KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

INSTITUTE OF DISTANCE LEARNING

CARBON STOCK UNDER FOUR DIFFERENT LAND-USE SYSTEMS IN THE SAVANNA ECOSYSTEMS, IN GHANA

BY

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A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF DEGRRE OF MASTER OF SCIENCE

BY

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FEBRUARY, 2014

DECLARATION

I hereby declare that this submission is my own work towards the award of M Sc., Environmental Science and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any degree of the University, except where due acknowledgement has been made in the text.

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(Head of Department) Signature Date

DEDICATION

This work is my lovely mother Madam Rebecca Dongi Fambali and my son Nasigri Evans.

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ABSTRACT

The savanna ecosystem is currently undergoing rapid and wide-ranging changes in land use and vegetation due to degradation and deforestation. Rates of land-use change which causes changes in carbon stock following degradation and deforestation are the determined factors of carbon emissions in tropical savanna ecosystem in Ghana. The study was conducted to assess the impact of four different land-use systems namely; natural forest, teak plantation, cultivated land and fallow land on carbon stock and to determine carbon emission factors in the four land uses. This was carried out in Walewale which is guinea savanna ecosystem in Ghana. Carbon accumulation in trees, herbaceous plants, litter and soil (up to 40cm depth) were assessed. Temporary Sampling Plots (TSPs) of size 25m by 25m, giving rise to an area of 0.0625ha were created in the various land-use systems in the selected sites in forest districts. The TSPs were created to capture the variability of the particular stand characteristics. All trees in the various land-use systems that were above two meters were inventoried and stem diameter at breast height of 1.3m measured, a standard point of measuring tree diameter. In addition, four sub-plots (quadrats) of size 1.0m by 1.0m were created in all the TSPs. All herbaceous and woody plants in the sub-plots were destructively sampled and litter collected. Fresh weights were determined immediately using electronic (digital) mass measure, and samples of the plant and litter collected for dry weight determination, by oven drying to constant weight. Sub-samples were also reserved for carbon content analysis. Soil samples were collected from the soil depth of 0 to 20 cm and 20 to 40 cm within the quadrates, air dried and sieved through 2.0 mm mesh, and texture and soil organic C content determined. Soil organic C was determined in the laboratory by Walkley and Black (1934) method. The mean carbon content of litter, herbs and wood was in increasing order of 30.2% ±3.906 (SD), 35.01%±4.095 (SD) and 45.43%±2.110 (SD) respectively. There was

significant difference in carbon content among the various plant functional type ($P<0.05$). The highest total carbon stock was recorded in the natural forest with 62.592 Mg C ha^{-1} followed by teak with 52.3205 Mg C ha^{-1} and cultivated land recorded the least total carbon of 34.564 Mg C ha^{-1}. In terms of tree carbon stock, the highest was recorded by teak stand with 26.644 Mg C ha^{-1} followed closely with natural forest which recorded 26.052 Mg C ha^{-1}. The highest total soil carbon stock was recorded in the natural forest with 36.35 Mg C ha-^{1} followed by fallow land which recorded 34.02 Mg C ha-^{1}. However, for the top 0-20cm, the highest carbon stock was in the fallow land followed by natural forest and cultivated land whiles the teak stand had the least. At $P<0.05$, there was significant difference in the total soil carbon among the various land-use systems. Post Hoc LSD test shows that the mean difference between natural forest versus fallow land, and fallow land versus cultivated land was not statistically significant. However the mean difference between natural forest versus cultivated land, natural forest versus teak plantation, fallow land versus teak plantation, and cultivated land versus teak plantation was found to be statistically significant. Using the natural forest as a bench mark, the impact of carbon loss on the conversion of the natural forest to other land-use systems was found was in increasing order, teak plantation, fallow land and cultivated land. Using teak plantation as a bench mark, more carbon is gained in converting cultivated land to teak plantation than in converting fallow land to teak plantation.

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1.0 INTRODUCTION

Carbon is present in every living organism, our atmosphere, oceans and earth. It's all around us and constantly circulating, being absorbed and released in cycles that have been taking place since the beginning of the earth. The carbon cycle is the flow of carbon in and between four areas of our planet. These are the terrestrial biosphere, atmosphere, oceans and geosphere.

The terrestrial ecosystems, in which carbon (C) is retained in the live biomass, decomposing organic matter, and soil, serves as reservoir of carbon and thus plays an important role in the global carbon cycle. A consequence of deforestation and degradation is the release of the carbon originally held in the forest to the atmosphere, either immediately through the burning of the vegetation or more slowly as unburned organic matter decays. Cultivation further oxidizes 25-30% of the organic matter in the upper part of the soil and these are released into the atmosphere (Houghton, 2005). Deforestation and forest degradation are said to contribute to between 20 and 25% of the global greenhouse gas emissions. However, these losses can be reversed through reforestation and afforestation. Rates of land-use change and changes in C stock following degradation and deforestation are the determined factors of the emissions of carbon from the tropical forest. Ecosystem and land –use systems have major influence on changes in C stock. The net flux of C between the terrestrial biosphere and atmosphere is determined by the changes in the various reservoirs namely, living vegetation, soils, woody debris and wood products. It is therefore necessary to examine how C flows between different reservoirs and how C stocks change in response to various land-use activities (IPCC, 2000). The main causes of the land use change in West Africa are shifting cultivation, timber extraction and conflicts.

Plant production and decomposition determine C inputs into the soil profile. The type of vegetation cover may influence the abundance of organic C in the soil, which in turn affects plant production (Jobbagy and Jackson, 2000). The conversion of the natural forest to other land uses may affect both biomass C and soil C stocks.

