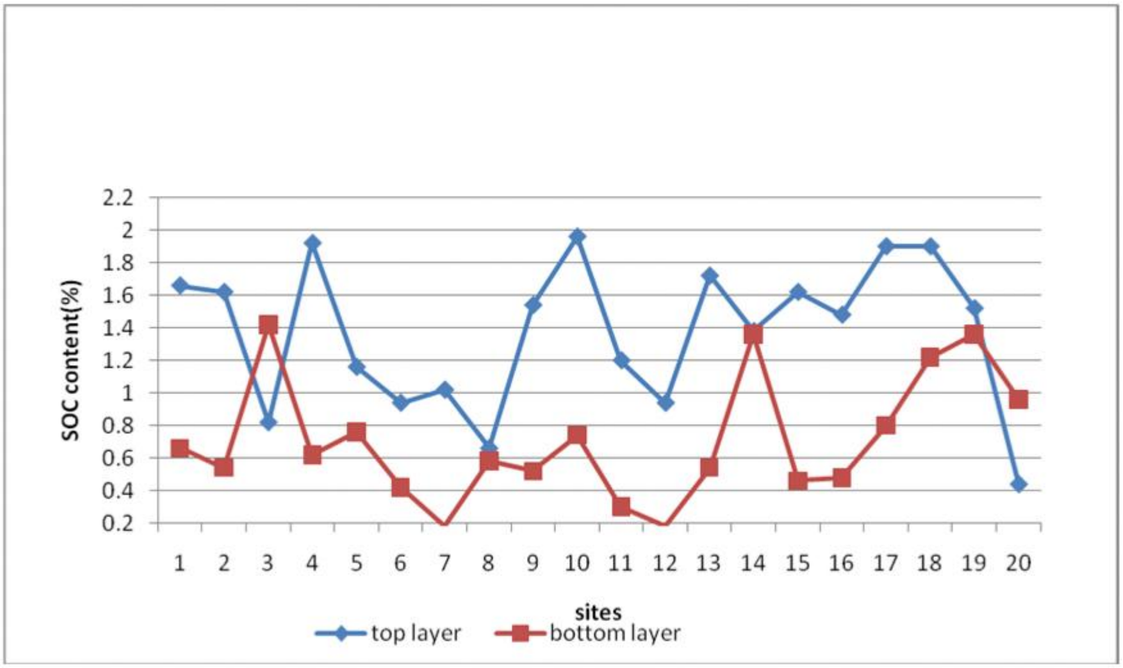

Figure 9 : Soil organic carbon for two layers across 20 sites in tree crops land use

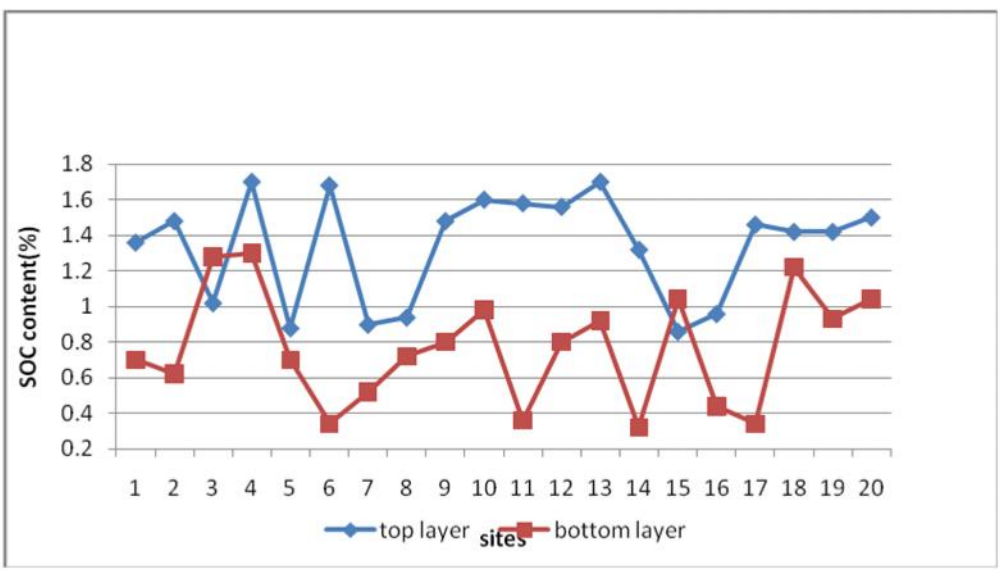

Figure 10 : Soil organic carbon for two layers across 20 sites in mixed fields land use

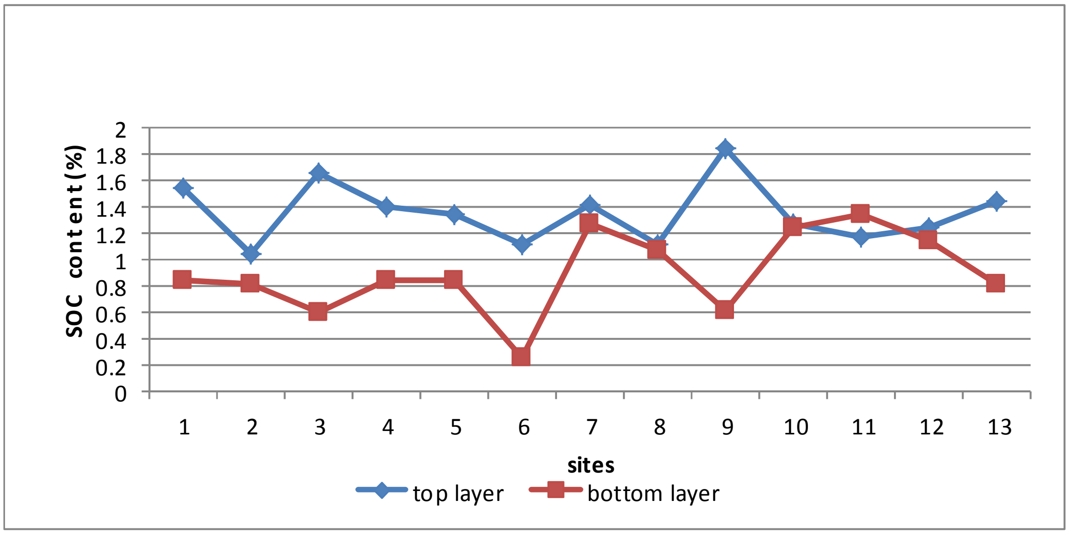

Figure 11 : Soil organic carbon for two layers across 13 sites in tree plantations

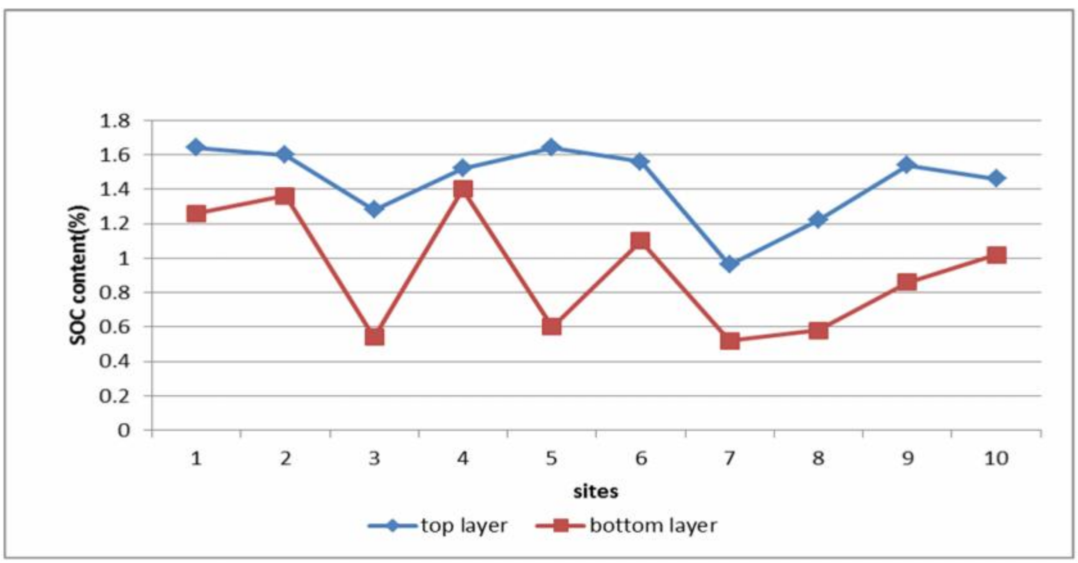

Figure 12 : Soil organic carbon for two layers across 10 sites in forest

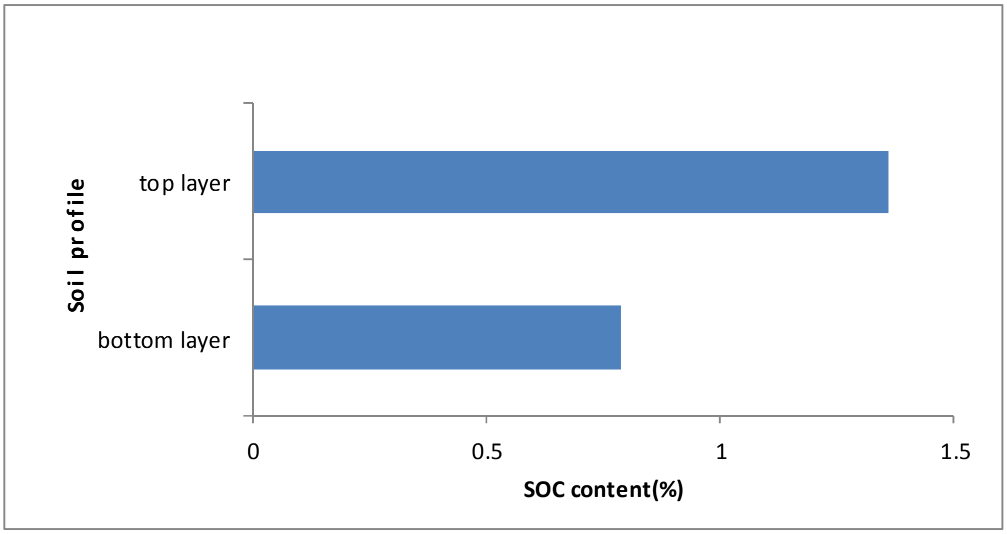

Figure 13 : Vertical variability of soil organic carbon across (layer aggregate) land use types

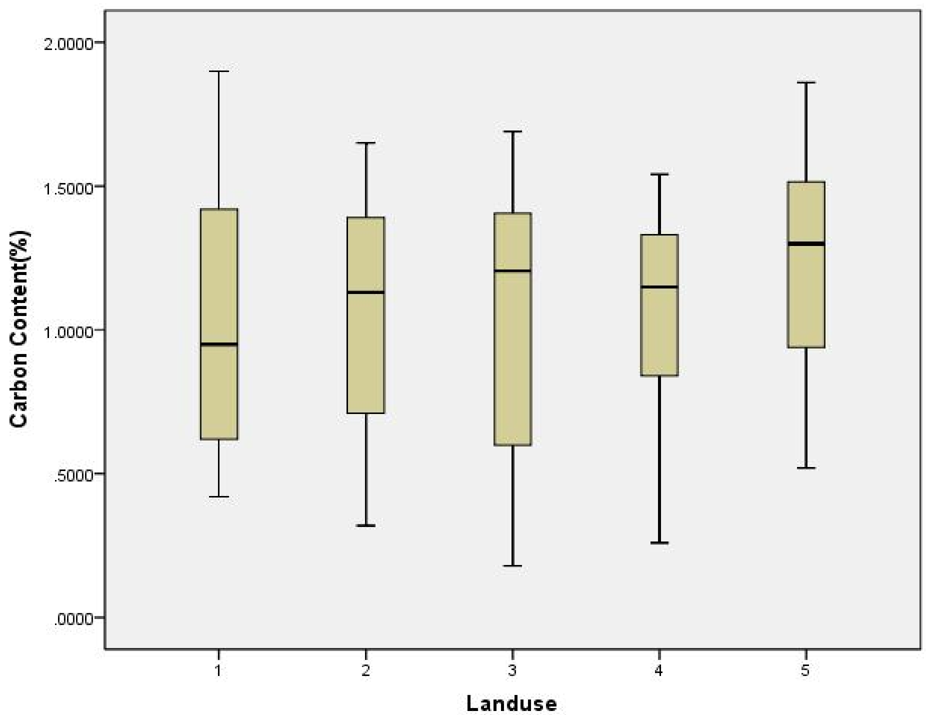

Figure 14 : Box plots displaying horizontal variability of soil organic carbon across land use types (land use aggregate): 1 = Agroforestry, 2 = mixed fields, 3 = tree crops, 4 = tree plantation, 5 = forest

3.5. SOC density and stock estimation

3.5.1. SOC density

Tables 7 summarises the soil organic carbon density for the two layers by land use type within the study area. The mean SOC density was computed using the SOC content (%) and the bulk density as stated in equation 3 under the materials and methods chapter. The coefficient of variation (CV) was calculated to show the variation per land use type per soil profile (Table 7).

In top layer, the soil organic carbon density decreased from 4.34kg/m² in Forest to 3.59kg/m² in mixed fields. The variation in the SOC density across the land use types was large and CV ranged from 19% to 34%. The highest variations were recorded within the farming systems.
The estimated Soil organic carbon density in the bottom layer decreased from 4.17kg/m² in Forest to 2.96kg/m² in mixed fields. The variation in the measured SOC density across the land use types was large and CV ranged from 31% to 45%.

The mean organic carbon density decreased with soil depth for every land use type, and generally differed with land use type for every depth. Additionally, the variation within individual land use types differed. The variation in the measured SOC density for the farming systems compared with the forest land use was large. The CV for the farming systems was between 29-34% compared to 19% for forest. It is clear that the land use types with current human activities have large variability than those with less or no human activities.

SOC density was significantly positively correlated ($R=0.464$, $p<0.01$) with bulk density for the top layer but the bottom layer had a weak negative correlation($R=0.034$)(Appendix J). This means that the higher the bulk density the higher the SOC density especially for the top layer.

Table 7 : Mean and range of soil organic carbon density by land use type for two soil layers

Land use type	Sample size (N)	0-20cm(top layer)				20-50cm(bottom layer)			
		Mean (kgm^{-2})	Max (kgm^{-2})	Min (kgm^{-2})	CV (%)	Mean (kgm^{-2})	Max (kgm^{-2})	Min (kgm^{-2})	CV (%)
Agroforestry	15	3.64	5.13	1.23	33.96	3.00	4.67	1.73	31.14
Tree Crops	20	3.72	5.57	1.27	33.81	3.04	5.38	1.45	45.02
Mixed cropping/fields	20	3.59	5.07	1.98	29.15	2.96	5.75	0.93	45.02
Tree plantations	13	3.50	5.48	2.25	20.68	3.67	6.57	1.37	42.84
Forest	10	4.34	5.79	3.27	19.23	4.17	7.14	2.12	43.67

CV: coefficient of variation, max: maximum, min: minimum

3.5.2. SOC stock estimation

Table 8 lists the estimated mean organic carbon stock for two depth intervals. Since SOC density has been estimated for each land use type, SOC stock was estimated for each depth at tons per hectare (t SOC ha^{-1}).The 0-20cm soil profile contained the highest average estimate of 43(±2.6) t $SOCha^{-1}$ for forest whilst the lowest averages estimate of 35(±2) t $SOCha^{-1}$ for tree plantations. Amongst the farming systems, tree crops had the highest average estimate of 37(±2) t $SOCha^{-1}$ with mixed fields recording the lowest average estimate of 35(±2.3) t $SOCha^{-1}$.

The 20cm – 50cm soil profile contained the highest average estimate of 41.7(±5.8) t $SOCha^{-1}$ for forest whilst the lowest average estimate of 29.6(±3) t $SOCha^{-1}$ for tree crops. Amongst the farming systems, mixed fields had the highest average estimate of 30.4 (±2.6) t SOC ha^{-1} with tree crops recording the lowest average estimate of 29.6(±3) t SOC ha^{-1} .

Combining the land use area estimates (Table 2) with estimated total SOC (Table 8), SOC stocks storage to a depth of 50cm was estimated as 1.36×10^5 t SOC (Agroforestry), 2.40×10^5 t SOC (Tree plantations), 8.21×10^4 t SOC (Mixed fields), 1.15×10^5 t $SOCha^{-1}$ (Tree plantations) and 2.71×10^5 t SOC (Forest) respectively. Combining the overall SOC stock mean (Table 8) with the total estimated area for the study (Table 2), the SOC stock was estimated as 8.78×10^5 t SOC.

Table 8 : Mean soil organic carbon stock with depth by land use type

Land use type	Top layer(0-20cm) Mean(t C ha^{-1})	bottom layer(20-50cm) Mean(t C ha^{-1})	Total(0-50cm) (t C ha^{-1})	% of Top layer in total (%)	Rel. Dist.(%)
Agroforestry	36.369±3.2	29.98±2.4	66.34	55	18.54
Tree crops	37.206±2.8	29.56±3.00	66.77	56	18.82
Mixed crops/fields	35.855±2.3	30.43±2.6	66.29	54	18.54
Tree plantations	34.945±2.0	36.74±4.4	71.69	49	20.23
Forest	43.381±2.6	41.66±5.8	85.04	51	23.88

Overall mean±SE:71.22±3.6, Standard error: 8.05

3.6. Land use pattern and SOC stock distribution

To assess the statistical significance in the distribution of SOC stock across the land use types. A normality test (Kolmogorov-Smirnov and Shapiro-Wilk) indicated that the distribution of SOC in tree crops and tree plantations were not normally distributed (Appendix K). Therefore, outliers were removed to improve the normality of data before being used for the statistical test (Appendix L).

By statistical analysis (ANOVA), there is no significant difference ($p=0.268$ for top layer and $p=0.104$ for bottom layer) in SOC stock across the land use types (Appendix M).

However, for the top layer the variability of SOC content distribution followed this sequence where the mean SOC content increased: tree plantations< mixed fields<agroforestry<tree cropss< forests.

In the bottom layer, mean SOC increased in the following sequence: tree crops<agroforestry<mixed fields< tree plantations<forest. Similarly there was no significant statistical difference in the SOC content means across the various land use types.

From Table 8, total SOC ha^{-1} to 50cm across the land use types contained an average of 71(±3.6) t SOC ha^{-1}, 49-56% of which reside in the top 20cm.Amongst the farming systems Tree crops hold 56%, agroforestry 55% and mixed crops 54% respectively in the top layer. This makes the top soil susceptible to land use change. There is approximately 20tons soil organic carbon loss per hectare when land use changes from forest to any of the farming systems and 14 tons SOC per hectare when land use changes to tree plantations (Figure 15).

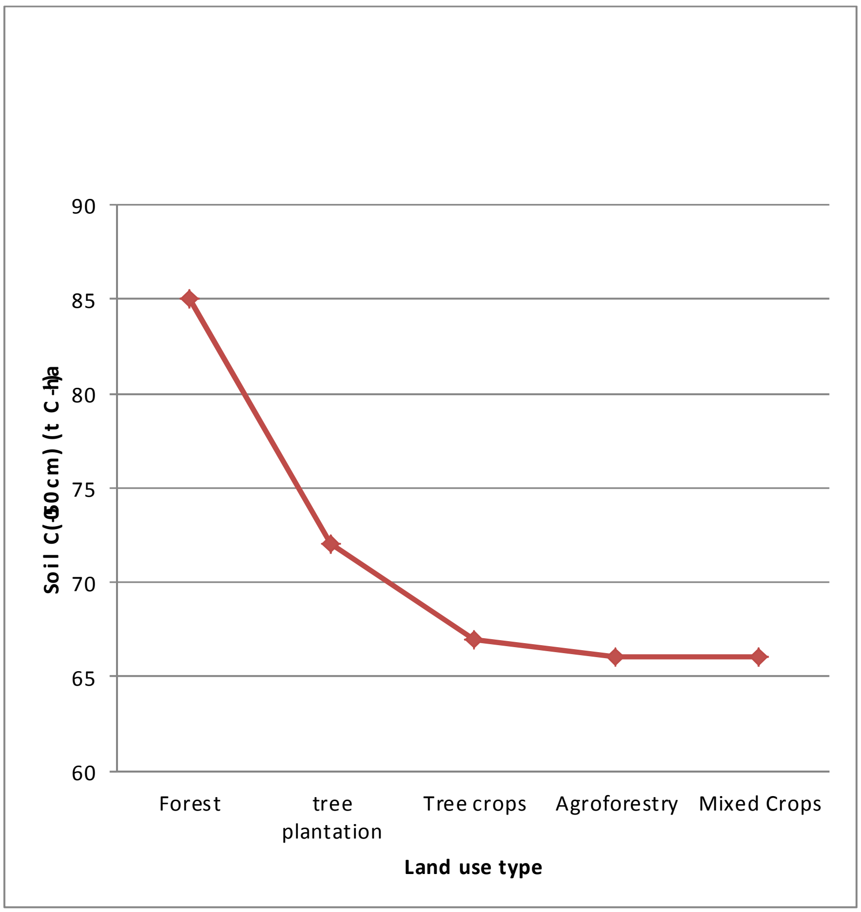

Figure 15 : Soil organic carbon stock changes across five land use types

3.7. Spatial distribution of SOC

The spatial distribution of SOC content in the two profiles after the spatial interpolation process is as in Figures 16 & 17. The Inverse Distance Weighted (IDW) results showed that areas with high values (high colour intensity) are mainly forest and tree plantation areas (North and west). The south and east are generally occupied by farms and have low values, hence low colour intensity. Therefore less disturbed areas had higher SOC levels. For the forest areas, the forest located at the east had lower SOC values because it is more sparse than the forest at the North.The areas closer to settlements had low SOC levels.