The IPCC (2000) report specifies that for full C accounting system, changes in C stocks across all C pools should be completely accounted for. It is therefore imperative that C stock data under various lands –use systems are collected and related to environmental variables. This will enable rate of change of C stock with respect to land-use system as well as environmental variables to be predicted and also to help in understanding the influence of the terrestrial ecosystems on the climate. Data on soil and vegetation C stock that could aid in elucidating the impact of land-use change under various climatic conditions are scarce in Ghana. However, a fairly representative soil organic C stock value, up to the depth of 20 cm, was reported for forest, forest-savannah transition zone and savannah soils by Acquaye and Oteng (1972), but vegetation C was not included. It is therefore important to estimate carbon emission trends in both soil organic matter and vegetation in the different land uses.

The aims of the study are therefore:

1. To assess the impact of four different land-use systems on the C stock
2. To determine carbon emission factors in the four land uses.

2.0 LITERATURE REVIEW

2.1.0 CARBON CYCLE

The global carbon cycle is now usually divided into the following major reservoirs of carbon interconnected by pathways of exchange:

- The Atmosphere
- The terrestrial biosphere
- The oceans, including dissolved inorganic carbon and living and non-living marine biota
- The sediments including fossil fuel, fresh water systems and non-living organic material, such as soil carbon
- The Earth's interior, carbon from the Earth's mantle and crust. These carbon stores interact with the other components through geological processes

The carbon exchanges between reservoirs occur as the result of various chemical, physical, geological, and biological processes. The ocean contains the largest active pool of carbon near the surface of the Earth. The natural flows of carbon between the atmosphere, ocean, and sediments are fairly balanced, so that carbon levels would be roughly stable without human influence.

Carbon in the earth's atmosphere exists in two main forms: carbon dioxide and methane. Both of these gases absorb and retain heat in the atmosphere and are partially responsible for the green house effect. Methane produces a large greenhouse effect per volume as compared to carbon dioxide, but it exists in much lower concentrations and is more short-lived than carbon dioxide, making carbon dioxide the more important greenhouse gas of the two(Wikipedia, 2013).

Carbon dioxide leaves the atmosphere through photosynthesis, thus entering the terrestrial and oceanic biospheres. Carbon dioxide also dissolves directly from the atmosphere into bodies of water (oceans, lakes, etc.), as well as dissolving in precipitation as raindrops fall through the atmosphere. When dissolved in water, carbon dioxide reacts with water molecules and forms carbonic acid, which contributes to ocean acidity. It can then be absorbed by rocks through weathering. It also can acidify other surfaces it touches or be washed into the ocean (Fig. 1).

Human activity over the past two centuries has significantly increased the amount of carbon in the atmosphere, mainly in the form of carbon dioxide, both by modifying ecosystems' ability to extract carbon dioxide from the atmosphere and by emitting it directly, e.g. by burning fossil fuels and manufacturing concrete(Wikipedia, 2013).