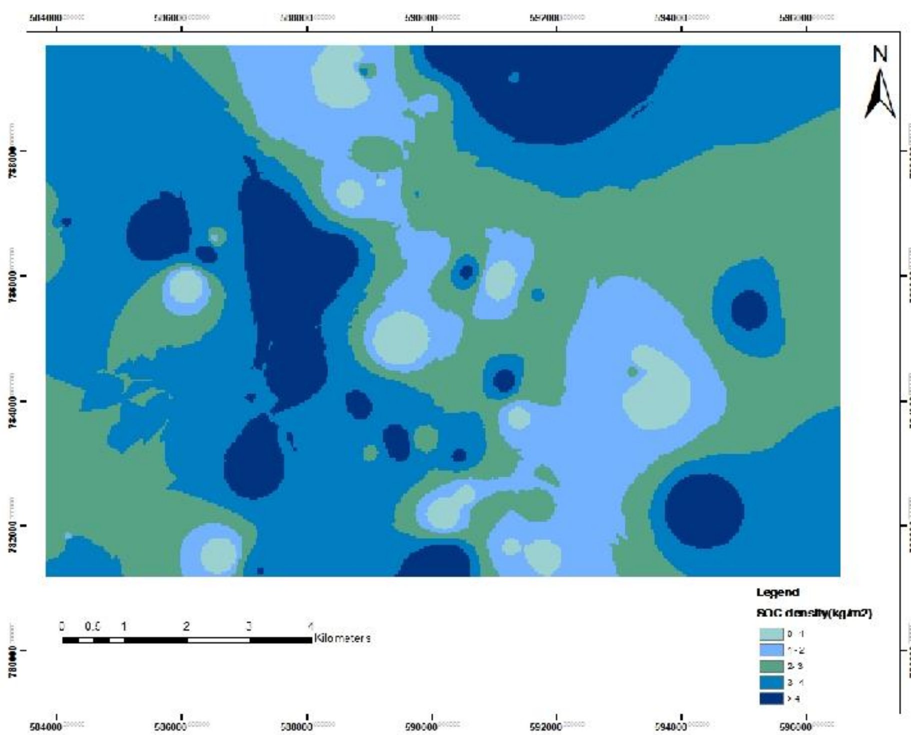

Figure 16 : Spatial distribution of soil organic carbon for top layer

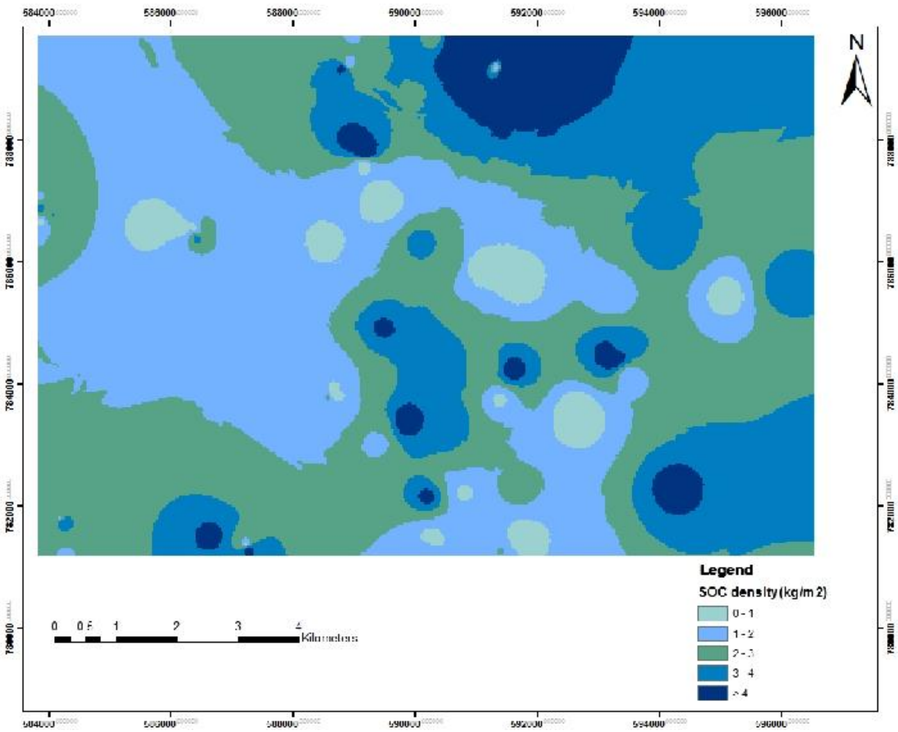

Figure 17 : Spatial distribution of soil organic carbon for bottom layer

3.8. Land use management practises

In all 55 farmers were interviewed on their land use management practises (Table 9). Out of the number interviewed, 73% were males and 27% represented females (Figure 18). Data acquisition was difficult because record keeping amongst the farmers was non-existent. Most of the farms visited were small scale and sizes ranged between 0.1- 6hactares.

Interviews were not conducted within the forest and tree plantation land use types. This is because the forest is a protected area and has been kept in its natural state as far as practicable. However, some parts of the forest had either been logged or burnt.

During data collection some logging activities were sighted. In the tree plantations; which are predominantly teak and cedrella; once the seedlings are planted the site is abandoned till the trees are matured for harvesting. Therefore the soils are less disturbed. In all, five land use management practises were identified in the study area (Table 10 & Figure 19).

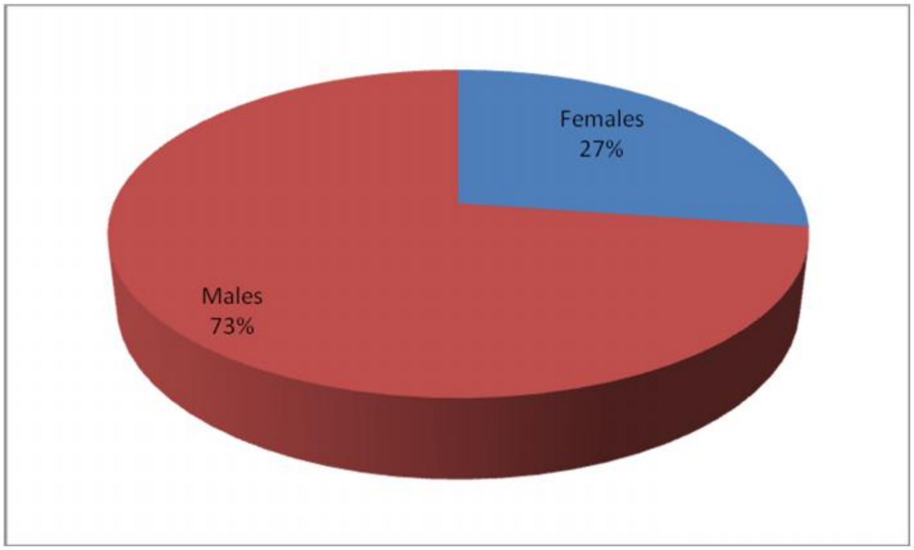

Figure 18 : Distribution of respondents in the study area

In agroforestry, farmers only practise residue retention where litter from trees and dead weeds are left on the farms. Most of the agroforestry land use is tendered by farmers for 1-3years after which the farms are abandoned. This is because the trees shade the crops which results in crop death. The agroforestry system is basically meant to restore the degraded portions of the forest reserves, therefore farmers abandon the cultivated area once they harvest the produce and the trees starts to grow.

In the tree crop land use, farmers grow mostly cocoa which is a major cash crop in Ghana. Hence such farms are purely for commercial reasons and farmers therefore deploy an array of management practises to improve the yields from the farms. The predominant management practice is residue retention and other minor practises include manure and fertilizer application. Though litter were not measured, huge litter accumulation were observed in all the tree crop fields. Only 40% of the number interviewed have ever used fertilizer but could not indicate the exact time (4-5years).

In the mixed fields, most of the produce is meant for domestic consumption and only the surplus is sold for some income. All the farmers interviewed have continually cultivated the land for periods between 1-5years and alternative the crops grown on the farms depending on the time of the year. Residue retention and cover crops are common management practises used by farmers. However, the residue are removed or burnt to clear the site for the next planting time. None of the number interviewed had ever used manure or fertilizer in their farms. The reasons assigned are financial with respect to fertilizer acquisition and non-availability with respect to manure.

Table 9 : Summary of respondents in the respective land use types

Land use	Females	Males
Agroforestry	4	11
Tree crops	6	14
Mixed fields	5	15
Sub total	**15**	**40**
Total of people interviewed	**55**	

Table 10 : Summary of land use management practises within the study area

Land use type	Land use management practises					
	Fertilizer Application	Manure Application	Residue Retention	Minimum tillage	Cover crops	others
Agroforestry	×	×	√	×	√	×
Tree Crops	√	√	√	√	×	√
Mixed fields	×	×	√	×	√	×
Total	**3**	**1**	**55**	**17**	**7**	

√: Yes, X: No

At least each of the respondents practices some level of land use management. The most common land use management practise is the retention of crop residue (Figure 19). Farmers on mixed fields and agroforestry land use types remove or burn the residue during land preparation. This represents more than half (54%) of those who practise residue retention; predominant soil management practise; in the study area.

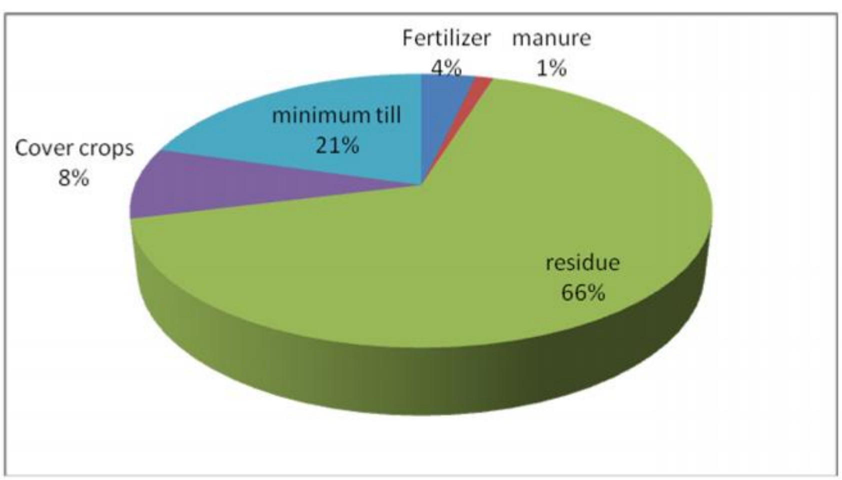

Figure 19 : Distribution of land use management practices in the study area

Based on the assumption that each land use management practise has an equal realistic capacity to influence SOC gains. Each land use management practises identified was assigned an equal weight (1point) and the tree crop fields scored the highest weight and the most diverse management practises because the farmers give priority to such crops (Figure 20 & Table 11). Therefore, tree crops recorded the highest soil organic carbon for both layers (Table 11)

Table 11 : Aggregate of land use management practises and soil organic carbon per land use type

Land use type	Soil organic carbon density(kgm^{-2})		Land use management weight aggregate
	Top layer (0-20cm)	Bottom layer (20-50cm)	
Tree Crops	3.72	3.04	5
Mixed fields	3.59	2.96	2
Agroforestry	3.64	3.00	2

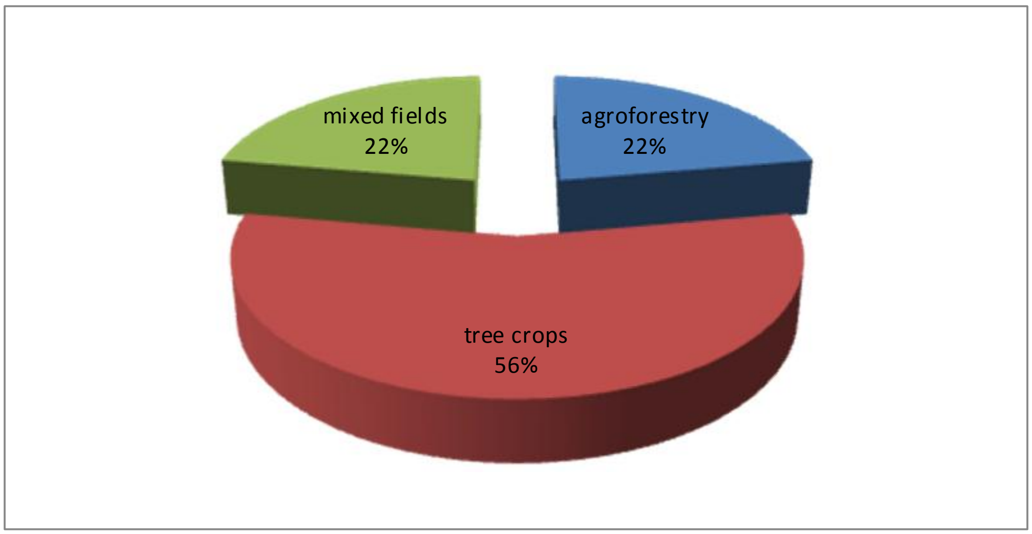

Figure 20 : Aggregation of management practises per land use type

3.8.1. Crop yields (2005 - 2009)

During the field data collection, major crops identified include cassava and plantain (Table 2). Therefore yields from such crops over a five year period were used as a proxy for fertility status of the study area. Furthermore, SOC is a measure of soil fertility since it influences most of the physical, biological and chemical properties of the soil and this enhances yield. Harvested area and yield data were obtained from the Statistics Research and Information Directorate, Ministry of Food and Agriculture, Ghana (Appendix N).

From the graphs (Figures 21 & 22); the areas cultivated and crop yields from 2005 to 2009; the areas under cultivation increased whilst the yields remained stagnant.

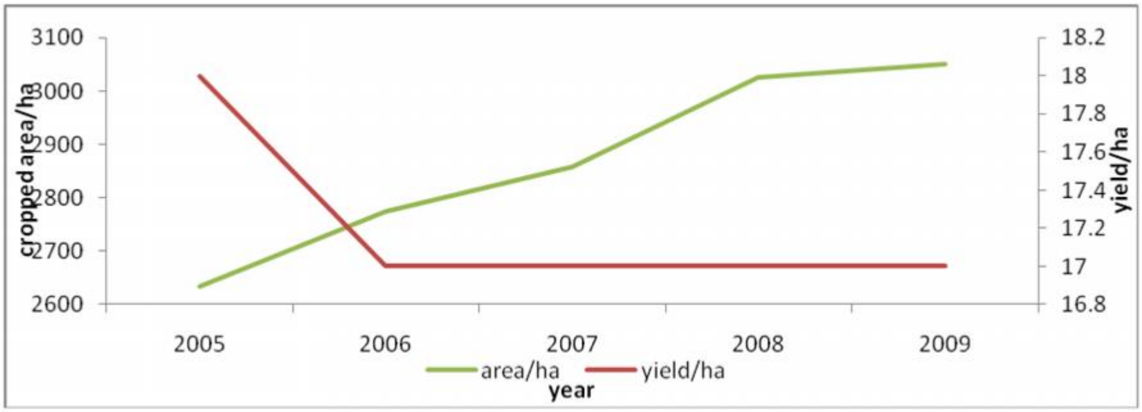

Figure 21 : Cultivated area/ha and yield/ha-Cassava

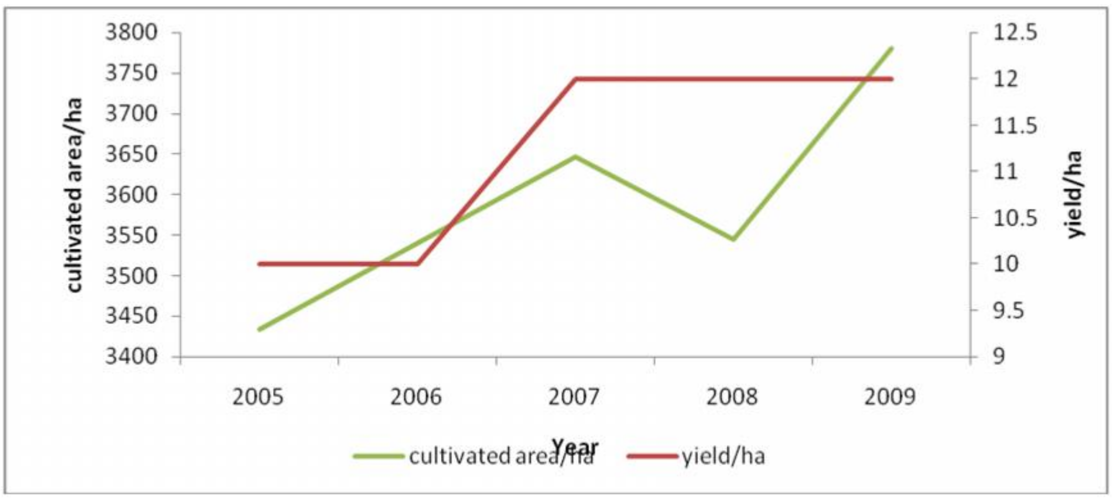

Figure 22 : Cultivated area/ha and yield/ha-Plantain

For cassava, area cultivated had increased by 16% whilst yield experienced a decreased trend of 6% over the period. For plantain, the cultivated area increased by 10% over the period whilst yield also increased by 18% from 2005 to 2007 and remained stagnant for the rest of the period (Figure 22).

4. DISCUSSIONS

4.1. Land use classification

The overall accuracy of the land use/land cover classification was 76% with a kappa of 0.6873. These results are lower than what was obtained by (Benefoh, 2008). However, it is consistent with the results obtained by (Asante-Yeboah, 2010).

The low classification results compared with (Benefoh, 2008) might be explained by the fact that individual ground features in a high spatial resolution image might be composed of multiple pixels with the tendency to display variable spectral reflectance behaviour (Johansen *et al*., 2010). This situation defeats the assumption that homogenous features have unique spectral reflectance values (Johansen *et al*., 2010).

4.2. Soil bulk density, texture and pH

land use types affects soil texture characteristics which in turn affect the fertility status of a field(Yao *et al*., 2010). From the results, the high variation recorded in mixed fields agrees with the fact that land use type and management practises can introduce some variability in soil property(Omotoso & Akinbola, 2007). The mean bulk density values recorded in this research are higher than those recorded in the Tene protected forest (0.6g/cm^3) and cultivated areas (0.9g/cm^3) in Ivory Coast. However, the values are within the ranges reported by (Batjes and Dijkshoorn, 1999). The bulk densities recorded increased from cultivated areas to forests this is a reverse pattern with respect to findings from(Batjes and Dijkshoorn, 1999). The reason assigned to this trend could be the history of heavy logging in the forest which might be responsible for compaction of soil particles and resulting in higher bulk densities(Murphy *et al.,* 2004). Since the forest soils had higher clay content, it is possible that the particles will compress and compact easily with the movement of heavy logging equipment(Gol *et al.,* 2010). However this trend could be further researched to unearth detailed reasons for increased bulk density from cultivated areas to forest.

Agroforestry practise is seen as a means to replenish lost nutrients in soils(Tornquist *et al.,* 1998). Therefore in the study area, the soils in the agroforestry land use recorded low clay content which is a reflection of low SOC levels compared with other land use types in the area. Such areas are degraded portions of the forests which has been exposed and erosion might have washed away the fine sized particles with the resultant low clay content(Gana, 2000). Hence, the agroforestry practise which is a Government sponsored initiative towards restoring the soil properties is a step in the right direction. The large agroforestry coverage (2062ha) gives some insight into the extent of forest degradation within the study area.

The low variability (9-10% for top layer and 9-17% for bottom layer) in pH across all land use types indicates that the pH is uniform or homogenous in the study area. This low variability in pH agrees with other research findings(Adigun *et al.,* 2008; Omotoso & Akinbola, 2007).This homogeneity can be attributed to the land use management practises by the farmers as per the interview, use of fertilizers and other chemicals is almost non-existent in the area(Ololade *et al.,* 2010). From the interview data, only 3 farmers indicated they have ever used fertilizers and they could not even remember when the application was done. Variability in the use of fertilizers and other chemicals can introduce some fluctuations in pH levels(Ololade *et al.,* 2010).

4.3. Soil organic carbon (content, density and stocks)

4.3.1. Soil organic carbon content

The SOC content (%) decreased with increasing depth across all land use types. This trend in the data has also been reported in several research findings (Morisada *et al.*, 2002; Morisada *et al.*,2004; Sheikh *et al.,* 2009; Su *et al.,* 2006; van Noordwijk *et al.,* 1997). From research, it has been noted that spatial variability in soil organic content for vertical distribution depends on the depth of the layer because SOC content decreases with increase in depth(Su *et al.*,2006). Therefore the results obtained agree with this assertion and the statistically significant differences within each land use type suggest a steep decrease in SOC with depth.

The high variability(>20%) observed within the farm based systems as compared with the tree based systems in the top layer which is also referred to as the plough layer agrees with other research findings(Adigun *et al.,* 2008; Omotoso & Akinbola, 2007). The resultant high variability could be associated with the land use type and the kind of management practise in place(Omotoso & Akinbola, 2007). During the field work, it was noted that farmers are continually cultivating the land without recourse to replenishing the nutrients. Tree crops land use recorded the highest weight aggregate in terms of soil management to improve yields. Furthermore, tree crops had the highest mean soil organic carbon content (1.4%) amongst the farm based systems. This agrees with the notion that land use management practises has high influence on chemical properties of soil and in this case SOC(Omotoso & Akinbola, 2007; Wang *et al.,* 2010).

There was high variability in SOC across the different land use types and the mean SOC value for forest was the highest amongst all the land use types. However, a statistical test did not provide any significant differences in the land use types. This outcome is similar to other research observations from small scale landscape studies (Ololade *et al.,* 2010; Su *et al.,* 2006).