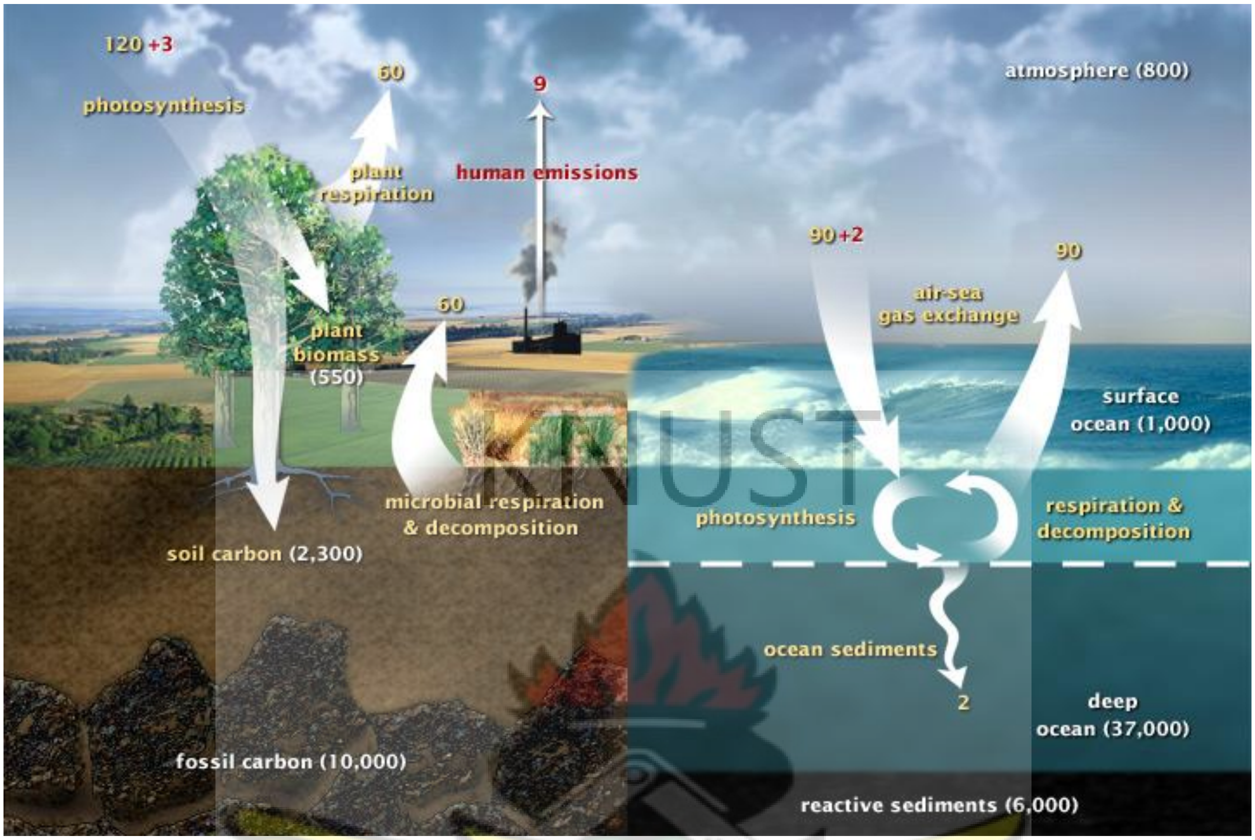

Fig.1 THE CARBON CYCLE

Adapted from: Wikipeadia, the free encyclopedia

2.2.0 CARBON EMMISSION

Carbon emissions, most notably carbon dioxide (CO_2), are part of a collection of gases that negatively influence the quality of our air and increase the greenhouse effect. Greenhouse gases have a direct influence on the environment, causing extreme weather changes, a global temperature increase, the loss of ecosystems and potentially hazardous health effects for people.

The World Meteorological Organization reports that the amount of CO_2 in the atmosphere reached a record levels in 2012, or 140% of the pre-industrial level of 280 parts per million. The daily average of atmospheric CO_2 as measured in Hawaii surpassed 400 ppm on May 10, 2013. It was 391.03 ppm in October 2012; 388.92 ppm in October 2011; and 387.15 ppm in October 2010. According to NOAA, 2012 was the hottest year in the U.S. (coterminous 48 states) since record-keeping began in 1895, and the ninth warmest on record globally (Global Future Studies and Research, 2013).

The total human-induced Green House Gas (GHG) emission is about 49.5 gigatons of CO_2 equivalent per year ($GtCO_2$ –eq/yr). Nature absorbs about half of this annually, but that ability is diminishing. To achieve carbon cycle equilibrium, assuming nature's absorption capacities remained the same, we would have to cut back to about 25 Gt CO_2-eq per year, which is deemed politically and economically unacceptable. The politically accepted target is a 2°C increase by 2100, requiring a reduction to around 44 $GtCO_2$ -eq by 2020. The business-as-usual scenario is an increase to about 56 $GtCO_2$ -eq by 2020. Oceans absorb atmospheric CO_2 (about 25% of it today) and will continue absorbing human-generated CO_2 for decades if not centuries, which increases acidity, affecting coral reefs and other sea life. Over the long term, increased CO_2 in the atmosphere leads to a proliferation of microbes that emit hydrogen sulfide—a very poisonous gas.

2.3.0 GLOBAL CARBON EMMISSION

The global C budget for the decade of 1980s included 5.4±0.3 Pg C emission by fossil fuel combustion and cement production, and 1.7±0.8 Pg C emission by land use change (Table. 1). The latter consists of deforestation and biomass burning, and conversion of natural to agricultural ecosystems. The annual increase in atmospheric concentration of CO_2 during the 1980s was 3.3±0.2 Pg C/year, absorption by the ocean was 2.0±0.8 Pg C/year, and the unknown residual terrestrial sink was 1.9±1.3 Pg C/year. For the decade of the 1990s, emission by fossil fuel combustion and cement production were 6.3±0.4 Pg C/year, and the emission by land use change was 1.6±0.8 Pg C/year (Table.1).

IPCC report 2007 indicated that there are large emissions from deforestation and other land use change activities in the tropics; these have been estimated in IPCC (2007a) for the 1990s to have been 5.9 $GtCO_2$-eq, with a large uncertainty range of 1.8–9.9 $GtCO_2$-eq (Denman *et al.*, 2007). This is about 25% (range: 8–42%) of all fossil fuel and cement emissions during the 1990s. The underlying factors accounting for the large range in the estimates of tropical deforestation and land-use changes emissions are complex and not fully resolved at this time (Ramankutty *et al.*, 2006). For the Annex I Parties that have reported Land-use, Land-use Change and Forestry (LULUCF) sector data to the United Nations Framework Convention on Climate Change (UNFCCC), (including agricultural soils and forests) since 1990, the aggregate net sink reported for emissions and removals over the period up to 2004 average out to approximately 1.3 $GtCO_2$-eq (range: –1.5 to –0.9 $GtCO_2$-eq) .

Table 1. An approximate global carbon budget (IPCC, 2001)

Source/Sink	1980s Billion ton	1990s
A. Source		
1. Fossil fuel combustion and cement production	5.0	6.3
2. Land Use Change	1.7	1.6
Total	**6.7**	**7.9**
B. Known Sinks		
1. Atmosphere	3.3	3.2
2. Oceans	1.9	1.7
Total	**5.2**	**4.9**
C. Missing Sinks (the fugitive CO_2) or probable terrestrial sink	1.5	3.0

2.4.0 PARADIGMS OF LAND USE CHANGES

To date, there is no single unifying theory of land-use change. This results from difficulty in linking the complex social and environmental dimensions of LUCC. The absence of formal process theories of land-use change implies that theories developed in social and natural sciences are adapted for case studies of LUCC (Veldkamp *et al*,. 2001). Such theories include the Malthusian, Boserupian and Chayanovian paradigms that relate land-use to population growth; the Ricardian paradigm that links land-use to intrinsic land quality; the Von Thunen paradigm that associate land-use to location of land parcels; and landscape, Human and Political Ecology paradigms that examine interrelationships of scales, patterns and processes and emphasize the role of people and exogenous variables in shaping the environment.