According to research, the horizontal variability in SOC distribution depended on large scale factors as regional climate, vegetation, soil type and topography (Su *et al.,* 2006; Wang *et al.,* 2010). The study area for this research is relatively small therefore climate, soil type and terrain as variables could be overlooked as the study was conducted in a homogenous area(Wang *et al.,* 2010). Hence, this conforms to the assumption that land cover and land use change and management patterns will largely contribute to the spatial variability in soil organic carbon content (Guo & Gifford, 2002; Su *et al.,* 2006). The estimates compared with other finding were low except for forest land use which recorded a higher SOC levels.

4.3.2. Soil organic carbon density

The soil density (kgm^{-2}) also decreased with increasing depth. The estimated soil density for this research took into account the bulk density and the land use type and management (Smaling *et al.,* 2010). The estimated SOC densities compared with others were low except for the forest land use type (Batjes, 1996; Kimble *et al.*, 1990; Morisada *et al.*, 2004). The soil organic carbon density varied(19-34%) with different land use types especially in the top layer where land use management practises have the most influence(Batjes, 2001; Post *et al.*, 2001; Su *et al.*, 2006).

The forests had the highest followed by the farm based systems. This points to the fact that the land use types currently experiencing some cultivation recorded low SOC densities with high coefficient of variations and further emphasizes the notion that in estimating SOC density the land use/land cover with the kind of management should be taken into consideration (Su *et al.,*2006).

Within the farm based systems, mixed fields which are the most cultivated recorded the lowest SOC density whilst tree crops land use which is less disturbed recorded the highest SOC density. Furthermore, the tree crops which is a cash crop have received some level of nutrient addition as per the interview data as the farmers give some priority to such fields (Smaling *et al.,* 2010). This could explain the higher SOC density levels for the tree crops as compared with other farm based systems.

4.3.3. Soil organic carbon stock

The observations for the soil organic stock were not different from the decreasing trends with depth in both SOC content and density. The importance of SOC density as a key indicator for SOC stock estimation has been highlighted by researchers at global, continental and regional levels(Morisada *et al.,* 2004). However in Ghana, a national SOC database is not available and this could limit the country's ability to assess funds for natural resources conservation in the context of the Clean Development Mechanism (CDM) as proposed under article 12 of the Kyoto Protocol (Batjes, 2001). Therefore SOC density estimation at local or district levels could serve as a starting point for large scale estimations and help provide some accuracy for a national SOC data.

The average estimated value of 71.22 t C ha^{-1} are higher than those estimated for Senegal, West Africa and Africa but lower than mean estimates for the world (Batjes, 2001; Woomer *et al.,* 2004).The global, continental or regional mean SOC estimates have been made to the depth of 1metre(Batjes, 2001). However in this study, due to limited logistics and time constraints, the samples were collected to a depth of 50cm in each profile. In the event of a national SOC stock inventory, estimates should be made to the 1metre depth.

On the whole, the estimated average SOC stock per land use when compared to other research findings was mixed. Specifically, the estimated values of each of the land use type when compared to other measurements was low except for forest where the values agree with estimates for West Africa but lower than global or continental(Africa) estimates. The land use and management patterns could be assigned for this trend because the other factors (soil type and climate) that could introduce some variability in SOC stock are the same.

4.4. Land use pattern and SOC stock distribution

Variability in SOC stock across the land use types changed with land use pattern change in an increasing sequence: mixed fields<agroforestry<tree crops<tree plantation<forests. In spite of this observed range (66-85t C ha^{-1}) across the land use types, a test of significance (ANOVA) at 95% confidence interval did not show any difference between the land use types. This observation or outcome might be due to under replication or the reasoning that SOC below 10cm are the same (Sheikh *et al.*,2009; Woomer *et al.,* 2004).
Additionally, since the area is homogenous, it is most probable that the differences in SOC stock is caused by the land use/cover pattern and the management practises.

More than half (49-56%) of the SOC resides in the top layer this makes this layer most prone to land use change (Batjes & Dijkshoorn,1999; Morisada *et al*., 2004; Woomer *et al*., 2004). This relative distribution in the top layer agrees with the FAO-UNESCO soil units(Batjes, 1996). From the results, the forests recorded the highest SOC stock and were higher than what was recorded for the farm based systems. Therefore the high concentrations of organic carbon in the top layers suggests that there is a potential for 14-20 tons per hectare carbon loss if there is a land use change from forest to other land use types. Other authors have reported higher SOC losses in cultivated areas (Yao *et al.,* 2010).

The lower losses reported in this study presents an opportunity for cultivated areas to serve as carbon sink as the parent soil material is intrinsically fertile and the adoption of sustainable management practises will be vital in this direction(Obeng,2000;Yao *et al.,* 2010). Additionally, the tree based systems (forest and tree plantations) which are currently undisturbed had higher SOC than areas under cultivation or farm based systems (tree crops, agroforestry and mixed fields). Therefore management practises could be explained as the key factor influencing the SOC content and therefore responsible for the low SOC levels(Su *et al.,* 2006).

4.5. land use management practises

Larger proportions (77%) of the respondents were males and this makes the sector a male dominated one with less contribution from women. Most of the farmers are small scaled as the farm holdings are between 0.5-6ha and record keeping for monitoring purposes is difficult(Batjes,2001).

The type of land use management practise depended on the type of land use as farmers gave priority to some land use types like tree (cash) crops(Smaling *et al.*, 2010). Such fields are likely to have high nutrient levels and SOC content(Ololade *et al.,*2010; Omotoso & Akinbola, 2007). This was evident in the results obtained as tree crops in the study area showed heavier weight aggregates in terms of management practises and recorded higher SOC values as compared to mixed fields and agroforestry which recorded lower weights aggregates in terms of management practises. This might confirm the fact that land use management practises is a major factor influencing soil organic carbon content. From the yield graphs (Figures 21&22), the decreasing or stagnant trend in yields whilst areas under cultivation increase might indicate that the soils are losing its fertility and consequently the SOC. Hence, the poor soil management practises in the study area could pose some risk to forests as the farmers might clear the forest to sustain yield(Cerri *et al.*, 2007).

According to (Wang *et al.,* 2010) the amount of SOC in an agricultural soil is an indicator of soil productivity. Therefore, low soil fertility inevitably leads to low agricultural productivity(Omotayo & Chukwuka, 2009). The graphs of the yields for the area showed a stagnant/declining productivity levels. Residue retention was identified as the predominant land use management practise. However, more than half (54%) remove this residue from their fields during land preparation thereby limiting decomposition which will subsequently contribute to SOC levels. Furthermore, there is low fertiliser usage (4%), manure application (1%) and cover crops (8%) use amongst the farmers indicate inadequate adoption of modern farming technologies. Therefore the continuous tillage of the land without any stringent remedial action will lead to low yields, new land clearance, soil compaction, loss of SOC and nutrient mining(Paustian *et al.,*1997;Smaling *et al.,* 1996; Sukkel *et al.,*2008).

The small differences(no significance difference) in SOC across the various land use is indicative that though there is a difference between forest and other land use types (agricultural lands), it does not show which type helps to categorically conserve SOC. However, there seems to be a loss of approximately 14--20t SOC ha^{-1} if the forests are converted to any other land use type. Therefore an effective land use management system can enhance SOC levels, soil fertility, crop yields and general soil properties(Smaling *et al.*,1996).

Soil organic carbon has been identified as a basic index of soil quality in several soil quality enhancement and land use management mechanisms research (Lal, 2002; Marks *et al.,* 2009). Some of the management mechanisms proposed include fertilizer use, agroforestry, cover crops,manuring,complex rotation with deep rooted plants, integrated pest management, rice paddies, conservation tillage, irrigation and water management for croplands and timber harvest, site preparation, improved species and stand management for forest lands(Batjes, 2001; Lal,2004; Marks *et al.*, 2009).

In this study the focus is on croplands because the need for sustained management of cultivated areas has become important in the era of climate change, rapid deforestation and degradation of forest resources, therefore options to improve SOC in forests will not be discussed. The development and adoption of effective soil quality improvement mechanisms in Africa is a big challenge and moreover the complex carbon dynamics between soils and plants are not well understood (Batjes,1996; Cerri *et al.*,2007; Snapp *et al.*,1998). Therefore recommending management strategies or options to improve SOC will be based on the existing practises in the study area.

In this study, it was noticed that only one farmer had ever used manure on the farm but the application was very irregular. However, increased manure use has been considered technically feasible and will remain pivotal as a management practise to improve soil organic carbon gain (Harris, 2002). During data collection, the farmers identified the barrier of its non-availability as the main reason behind the low patronage. Hence, the adoption of this practise will be limited by the number and type of animals and rangeland features and its availability(Bationo *et al.*,2007). No poultry or livestock keeping was recorded in the study area.

Fertilizer application in the study area as reported in other African countries was low (4%)(Arifalo & Mafimisebi, 2011). Although it has been reported that fertilizers have influence on SOC dynamics, its application is hampered by barriers like affordability/finance and scarcity(Hossner & Juo, 1999). The current subsidy on fertilizers in Ghana if extended to cover the study area or if the farmers are encouraged to patronize such an initiative it could help to improve SOC levels. This notwithstanding, the use of inorganic fertilizer for a long period can be deleterious to the soil(Bationo *et al.*,2006). With improper record keeping as observed during the field work the use of fertilizers should be under effective monitoring.

Agroforestry is already in practise in the study area; therefore it is important that the initiative is continued. However, the current system in place which is only used to restore degraded portions of the forest reserve could be modified for farmers to also practise other forms of agroforestry like alley cropping or introduction of trees on their farmlands.

Cover crops as a land use management practise amongst the respondents was better (8%) than manure and fertilizer application. Cover crops which were mainly leguminous (beans) have been intercropped with other crops. Therefore, the use of cover crops as a soil management practise can be encouraged in the area as it is good for erosion control, weed suppression and soil fertility improvement especially within the plough or top layer (Wilson *et al.*, 1982). With these advantages associated with cover crops, the disturbance (tillage) of the soil will be minimised(Hossner & Juo, 1999). Additionally, the cover crops can serve as a source of income when sold(Arifalo & Mafimisebi, 2011).

Based on review of published research and the interview conducted during the fieldwork, the following are considered viable and attainable options to increase SOC in the study area

- Promotion of residue retention on croplands and farmers must avoid removing/burning the residue but should store and use them as mulch.
- Introduction of alley cropping or other forms of agroforestry practises.

- Deliberate introduction of cover crops in farms.
- Guided use of inorganic fertilizers.
- Implementation of socio-economic incentives like fertilizer subsidy.
- Awareness creation on the benefits of such practises in terms of improving yields, soil fertility and the role of SOC in contributing to climate change mitigation as well as the potential financial benefits associated with the carbon trade under the Kyoto Protocol.

5. CONCLUSIONS

Objective 1: To describe farming systems and other land uses within the Bechem Forest District.

- **What are the land use types and their distribution in the area?**
  - The land use types identified in the study area are: forests (3191 ha/25.9%), tree plantations (1603ha/13%), mixed fields/crops (1244ha/10.1%), tree crops (3585ha/29.9%), agroforestry (2062 ha/16.7%) and settlements (643ha/5.2%).
  - The forest and the tree plantations are referred to as tree based systems and agroforestry (taungya), mixed fields/crops and tree crops are referred to as farm based systems.