Malthus (1967) originally argued that food production could only grow at a linear rate compared to population that grows geometrically. Thus, population growth would ultimately outstrip the capability of the economy to meet the demand for food, owing to the ecological limits imposed by natural resources. The most important parameter that relates to LUCC in the Malthusian paradigm is population density (Mortimore, 1993). The increase in population density results in a corresponding increase in the frequency of cultivation and the shorting of fallow periods needed to rejuvenate soil fertility. As fallow length is reduced, soil fertility declines, and this leads to declining yields. Falling output is experienced which eventually culminates in food scarcity. The problem of food scarcity leads to further increases in cultivation. As arable land decreases,farmers move to marginal lands where cultivation accelerates land degradation, soil erosion and subsequently environmental degradation. So far, results of the application of the Malthusian paradigm of land-use change cannot be generalized.

Contrary to Malthus' earlier proposition, advancements in science in the last 50 years have played a major role in meeting the challenges to produce enough food to feed the global population. Evidence of a Malthusian response to LUCC has been found in several regional case studies. An example is the case of Honduras (Kok, 2001). Population growth was observed to lead to deforestation, while crop yields stagnated for a period of twenty years. However, land degradation may not always be associated with high population pressure, as land productivity does not only depend on its intrinsic properties, but also on management practices adopted for farming (Tiffen *et al*., 1994).

2.5.0 SOIL CARBON

The increase in atmospheric concentration of CO_2 by 31% since 1750 from fossil fuel combustion and land use change necessitates identification of strategies for mitigating the threat of the attendant global warming. Since the industrial revolution, global emissions of carbon (C) are estimated at 270±30 Pg (Pg = petagram = 10^{15} g = 1 billion ton) due to fossil fuel combustion and 136±55 Pg due to land use change and soil cultivation. Emissions due to land use change include those by deforestation, biomass burning, conversion of natural to agricultural ecosystems, drainage of wetlands and soil cultivation.

Depletion of soil organic C (SOC) pool has contributed 78±12 Pg of C to the atmosphere. Some cultivated soils have lost one-half to two-thirds of the original SOC pool with a cumulative loss of 30–40 Mg C/ha (Mg = megagram = 106 g = 1 ton). The depletion of soil C is accentuated by soil degradation and exacerbated by land misuse and soil mismanagement. Thus, adoption of a restorative land use and recommended management practices (RMPs) on agricultural soils can reduce the rate of enrichment of atmospheric CO_2 while having positive impacts on food security, agro-industries, water quality and the environment. A considerable part of the depleted SOC pool can be restored through conversion of marginal lands into restorative land uses, adoption of conservation tillage with cover crops and crop residue mulch, nutrient cycling including the use of compost and manure, and other systems of sustainable management of soil and water resources. Measured rates of soil C sequestration through adoption of RMPs range from 50 to 1000 kg/ha/year. The global potential of SOC sequestration through these practices is 0.9±0.3 Pg C/year, which may offset one-fourth to one-third of the annual increase in atmospheric CO_2 estimated at 3.3 Pg C/year. The cumulative potential of soil C sequestration over 25–50 years is 30–60 Pg. The soil C sequestration is a truly win–win strategy. It restores degraded soils, enhances biomass production, purifies surface and ground waters, and reduces the rate of enrichment of atmospheric CO_2 by offsetting emissions due to fossil fuel.

2.5.1 GLOBAL SOIL CARBON POOL

There are five principal global C pools. The oceanic pool is the largest, followed by the geologic, pedologic (soil), biotic and the atmospheric pool. All these pools are inter-connected and C circulates among them. The pedologic or soil C pool comprises two components: SOC and the soil inorganic carbon (SIC) pool. The SIC pool is especially important in soils of the dry regions. The SOC concentration ranges from a low in soils of the arid regions to high in soils of the temperate regions, and extremely high in organic or peat soils. The SOC pool also varies widely among ecoregions, being higher in cool and moist than warm and dry regions. Therefore, the total soil C pool is four times the biotic (trees, etc.) pool and about three times the atmospheric pool.

There are some estimates of the historic loss of C from geologic and terrestrial pools and transfer to the atmospheric pool. From 1850 to 1998, 270±30 Pg of C were emitted from fossil fuel burning and cement production (Marland *et al*., 1999: IPCC 2000). Of this, 176±10 Pg C were absorbed by the atmosphere (Etherigde *et al*., 1996; Keeling and Whorf 1999), and the remainder by the ocean and the terrestrial sinks. During the same period, emissions from land use change are estimated at 13±F55 Pg C (Houghton 1995, 1999). There are two components of estimated emissions of 136±55 Pg C from land use change: decomposition of vegetation and mineralization/oxidation of humus or SOC. There are no systematic estimates of the historic loss of SOC upon conversion from natural to managed ecosystems. Jenny (1980) observed that

‘‘among the causes held responsible for CO_2 enrichment, highest ranks are accorded to the continuing burning of fossil fuels and the cutting of forests. The contributions of soil organic matter appear underestimated.'' The historic SOC loss has been estimated at 40 Pg by Houghton 1999, 55 Pg by IPCC (1996) and Shimel (1995), 500 Pg by Wallace (1994), 537 Pg by Buringh (1984) and 60–90 Pg by Lal (1999). Until the 1950s, more C was emitted into the atmosphere from the land use change and soil cultivation than from fossil fuel combustion. Whereas the exact magnitude of the historic loss of SOC may be debatable, it is important to realize that the process of SOC depletion can be reversed. Further, improvements in quality and quantity of the SOC pool can increase biomass/agronomic production, enhance water quality, reduce sedimentation of reservoirs and waterways, and mitigate risks of global warming.

2.5.2 FACTORS AFFECTING DEPLETION OF SOIL ORGANIC CARBON POOL

Depletion of the SOC pool has major adverse economic and ecological consequences, because the SOC pool serves numerous on-site and off-site functions of value to human society and well being.