Objective 2: To estimate and map SOC stocks within the different farming systems and other land use types.

- **How is the soil organic carbon stock distributed across the land use types?**
  - The tree based systems recorded the highest values and the farm based systems recorded low values.
  - Therefore in the carbon distribution map, the tree based systems showed the high colour intensity whilst the farm based systems showed low colour intensity.
  - In all the land use types SOC levels decreased with depth with, 49-56% of SOC held in the top layer. Therefore, there is a steep decrease in SOC with depth.
- **What is the concentration of soil organic carbon stocks within the different land use types?**
  - The estimated mean carbon stock are as follows: Agroforestry 36.37±3.2 t C ha^{-1}(top layer) and 29.98±2.4t C ha^{-1}(bottom layer),tree crops 37.21±21t C ha^{-1}(top layer) and 29.56±3t C ha^{-1}(bottom layer),mixed fields/crops 35.86±2t C ha^{-1}(top layer) and 30.43±2.6t C ha^{-1}(bottom layer),tree plantations 34.95±2t C ha^{-1}(top layer) and 36.74±4.4t C ha^{-1}(bottom layer),forest 43.38t C ha^{-1}(top layer) and 41.66±5.8t C ha^{-1}(bottom layer).
  - The total SOC stock for the study area was estimated at 8.78 x 10^5 t SOC.
- **Is the concentration of soil organic carbon stocks across the land use types significant?**
  - The coefficient of variation across the land use types was large which indicates variability amongst the land use types. However, a test of significance (ANOVA) indicated no significant difference (p=0.231 for top layer and p=0.951 for bottom layer) within the land use types.
  - This therefore gives enough evidence to reject the hypothesis.

- **Which farming system and land use type has the highest Soil Organic carbon stock?**
    - Amongst the farm based systems, tree crops which received the highest weight by way of land use management recorded the highest SOC stock of 67t C ha^{-1}.
    - Amongst all the land use types, forest had the highest estimate of 85t C ha^{-1}. This shows that that natural forest vegetation provides the best potential for soil quality enhancement.

Objective 3: To recommend options to raise SOC stocks in the area

- **What is/are the predominant land use management practise(s) in the area?**
    - Five main land use management practises; residue retention, cover crops, minimum tillage, fertilizer and manure application; were identified.
    - 66% of the respondents practise residue retention and this makes it the predominant land use practise in the study area. However, more than half (54%) remove/burn the residue before it adds organic matter to the soil.
- How can the SOC stocks be enhanced in the area?
    - Based on review of published research and the interview conducted during the field, the following options are considered viable options to increase SOC in the study area:
        - Promotion of residue retention on croplands and farmers must aviod removing/burning the residue but store and use them as mulch.
        - Introduction of alley cropping or other forms of agroforestry practises.
        - Deliberate introduction of cover crops in farms.
        - Guided use of inorganic fertilizers.
        - Implementation of socio-economic incentives like fertilizer subsidy.
        - Awareness creation on the benefits of such practises in terms of improving yields, soil fertility and the role of SOC in contributing to climate change mitigation as well as the potential financial benefits.
    - Amongst the farm based systems, tree crops which are cash crops received the highest weight aggregate in terms of management and also had the highest carbon stock. This is because, farmers gave priority to such fields, and hence management plays a crucial role in enhancing SOC levels. Therefore land users can adopt appropriate land use management practises to increase SOC levels.

6. RECOMMENDATIONS

The global effort towards finding sustainable solution to the greenhouse effect has identified the potential of soils as a carbon sink. However, for an accurate and reliable large scale determination of soil organic stock depends on SOC density determination at local or small scale level(Su *et al*.,2006). Further, it has been proven in this research that land use/cover change affects the soil organic carbon status and land use/cover change should be critical in the estimation of soil organic stocks. Again, it has been shown that management practises within a particular land use types influences the soil organic carbon and subsequently the soil fertility and the yield.

Therefore it is being recommended that:

- A lot more soil organic carbon research should be conducted at the local or small scale levels to provide an accurate baseline data for a proper national soil carbon inventory for Ghana. However, the respective layer depths should be smaller (0-10cm, 10-20cm) to 1metre depth. This will be helpful in preparing the country for carbon sequestration projects under the CDM of the Kyoto Protocol.

- Awareness creation especially for farmers on the benefits of sustainable land use practises in terms of improving yields, soil fertility and the role of SOC in contributing to climate change mitigation as well as the potential financial benefits from the carbon trade . This will help raise the SOC potentials of agricultural soils.

- Implementation of socio-economic incentives like fertilizer subsidy and other packages to induce land users to adopt sustainable land use management practises.

6.1. Limitations of the study

- Improper record keeping affected data collection on fertilizer use and crop yields.
- High laboratory costs hindered the collection of large samples for analysis.

7. REFERENCES

Adigun, M. O., Akinbola, G. E., Olaleye, A. O., & Obuh, J. (2008). Variability of Soil Properties Across Planted Fallows under Earthworm Casts on an Alfisols in South Western Nigeria. *World Journal of Agricultural Sciences 4* (4), 435-441.

Albrecht, A., & Kandji, S. T. (2003). Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems & Environment, 99*(1-3), 15-27.

Anderson, J. M., & Ingram, J. S. I. (1993). Tropical soil biology and fertility: a Handbook of Methods : CAB International. Oxon, UK.

Ardö, J., & Olsson, L. (2003). Assessment of soil organic carbon in semi-arid Sudan using GIS and the CENTURY model.. *Journal of Arid Environments, 54*(4), 633-651.

Arifalo, S. F., & Mafimisebi, T. E. (2011). Assessment of the effects of soil fertility management technologies on the yield of selected food crops in Oyo State, Nigeria. *Journal of Agricultural Technology, 7*(1), 1-8.

Asante-Yeboah, Evelyn (2010). *Assessing the impacts of Silvicultural treatment systems on Ecosystem services: a case of Carbon sequestration and Biodiversity conservation*. ITC, Enschede.

Atsivor, L., Dowuona, G. N., & Adiku, S. G. K. (2001). Farming system-induced variability of some soil properties in a sub-humid zone of Ghana. *Plant and Soil, 236*(1), 83-90.

Awanyo, L. (2009). Exploring the connections: Land tenure,social identities and agrobiodiversity practises in Ghana. *Human Geography . 91*(2), 137–155.

Baker, J. M., Ochsner, T. E., Venterea, R. T., & Griffis, T. J. (2007). Tillage and soil carbon sequestration--What do we really know? *Agriculture, Ecosystems & Environment, 118*(1-4), 1-5.

Bationo, A., Hartemink, A., Lungu, O., Naimi, M., Okoth, P., Smaling, E., & Thiombiano, L. (2006). *African soils : Their productivity and profitability of fertilizer use*. Paper presented at the African Fertilizer Summit : Abuja,Nigeria June 9-13,2006.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., & Kimetu, J. (2007). Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural Systems, 94*(1), 13-25.

Batjes, N. (1996). Total C and N in soils of the world. *Eur J Soil Sci, 47*, 151 - 163.

Batjes, N. (2004). Estimation of Soil Carbon Gains Upon Improved Management within Croplands and Grasslands of Africa. *Environment, Development and Sustainability, 6*(1), 133-143.

Batjes, N. H. (2001). Options for increasing carbon sequestration in West African soils: an exploratory study with special focus on Senegal. *Land Degradation & Development, 12*(2), 131-142.

Batjes, N. H., & Dijkshoorn, J. A. (1999). Carbon and nitrogen stocks in the soils of the Amazon Region. *Geoderma, 89*(3-4), 273-286.

Batjes, N. H., & Sombroek, W. G. (1997). Possibilities for carbon sequestration in tropical and subtropical soils. *Global Change Biology, 3*(2), 161-173.

Bellassen, V., Manlay, R. J., Chéry, J.-P., Gitz, V., Touré, A., Bernoux, M., & Chotte,J.-L. (2010). Multi-criteria spatialization of soil organic carbon sequestration potential from agricultural intensification in Senegal. *Climatic Change, 98*(1), 213-243.

Benefoh, T. D. (2008). *Assessing the effects of land - use or cover change on ecosystem services in Ejisu - Juaben district, Ghana : the case study of carbon sequestration.* ITC, Enschede.

Benneh, G. (1972). Systems of Agriculture in Tropical Africa. *Economic Geography, 48*(3), 244-257.

Bouyoucos, G. J. (1962). Estimation of colloidal material in soils. *Science (New York, N.Y.), 64*(632).

Braimoh, A. K., & Vlek, P. L. G. (2005). Land-Cover Change Trajectories in Northern Ghana. *Environmental Management 36*(3), 356–373.

Briggs, L., & Twomlow, S. J. (2002). Organic material flows within a smallholder highland farming system of South West Uganda. *Agriculture, Ecosystems & Environment, 89*(3), 191-212.

Brown, D. J., Shepherd, K. D., Walsh, M. G., Dewayne Mays, M., & Reinsch, T. G. (2006). Global soil characterization with VNIR diffuse reflectance spectroscopy. *Geoderma, 132*(3-4), 273-290.

Cerri, C. E. P., Easter, M.,Paustian, K., Killian, K.,Coleman, K., Bernoux, M.,Falloon,P.,Powlson, D.S.,Batjes, N.H.,Milne, E., & Cerri C.C. (2007). Predicted soil organic carbon stocks and changes in the Brazilian Amazon between 2000 & 2030.*Agriculture, Ecosystems & Environment,122*(1),58-72.

Chiti, T., Certini, G., Grieco, E., & Valentini, R. (2010). The role of soil in storing carbon in tropical rainforests: the case of Ankasa Park, Ghana. *Plant and Soil, 331*(1), 453-461.

Dale, V. H., & Polasky, S. (2007). Measures of the effects of agricultural practices on ecosystem services. *Ecological Economics, 64*(2), 286-296.

Dersch, G., & Böhm, K. (2001). Effects of agronomic practices on the soil carbon storage potential in arable farming in Austria. . *Nutrient Cycling in Agroecosystems, 60*(1), 49-55.

Doraiswamy, P. C., McCarty, G. W., Hunt, J. E. R., Yost, R. S., Doumbia, M., & Franzluebbers, A. J. (2007). Modeling soil carbon sequestration in agricultural lands of Mali. *Agricultural Systems, 94*(1), 63-74.

Duiker, S. W., & Lal, R. (1999). Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. *Soil and Tillage Research, 52*(1-2), 73-81.

Dutta, R., Stein, A., Smaling, E. M. A., Bhagat, R. M., & Hazarika, M. (2010). Effects of plant age and environmental and management factors on tea yield in Northeast India. *Agron. J., 102*, 1-12.

FAO. (1998). World Reference Base for Soil Resources. World Soil Resources Reports, 84. Rome, Italy, 88 pp.

FAO(Food and Agriculture Organization). (2003). FAOSTAT Agriculture Data, http://apps.fao/cgi-binnph-db.pl?suset=agriculture. FAO, Rome Italy.

Freibauer, A., Rounsevell, M. D. A., Smith, P., & Verhagen, J. (2004). Carbon sequestration in the agricultural soils of Europe. *Geoderma, 122*(1), 1-23.

Gana, B. K. (2000). *Effects of Agriculture On Soil Quality in Northeastern Ghana.* Unpublished Doctor of Philosophy Thesis, University of Saskatchewan, Saskaton,Saskatchewan.

Göl, C., Çakir, M., Edi, S., & Yilmaz, H. (2010). The effects of land use/land cover change and demographic processes (1950 - 2008) on soil properties in the Gökçay catchment, Turkey. *African journal of Agricultural Research, 4*(13), 1670-1677.

Guo, L. B., & Gifford, R. M. (2002). Soil carbon stocks and land use change: a meta analysis. [Article]. *Global Change Biology, 8*(4), 345-360.

Hapsari, A. (2010). *Assessing and mapping ecosystem services in Offinso district, Ghana.* ITC, Enschede.

Harris, F. (2002). Management of manure in farming systems in semi-arid West Africa. *Experimental Agriculture, 38*(02), 131-148.

Herrick, J. E. (2000). Soil quality: an indicator of sustainable land management? *Applied Soil Ecology, 15*(1), 75-83.

Hossner, L. R., & Juo, A. S. R. (1999). *Soil Nutrient Management for Sustained Food Crop Production in Upland Farming Systems in the Tropics*: Soil and Crop Sciences Department,College Station, Tennessee.

Intergovernmental Panel on Climate Change (IPCC). (2003). Good Practice Guidance for Land Use, Land Use Change and Forestry. IPCC/OECD/IEA/IGES, Hayama, Japan.

IPCC. (2007). *Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report.*

Johansen, K., Bartolo, R., & Phinn, S. (2010). Special Feature- Geographic Object-Based Image Analysis. *Journal of Spatial Science, 55(1),* 3-7.

Khresat, S., Al-Bakri, J., & Al-Tahhan, R. (2008). Impacts of land use/cover on soil properties in the Mediterranean region of northwestern jordan. *Land Degrad. Develop., 19*, 397–407

Kimble, J., Cook, T., & Eswaran, H. (1990). Proc Symp Characterization and Role of Organic Matter in Different Soils, 14th Soil Sci, Kyoto, Japan, 12-18 August, Wageningen. *the Netherlands*, 250 - 258.

Lal, R. (2002). Carbon sequestration in dryland ecosystems of West Asia and North Africa. *Land Degradation & Development, 13*(1), 45-59.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science (New York, N.Y.), 304*(5677), 1623-1627.

Lal, R. (2007). Soil Science and the Carbon Civilization. *Soil Sci. Soc. Am. J., 71*(5), 1425-1437.

Lal, R., & Bruce, J. P. (1999). The potential of world cropland soils to sequester C and mitigate the greenhouse effect. *Environmental Science & Policy, 2*(2), 177-185.

Lal, R., Follett, R. F., & Kimble, J. M. (2003). Achieving Soil Carbon Sequestration in the United States: A Challenge To the Policy Makers. *Soil Science, 168*(12), 827-845.

Lal, R., & Kimble, J. M. (1997). Conservation tillage for carbon sequestration. *Nutrient Cycling in Agroecosystems, 49*(1), 243-253.

Marks, E., Aflakpui, G. K. S., Nkem, J., Poch, R. M., Khouma, M., Kokou, K., Sagoe,R.,&Sebastia,M.T. (2009). Conservation of soil organic carbon, biodiversity and the provision of other ecosystem services along climatic gradients in West Africa. *Biogeosciences, 6* 1825–1838.

Marland, G., Garten, C. T. J., Post, W. M., & West, T. O. (2004). Studies on enhancing carbon sequestration in soils. *Energy, 29*(9-10), 1643-1650.

McCarty, G. W., Reeves III, J. B., Yost, R., Doraiswamy, P. C., & Mamadou, D. (2010). Evaluation of methods for measuring soil organic carbon in west african soils. *African journal of Agricultural Research, 5*(16), 2169-2177.

Miller, P., Engel, R., & Bricklemyer, R. (2004) Soil Carbon Sequestration in Agriculture:Farm Management Practices Can Affect Greenhouse Gas Emissions. *Montana State University Ext. Service, MT(4).*

MOFA. (2009). *Tano North District Annual Report*: Ministry of Food & Agriculture(MOFA).

Morisada, K., Imaya, A., & Ono, K. (2002). Temporal changes in organic carbon of soils developed on volcanic andesitic deposits in Japan. *Forest Ecology and Management, 171*(1-2), 113-120.

Morisada, K., Ono, K., & Kanomata, H. (2004). Organic carbon stock in forest soils in Japan. *Geoderma, 119*(1-2), 21-32.

Murphy, C. A., Foster, B. L., Ramspott, M. E., & Price, K. P. (2004). Grassland management effects on soil bulk density. *Transactions of the Kansas Academy of Science*.

Nandwa, S. (2001). Soil organic carbon (SOC) management for sustainable productivity of cropping and agro-forestry systems in Eastern and Southern Africa. *Nutrient Cycling in Agroecosystems, 61*(1), 143-158.

Nguyen, N. T. (2010). *Estimation and mapping of above ground biomass for the assessment and mapping of carbon stocks in tropical forest using SAR data : a case study in Afram headwaters forest, Ghana.* ITC, Enschede.

Nketia, K. S., Tutu Osei , P., & Asare, A. (2009). The Forest Dialogue-TFD, Implementing REDD+ in Ghana:Contextualization and Some Challenges. A background Paper for REDD+ Readiness Field Dialogue in Ghana, November,2009.

Obeng, H. (2000) Selected Economic Issues:Soil Classification in Ghana. *Vol. No.3*: Center for Policy Analysis (CEPA).

Oelbermann, M., Paul Voroney, R., & Gordon, A. M. (2004). Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and southern Canada. *Agriculture, Ecosystems & Environment, 104*(3), 359-377.

Oelbermann, M., Voroney, R. P., Kass, D. C. L., & Schlönvoigt, A. M. (2005). Above- and below-ground carbon inputs in 19-, 10- and 4-year-old Costa Rican Alley cropping systems. *Agriculture, Ecosystems & Environment, 105*(1-2), 163-172.

Ololade, I. A., Ajayi, I. R., Gbadamosi, A. E., Mohammed, O. Z., & Sunday, A. G. (2010). A Study on Effects of Soil Physico-Chemical Properties on Cocoa Production in Ondo State. *Modern Applied Science, 4*(5).

Omotayo, O. E., & Chukwuka, K. S. (2009). Soil fertility restoration techniques in sub-Saharan Africa using organic resources. *African Journal of Agricultural Research 4 (3)*, 144-150.

Omotoso, S. O., & Akinbola, G. E. (2007). Variability of soil properties at the transitional zone between two parent materials in south west Nigeria. *International journal of Soil Science, 2*(3), 218-223.

Paustian, K., Andrén, O., Janzen, H. H., Lal, R., Smith, P., Tian, G.,Tiessen,H.,van Noordwijk,M., & Woomer,P.L. (1997). Agricultural soils as a sink to mitigate CO2 emissions. *Soil Use and Management, 13*, 230-244.

Post, W. M., Izaurralde, R. C., Mann, L. K., & Bliss, N. (2001). Monitoring and Verifying Changes of Organic Carbon in Soil. [10.1023/A:1017514802028]. *Climatic Change, 51*(1), 73-99.

Ringius, L. (2002). Soil Carbon Sequestration and the CDM: Opportunities and Challenges for Africa. [10.1023/A:1016108215242]. *Climatic Change, 54*(4), 471-495.

Robert, M. (2001). *Soil carbon sequestration for improved land management*. Rome: FAO.

Sheikh, A. M., Kumar, M., & Bussmann, R. (2009). Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. *Carbon Balance and Management, 4*(6).

Smaling, E. M. A., & Dixon, J. (2006). Adding a soil fertility dimension to the global farming systems approach, with cases from Africa. *Agriculture, Ecosystems & Environment, 116*(1-2), 15-26.

Smaling, E. M. A., & Fresco, L. O. (1993). A decision-support model for monitoring nutrient balances under agricultural land use (NUTMON). *Geoderma, 60*(1-4), 235-256.

Smaling, E. M. A., Lesschen, J. P., van Beek, C. L., de Jager, A., Stoorvogel, J. J., Batjes, N. H.,&Fresco,L.O. (2010). Where do we stand, twenty years after the assessment of soil nutrient balances in Sub-Saharan Africa? *(in press)*.

Smaling, E. M. A., Nandwa, S. M., & Janssen, B. H. (1996). *Soil fertility in Africa is at stake,p. 47-61. In R.J. Buresh et al. (ed.) Replenishing soil fertility in Africa. SSSA Spec. Publ. 51. SSSA, Madison.* Paper presented at the an international symposium cosponsored by Divisions A-6 (International Agronomy) and S-4 (Soil Fertility and Plant Nutrition), and the International Center for Research in Agroforestry, held at the 88th Annual Meetings of the American Society of Agronomy and the Soil Science Society of America, Indianapolis, Indiana, 6th November 1996.

Smith, P. (2005).An overview of the permanence of soil organic carbon stocks: influence of direct human-induced, indirect and natural effects. *European Journal of Soil Science, 56,*673-680.

Snapp, S. S., Mafongoya, P. L., & Waddington, S. (1998). Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. *Agriculture, Ecosystems & Environment, 71*(1-3), 185-200.

So, H. B., Kirchhof, G., Bakker, R., & Smith, G. D. (2001). Low input tillage/cropping systems for limited resource areas. *Soil and Tillage Research, 61*(1-2), 109-123.

Stewart, C., Paustian, K., Conant, R., Plante, A., & Six, J. (2007). Soil carbon saturation: concept, evidence and evaluation. *Biogeochemistry, 86*(1), 19-31.

Su, Z.-Y., Xiong, Y.-M., Zhu, J.-Y., Ye, Y.-C., & Ye, M. (2006). Soil Organic Carbon Content and Distribution in a Small Landscape of Dongguan, South China. *Pedosphere, 16*(1), 10-17.

Sukkel, W., Geel, W.van & Haan, J.J. de.(2008). *Carbon sequestration in organic and conventional managedsoils in the Netherlands.* Paper presented at the 16th IFOAM Organic World Congress, Modena, Italy,June 16-2008.

Takimoto, A.,Nair, R.P.K., & Nair, V.D.(2008). Carbon stock and sequestration potential of traditional and improved agroforestry systems in the West African Sahel.*Agriculture,Ecosystems & Environment,*125,159-166.

Tiessen, H., Feller, C., Sampaio, E. V. S. B., & Garin, P. (1998). Carbon Sequestration and Turnover in Semiarid Savannas and Dry Forest. *Climatic Change, 40*(1), 105-117.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature, 418*(6898), 671-677.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D.,Schlesinger,W.H.,Simberloff,D., & Swackhamer,D.(2001). Forecasting Agriculturally Driven Global Environmental Change. *American Association for the Advancement of Science,*292,281-284.