Principal on-site functions of the SOC pool are:

(i) Source and sink of principal plant nutrients (e.g., N, P, S, Zn, Mo);

(ii) Source of charge density and responsible for ion exchange;

(iii) Absorbent of water at low moisture potentials leading to increase in plant available water capacity;

(iv) Promoter of soil aggregation that improves soil tilth; because factors that determine soil tilth include formation and stability of aggregated soil particles.

(v) Cause of high water infiltration capacity and low losses due to surface runoff;

(vi) Substrate for energy for soil biota leading to increase in soil biodiversity;

(vii) Source of strength for soil aggregates leading to reduction in susceptibility to erosion;

(viii) Cause of high nutrient and water use efficiency because of reduction in losses by drainage, evaporation and volatilization;

(ix) Buffer against sudden fluctuations in soil reaction (PH) due to application of agricultural chemicals; and

(x) Moderator of soil temperature through its effect on soil color.

In addition, there are also off-site functions of SOC pool, which have both economic and environ mental significance. Important among these are:

(i) Reduces sediment load in streams and rivers,

(ii) Filters pollutants of agricultural chemicals,

(iii) Reactors for biodegradation of contaminants, and

(iv) Buffers the emissions of GHGs from soil to the atmosphere.

It is because of these multifareous functions that led Albretch (1938) to observe that ''soil organic matter (SOM) is one of our most important national resources; its unwise exploitation has been devastating; and it must be given its proper rank in any conservation policy.'' Indeed, the unwise exploitation of this precious resource is due to human greed and short-sightedness causing land misuse and soil mismanagement. Anthropogenic perturbations exacerbate the emission of CO_2 from soil caused by decomposition of SOM or soil respiration (Schlesinger 2000). The emissions are accentuated by agricultural activities including tropical deforestation and biomass burning, plowing (Reicosky, 2002), drainage of wetlands and low-input farming or shifting cultivation (Tiesen *et al*., 2001). In addition to its impact on decomposition of SOM (Trumbore *et al*., 1996), macroclimate has a large impact on a fraction of the SOC pool which is active (Franzluebbers *et al.*, 2001). Conversion of natural to agricultural ecosystems increases maximum soil temperature and decreases soil moisture storage in the root zone, especially in drained agricultural soils (Lal, 1996)

Thus, land use history has a strong impact on the SOC pool (Pullemen *et al.*, 2000). Biomass burning is an important management tool, especially in agricultural ecosystems of the tropics. The process emits numerous gases immediately but also leaves charcoal as a residual material. Charcoal, produced by incomplete combustion, is a passive component, and may constitute up to 35% of the total SOC pool in fire-proneecosystems (Skjemstad *et al*., 2002). As the SOC pool declines due to cultivation and soil degradation, the more resistant charcoal fraction increases as a portion of the total C pool (Zech and Guggenburger, 1996; Skjemstad *et al*., 2001)

Similar to deforestation and biomass burning, cultivation of soil, by plowing and other tillage methods, also enhances mineralization of SOC and releases CO_2 into the atmosphere (Reicosky *et al*., 1999). Tillage increases SOC mineralization by bringing crop residue closer to microbes where soil moisture conditions favor mineralization (Gregorich *et al*., 1998), physically disrupts aggregates and exposes hitherto encapsulated C to decomposition. Both activities decrease soil moisture, increase maximum soil temperature and exacerbate rate of SOC mineralization.

Thus, a better understanding of tillage effects on SOC dynamics is crucial to developing and identifying sustainable systems of soil management for C sequestration. There is a strong interaction between tillage and drainage. Both activities decrease soil moisture, increase maximum soil temperature and exacerbate rate of SOC mineralization. Nutrient mining,

as is the case with low input and subsistence farming practices, is another cause of depletion of SOC pool (Smalling, 1993). Negative elemental balance, a widespread problem in sub-Saharan Africa, is caused by not replacing the essential plant nutrients harvested in crop and livestock products by addition of fertilizer and/or manure. Excessive grazing has the same effect as mining of soil fertility by inappropriate cropping. Uncultivated fallowing, plowing for weed control but not growing a crop so that soil moisture in the profile can be recharged for cropping in the next season, is another practice that exacerbates SOC depletion. In the west central Great Plains of the U.S., this system requires a 14-month fallow period between the harvest and continuous cropping in some instances. Fallowing during summer keeps the soil moist and enhances the mineralization rate. Therefore, elimination of summer fallowing is an important strategy of SOC sequestration (Rasmussen *et al*., 1998). The objective is to maintain a dense vegetal cover on the soil surface so that biomass C can be added/returned to the soil. Consequently, the SOC pool can be maintained or increased in most semi-arid soils if they are cropped every year, crop residues are returned to the soil, and erosion is kept to a minimum.

2.5.3 DEPLETION OF SOIL ORGANIC CARBON BY EROSION VERSUS MINERALISATION.

Depletion of the SOC pool on agricultural soils is exacerbated by and in turn also exacerbates soil degradation. It comprises physical degradation (i.e., reduction in aggregation, decline in soil structure, crusting, compaction, reduction in water infiltration capacity and water/air imbalance leading to anaerobiosis) and erosion, chemical degradation (i.e., nutrient depletion, decline in pH and acidification, build up of salts in the root zone, nutrient/elemental imbalance and disruption in elemental cycles), and biological degradation (i.e., reduction in activity and species diversity of soil fauna, decline in biomass C and depletion of SOC pool). Soil degradation decreases biomass productivity, reduces the quantity (and quality) of biomass returned to the soil, and as a consequence decreases the SOC pool. Among all soil degradative processes, accelerated soil erosion has the most severe impact on the SOC pool. Several experiments have shown on-site depletion of the SOC pool by accelerated erosion (De jong and Kachanoski, 1988). However, on-site depletion does not necessarily imply emission of Green House Gasses (GHGs) into the atmosphere. Some of the SOC redistributed over the landscape by erosion and carried into the aquatic ecosystems and depressional sites may be mineralized and released as CO_2 (Lal, 1999), while the other is buried and sequestered (Stallard, 1998; Smith *et al*., 2001). It is estimated that about 1.14 Pg of C may be annually emitted into the atmosphere through erosioninduced processes (Lal, 2001a), and must be accounted for in the global C budget. Knowledge of the impact of erosional processes on SOC dynamics, and understanding the fate of C translocated by erosional processes is crucial to assessing the role of erosion on emissions of GHGs