Tornquist, C. G., Hons, F. M., Feagley, S. E., & Haggar, J. (1998). Agroforestry system effects on soil characteristics of the Sarapiqui region of Costa Rica. *Agriculture, Ecosystems and Environment 73*(1999), 19-28.

Vågen, T.-G., Lal, R., & Singh, B. R. (2005). Soil carbon sequestration in sub-Saharan Africa: a review. *Land Degradation & Development, 16*(1), 53-71.

van Noordwijk, M., Cerri, C., Woomer, P. L., Nugroho, K., & Bernoux, M. (1997). Soil carbon dynamics in the humid tropical forest zone. *Geoderma, 79*(1-4), 187-225.

Velasquez, E., Lavelle, P., & Andrade, M. (2007). GISQ, a multifunctional indicator of soil quality. *Soil Biology and Biochemistry, 39*(12), 3066-3080.

Verma, B., Datta, S., Rattan, R., & Singh, A. (2010). Monitoring changes in soil organic carbon pools, nitrogen, phosphorus, and sulfur under different agricultural management practices in the tropics. *Environmental Monitoring and Assessment, 171*(1), 579-593.

Viscarra Rossel, R. A., Walvoort, D. J. J., McBratney, A. B., Janik, L. J., & Skjemstad, J. O. (2006). Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties. *Geoderma, 131*(1-2), 59-75.

Wallington, T. J., Jayaraman, S., Ole, J. N., & Ellie, J. H. (2004). Greenhouse Gases and Global Warming. *in Encyclopedia of Life Support Systems (EOLSS).*

Wang, X., Gassman, P. W., Williams, J. R., Potter, S., & Kemanian, A. R. (2008). Modeling the impacts of soil management practices on runoff, sediment yield, maize productivity, and soil organic carbon using APEX. *Soil and Tillage Research, 101*(1-2), 78-88.

Wang, Y., Fu, B., Lü, Y., Song, C., & Luan, Y. (2009). Local-scale spatial variability of soil organic carbon and its stock in the hilly area of the Loess Plateau, China. *Quaternary Research, 73*(1), 70-76.

Wang, Y., & Hsieh, Y.-P. (2002). Uncertainties and novel prospects in the study of the soil carbon dynamics. *Chemosphere, 49*(8), 791-804.

Wang, Z.-M., Zhang, B., Song, K.-S., Liu, D.-W., & Ren, C.-Y. (2010). Spatial Variability of Soil Organic Carbon Under Maize Monoculture in the Song-Nen Plain, Northeast China. *Pedosphere, 20*(1), 80-89.

West, T. O., & Post, W. M. (2002). Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation:A Global Data Analysis. *Soil Sci. Soc. Am. J., 66*, 1930–1946.

Wilson, G. F., Lal, R., & Okigbo, B. N. (1982). Effects of cover crops on soil structure and on yield of subsequent arable crops grown under strip tillage on an eroded alfisol. *Soil and Tillage Research, 2*(3), 233-250.

Woomer, P. L., Touré, A., & Sall, M. (2004). Carbon stocks in Senegal's Sahel Transition Zone. *Journal of Arid Environments, 59*(3), 499-510.

Yao, M. K., Angui, P. K. T., Konate, S., Tondoh, J. E., Tano, Y., Abbadie, L., & Benest,D.(2010). Effects of Land use types on soil organic carbon and nitrogen dynamics in Mid- West Cote d'Ivoire. *European Journal of Scientific Research, 40*(2), 211-222.

8. APPENDICES

Appendix A: SOIL SAMPLING SHEET

Recorder……………

Sample Date   Plot Id.….. …..   Farm Size:

Co-ordinates: X……………   Y…………………

No.	Item	Descriptions
1	Land cover	
2.	Land use	
3.	Soil texture	
4.	Soil type/moisture	
5.	Soil colour	
6.	Soil PH	
7.	Distance from Homesteads	
	Observations/Remarks	

Appendix B: Field work

Appendix C: Laboratory work

Appendix D: NUTMON Land use Inventory/Questionnaires (revised)

FARM CODE: . . . . Date. . . . .

Enumerator:. . . . . Farmers name: . . . .

1. What kind of crops have you grown over the last 5-10years?
2. Do you have any soil or nutrient management practices in place?
3. What kind of management practices? Any challenges with the practice?
4. Have your farm size changed over the past 5-10 years? Do you have plans to expand?
5. Can you give estimates of your yields over the past 5-10years?
6. How do you prepare for planting and harvesting? How do you handle crop residue?
7. Do you keep livestock or poultry? Can you explain how the waste from the animals is handled?
8. Do you have an irrigation or water use management system?
9. Do you know anything about climate change and soil carbon credits?
10. Do you have any comments or suggestions?
11. Remarks/Observations

Appendix E : Land use types in the study area

Appendix F: Correlation coefficients among soil texture properties and chemical variables as well as their significance levels

Variables	Sand	Silt	Clay	SOC	pH
Sand	1				
Silt	-0.668**	1			
Clay	-0.920**	0.323	1		
SOC	-0.001	0.065	0.032	1	
pH	0.397*	-0.046	-0.481**	0.016	1

***and ** Significant at the 0.05 and 0.01 levels respectively. The total number of observations is 78 per layer**

Appendix G: Test of significance (ANOVA) in SOC content for two soil profiles in five land use types

		Sum of squares	**df**	**Mean Square**	**F**	**Sig**
Top Layer	**Between groups**	0.509	3	0.170	1.477	0.231
	Within groups	6.198	54	0.115		
	Total	6.706	57			
Bottom Layer	**Between groups**	0.091	4	0.023	0.177	0.950
	Within groups	9.368	73	0.128		
	Total	9.458	77			

Appendix H:Tests of Normality for SOC content distribution in two soil profiles for five land use types

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Land use types	Statistic	df	Sig.	Statistic	df	Sig.
Bottom layer	Agroforestry	.135	15	.200*	.907	15	.123
	Tree Crops	.100	20	.200*	.942	20	.258
	Mixed fields	.151	20	.200*	.908	20	.059
	Tree plantation	.193	13	.198	.942	13	.479
	Forest	.222	10	.177	.881	10	.136
Top layer	Agroforestry	.133	15	.200*	.947	15	.474
	Tree Crops	.205	20	.028	.862	20	.009
	Mixed fields	.147	20	.200*	.941	20	.250
	Tree plantation	.126	13	.200*	.958	13	.723
	Forest	.238	10	.115	.843	10	.048

a. Lilliefors Significance Correction,*. This is a lower bound of the true significance.

Appendix I: Correlation coefficients among soil physical and chemical variables as well as their significance levels

Variables		Top layer			Bottom layer		
		SOC	**Bulk density**	**pH**	**SOC**	**Bulk density**	**pH**
Top layer	SOC	1					
	Bulk density	-0.039	1				
	pH	-0.079	0.063	1			
Bottom layer	SOC	0.041	0.342**	-0.127	1		
	Bulk density	0.049	0.729**	0.265*	0.382**	1	
	pH	-0.061	0.112	0.824**	-0.002	0.259*	1

***and ** Significant at the 0.05 and 0.01 levels respectively. The total number of observations is 78 per layer**

Table J: Correlation coefficients among soil physical and chemical variables as well as their significance levels

Variables		Top layer		Bottom Layer	
		SOC density	Bulk density	SOC density	Bulk density
Top layer	SOC density	1			
	Bulk density	0.464**	1		
Bottom layer	SOC density	0.059	-0.091	1	
	Bulk density	0.413**	0.729**	-0.034	1

***and ** Significant at the 0.05 and 0.01 levels respectively. The total number of observations is 78 per layer**

Appendix K:Normality test for SOC stock distribution in five land use types in the study area

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Land use types	Statistic	df	Sig.	Statistic	df	Sig.
Top layer	Agroforestry	.194	15	.133	.902	15	.103
	Tree Crops	.202	20	.032	.890	20	.026
	Mixed fields	.117	20	.200*	.950	20	.362
	Tree plantation	.258	13	.018	.824	13	.013
	Forest	.214	10	.200*	.927	10	.418
Bottom layer	Agroforestry	.134	15	.200*	.940	15	.388
	Tree Crops	.131	20	.200*	.944	20	.279
	Mixed fields	.111	20	.200*	.963	20	.613
	Tree plantation	.165	13	.200*	.954	13	.661
	Forest	.209	10	.200*	.889	10	.165

a. Lilliefors Significance Correction, *. This is a lower bound of the true significance.

Appendix L:Normality test after removing outliers from the top layers in mixed fields and tree crops land use

	Land use types	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Top layer	Agroforestry	.194	15	.133	.902	15	.103
	Tree Crops	.214	18	.029	.893	18	.044
	Mixed fields	.117	20	.200*	.950	20	.362
	Tree plantation	.175	12	.200*	.869	12	.064
	Forest	.214	10	.200*	.927	10	.418

a. Lilliefors Significance Correction , *. This is a lower bound of the true significance.

Appendix M:Test of significance (ANOVA) for SOC stock in five land use types in the study area

		Sum of Squares	df	Mean Square	F	Sig.
Top layer	Between Groups	5.764	4	1.441	1.327	.268
	Within Groups	76.011	70	1.086		
	Total	81.774	74			
Bottom Layer	Between Groups	14.240	4	3.560	1.996	.104
	Within Groups	130.183	73	1.783		
	Total	144.423	77			

Appendix N: Harvested area and yield/ha for two crops over five years in the study area

Year	Cassava		Plantain	
	Area/hectare	Yield/ha	Area/hectare	Yield/ha
2005	2634	17.67	3433	9.73
2006	2774	16.90	3540	9.80
2007	2857.22	16.53	3646.20	11.51
2008	3025	16.50	3544	11.6
2009	3050	17.14	3780	11.72

Source: Statistics Research and Information Directorate, MoFA, Ghana

Appendix O: Accuracy Assessment Report for Classified Study Area Image

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy (%)	Users Accuracy (%)
Agroforestry	7	9	7	100	77.78
Mixed fields	7	14	7	100	50
Tree Crops	20	8	11	62.50	82.24
Tree plantations	14	16	9	64.29	56.25
Forest	19	17	15	85	89.47
Settlements	3	4	3	100	75
Totals	70	70	53		

Overall Classification Accuracy = 75.71% Overall Kappa Statistics = 0.6873

Appendix O: Test of significance (ANOVA) for SOC content distribution across layers in five land use types in the study area

		Sum of Squares	df	Mean Square	F	Sig.
Agroforestry	Between Groups	2.546	1	2.546	17.947	.000
	Within Groups	3.972	28	.142		
	Total	6.519	29			
Tree Crops	Between Groups	3.278	1	3.278	34.468	.000
	Within Groups	3.613	38	.095		
	Total	6.891	39			
Mixed fields	Between Groups	4.422	1	4.422	25.547	.000
	Within Groups	6.578	38	.173		
	Total	11.000	39			
Tree plantation	Between Groups	1.343	1	1.343	18.091	.000
	Within Groups	1.782	24	.074		
	Total	3.126	25			
Forest	Between Groups	1.342	1	1.342	15.590	.001
	Within Groups	1.549	18	.086		
	Total	2.891	19			