into the atmosphere. Soil erosion is a major factor depleting SOC pool on sloping lands. On relatively flat soils with no erosion risks; however, mineralization predominates over erosion. For example, Rasmussen *et al*., (1998) observed that in Pendleton, eastern Oregon, biological oxidation of soil organic matter rather than accelerated erosion is the principal cause of SOC depletion. On steep slopes, however, erosional processes may be the principal cause of SOC depletion. Several studies have documented that long-term SOC loss in prairie soils is due to accelerated soil erosion (Gregorich and Anderson 1985; De Jong and Kachanoski, 1988; Dumanski *et al*., 1998). Therefore, adoption of conservation-effective farming systems and judicious management of soil erosion are crucial to maintaining and enhancing the SOC pool.

Soil degradation affects 1216 Mha by moderate plus severe categories in the world and 130 Mha in South Asia (Tab. 4). The ‘‘moderate’’ level refers to the degree of soil degradation in which the soil has a reduced productivity but is still suitable for use in local farming systems especially with an increased level of input (Oldeman, 1994). Some global hotspots of soil degradation are sub-Saharan Africa, South Asia, the Himalayan-Tibetan ecoregion, the Andean region, Central America and the Caribbean. Severely eroded soils may have lost one-half to two-thirds of their original carbon pool (Lal 2000), and the loss is more in soils with larger than smaller pools, and in the tropics than in temperate regions.

Table 2. Estimates of soil degredation in the world and South Asia at moderate +level of severity (Calculated from Oldeman, 1994, FAO, 1994)

Process	World (Mha)	South East Asia (Mha)
Water erosion	751	49
Wind erosion	280	47
Chemical Degradation	146	31
Physical degradation	39	3
Total degradation	1216	130

Most agricultural soils now contain a lower SOC pool than their potential as determined by the specific climatic conditions and soil profile characteristics. The historic loss of SOC pool in some sloping lands may be 30–40 Mg C/ha, or one-half to two-thirds of the original pool. The SOC pool can be enhanced by adopting recommended management practices (RMPs) and restoring degraded soils. Therefore, an important strategic question is ‘‘to what extent can SOC sink capacity potentially offset increases in atmospheric CO_2?’’

2.5.4 SOIL CARBON SEQUESTRATION: TECHNOLOGICAL OPTIONS

The term ‘‘soil C sequestration’’ implies removal of atmospheric CO_2 by plants and storage of fixed C as soil organic matter. The strategy is to increase SOC density in the soil, improve depth distribution of SOC and stabilize SOC by encapsulating it within stable micro-aggregates so that C is protected from microbial processes or as recalcitrant C with long turnover time. In this context, managing agro ecosystems is an important strategy for SOC/terrestrial sequestration. Agriculture is defined as an anthropogenic manipulation of C through uptake, fixation, emission and transfer of C among different pools. Thus, land use change, along with adoption of RMPs, can be an important instrument of SOC sequestration (Post and Kwon, 2000). Whereas land misuse and soil mismanagement have caused depletion of SOC with an attendant emission of CO_2 and other GHGs into the atmosphere, there is a strong case that enhancing SOC pool could substantially offset fossil fuel emissions (Kauppi *et al*., 2001). However, the SOC sink capacity depends on the antecedent level of SOM, climate, profile characteristics and management.

The sink capacity of SOM for atmospheric CO_2 can be greatly enhanced when degraded soils and ecosystems are restored, marginal agricultural soils are converted to a restorative land use or replanted to perennial vegetation, and RMPs are adopted on agricultural soils (Table 3).

Table 3.Comparison between traditional and recommended management practices in relation to soil organic carbon sequestration.(Adapted from Lal, 2004)

Traditional	Recommended Management practices
1 Biomass burning and residue removal	Residue returned as surface mulch
2 Conventional tillage and clean cultivation	Conservation tillage, no till and mulch farming
3 Bare/idle fallow	Growing cover crops during off-season
4 Continuous monoculture	Crop rotations with high diversity
5 Low input subsistence farming and soil fertility mining	Judicious use of off-farm input
6 Intensive use of chemical fertilizers	Integrated nutrient management with composts, biosolids and nutrient cycling, precision farming
7 Intensive cropping	Intergrating trees and livestock with crop production
8 Surface flood irrigation	Drip, furrow or sub-irrigation
9 Indiscriminate use of pesticides	Integrated pest management
10 Cultivating marginal soils	Conservation reserve program, restoration of degraded soils through land use change.

Although generic RMPs are similar (e.g., mulch farming, reduced tillage, integrated nutrient management (INM), integrated pest management (IPM), precision farming), site-specific adaptation is extremely important. With adaptation of RMPs outlined in Table 4, SOC can accumulate in soils because tillage-induced soil disturbances are eliminated, erosion losses are minimized, and large quantities of root and above-ground biomass are returned to the soil. These practices conserve soil water, improve soil quality and enhance the SOC pool. Incorporation of SOC into the sub-soil can increase its mean residence time (MRT). Converting agricultural land to a more natural or restorative land use essentially reverses some of the effects responsible for SOC losses that occurred upon conversion of natural to managed ecosystems. Applying ecological concepts to the management of natural resources (e.g., nutrient cycling, energy budget, soil engineering by macro invertebrates and enhanced soil biodiversity) may be an important factor to improving soil quality and SOC sequestration (Lavelle, 2000). Adoption of RMPs build up SOC by increasing the input of C through crop residues and biosolids (Paustian *et al*., 1997). Sequestered SOC with a relatively long turnover time (Swift, 2001), is returned to the recalcitrant soil pool, thus decreasing the rate of accumulation of atmospheric CO_2 concentration. The SOC concentration in the surface layer usually increases with increasing inputs of biosolids (Graham *et al*., 2002) although the specific empirical relation depends on soil moisture and temperature regimes, nutrient availability (N, P, K, S), texture and climate. In addition to the quantity of input, quality of biomass can also be important in determining the SOC pool. Biodiversity is also important to soil C dynamics. It is defined as ‘‘the variability among living organisms from all sources, including terrestrial, marine ecosystems and other aquatic ecosystems and ecological complexes of which they are part; this includes diversity within species, between species and for ecosystems. It is possible to distinguish between genetic diversity, organism species diversity, ecological diversity and functional diversity’’ (UNCB, 1992). A healthy soil is teeming with life, and comprises highly diverse soil biota. The latter comprises representatives of all groups of micro-organisms and fungi, green algae and cyanobacteria, and of all but a few exclusively marine phyla of animals (Lee, 1991). With reference to SOC pool and its dynamics, important members of soil biota include earthworms, termites, ants, some insect larvae and few others of the large soil animals that comprise ‘‘bioturbation’’ (Lavalle, 1997). Activity of these animals have a strong influence on soil physical and biological qualities especially with regards to soil structure, porosity, aeration, water infiltration, drainage, nutrient/ elemental cycling and organic matter pool and fluxes. Soil biodiversity has a positive impact on the SOC pool. All other factors being equal, ecosystems with high biodiversity sequester more C in soil and biota than those with reduced biodiversity. In managed ecosystems, soil biodiversity is likely to increase with conversion to conservation tillage, replacement of toxic chemicals with viable alternatives, substitution of monoculture with mixed crop rotations and complex/diverse systems, restoration of degraded soils and ecosystems, and conversion of crop or pasture land to a restorative land use (e.g., set aside land or Conservation Reserve Program [CRP]). The data from Yurimaguas, Peru show that application of chemicals in high input systems decrease population density of soil fauna and biomass. In comparison with cropland, biomass C is also more in pastures, fallow and forest ecosystems (Lavalle and Pashanasi, 1989). Soil biodiversity has a favorable impact on soil structure. Activity of soil biota produces organic polymers, which form and stabilize aggregates. Fungal hyphae and polysaccharides of microbial origin play an important role in soil aggregation. Earthworms and termites also positively impact soil structure, and enhance aggregation (Lal and Akinremi, 1983)

CHAPTER 3

3.0 MATERIALS AND METHODS

Four land-use systems were identified in the Walewale Forest District in the northern region of Ghana. These are the natural forest, teak plantation, fallow land and cultivated land (farm). The fallow land and farm land were identified in the Wulugu township (Page 25) whiles the natural forest and the teak plantation were selected from the Gambaga Scarp Forest Reserve (Page 26). The research was done between October 2012 to February 2013.

Temporary Sampling Plots (TSP_S) of size 25m by 25m, giving rise to an area of 0.0625ha were created in the various land-use systems in the selected sites in forest districts. The TSPs were created to capture the variability of the particular stand characteristics. All trees in the various land-use systems that were above two meters were inventoried and stem diameter at breast height of 1.3m measured, a standard point of measuring tree diameter (Adu Bredu *et al*., 2008).

In addition, four sub-plots (quadrats) of size 1.0m by 1.0m were created in all the TSPs. All herbaceous and woody plants in the sub-plots were destructively sampled and litter collected. Fresh weights were determined immediately using electronic (digital) mass measure, and samples of the plant and litter collected for dry weight determination, by oven drying to constant weight. Sub-samples were also reserved for carbon content analysis.

In the sub-humid regions carbon accumulates to greater depth in the soil profile, however in the semi-arid regions C is mostly contained in a relatively shallow depth of 15 to 25cm (Tiessen *et al*., 1998). Consequently, soil samples were collected from the soil depth of 0 to 20 cm and 20 to 40 cm within the quadrates, air dried and sieved through 2.0 mm mesh, and texture and soil organic C content determined. Soil organic C was determined in the laboratory by Walkley and

Black (1934) method. In this method carbon is oxidized by dichromate ion and the excess dichromate ion is then back titrated with ferrous ion. The reagents used were: potassium dichromate ($K_2Cr_2O_7$), ferrous ammonium sulphate ($Fe(NH_4)_2(SO4)_2.6H_2O$, sulpharic acid (H_2SO_4), phosphoric acid (H_3PO_4), and sodium fluoride (NaF). Particle size distribution was measured using Bouyoucos Hydrometer. Accompanying bulk density samples were also collected from the same soil depths, allowing carbon contents to be expressed on an area basis and as well as to assess the vertical distribution of soil C stock. The undisturbed soil sample was used for bulk density determination. The bulk density was determined from oven-dried core samples at 105^0C for 24 hours. Soil C per hectare was calculated from the organic C content and the bulk density. The diameter at breast height (1.3m aboveground) measurements was used to estimate aboveground phytomass of individual trees in the stand. Aboveground phytomass, W, of the individual trees was estimated from stem diameter at breast height, d, of 1.3 m (which is standard forestry menstruation technique) by employing various equations.

The equation for teak (Asomaning, 2000) is

$Wt=0.066\ dt^{2.565}$, where: Wt is total tree phytomass of teak and dt is diameter of teak. The value 2.565 is the allometric relation between tree height and diameter whilst 0.066 is the gradient of the line.

For natural forest in the savannah, the revised equation of Brown et al (1989) for dry zones with rainfall greater than 900mm per annum (cf Brown 1997) was used;

$Wn=Exp\ (-1.996+2.32*Ln(dn))$, where Wn is aboveground phytomass of trees in the natural forest and dn is diameter of tree in the natural forest. The value -1.996 is the intercept on the Wn axis whilst 2.32 is the gradient of the curve.

Below ground biomass, W_b, was estimated from the knowledge of the aboveground biomass based on the revised equation of Cairns *et al*., (1997) for tropical forest (cf. Pearson *et al*., 2005) as;

W_b =Exp (-1.0587 + 0.8836*Ln (Wn)), where Wb is belowground phytomass of trees in the natural forest. The intercept on the Wn axis (thus when Wn=0) is -1.0587 and the gradient of the curve is 0.8836.

Stand tree biomass was calculated from the summation of individual tree phytomass per plot, whereas the herbaceous and litter biomass was calculated from data obtained from the quadrates. Carbon content was analysed for 10 wood samples, 10 herbaceous samples and 10 litter samples drawn from the areas under study in order to minimize cost of laboratory analysis. The carbon content values were used to convert the biomass of the various plant functional types to carbon equivalent. The carbon content of the wood was used for the trees.

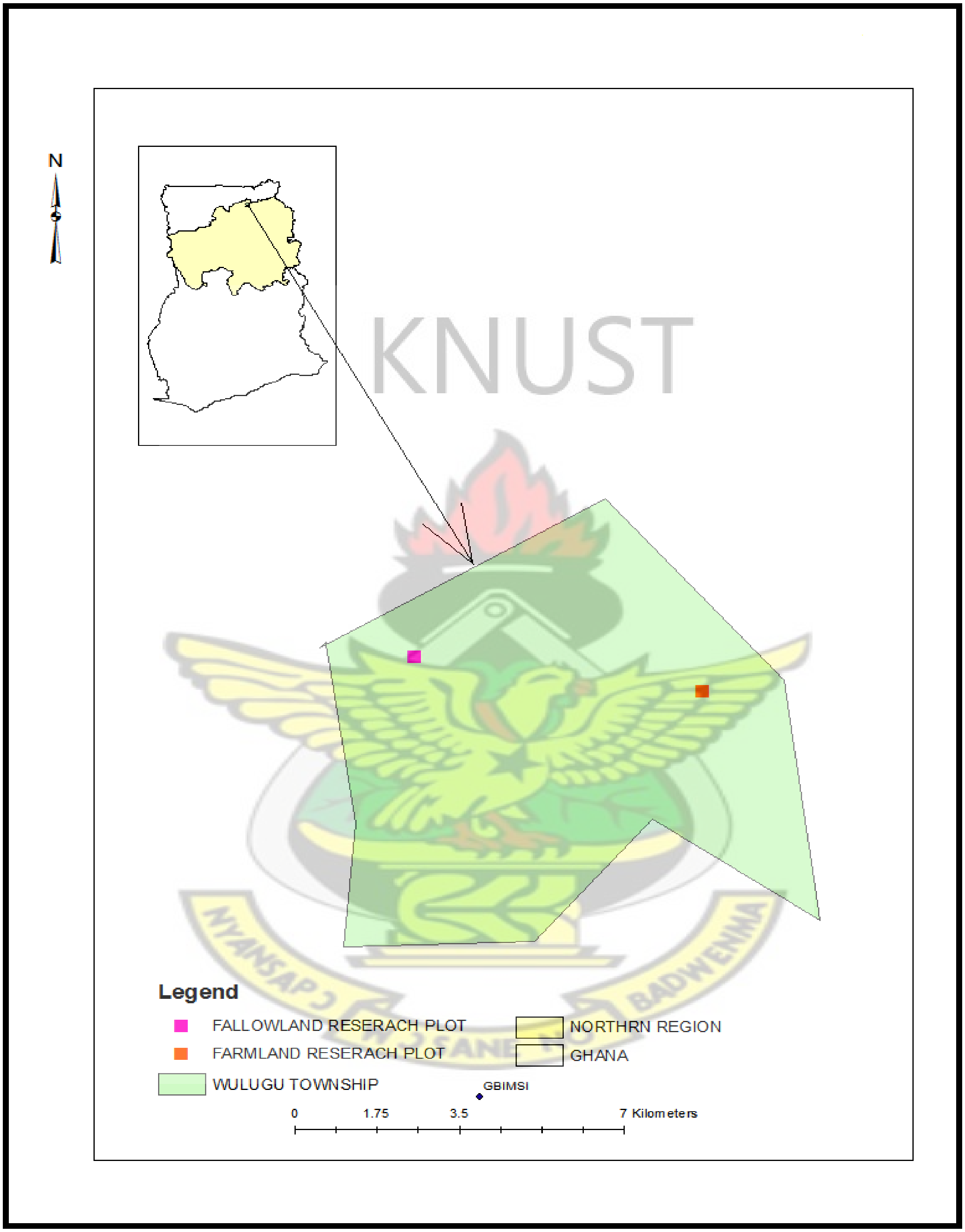

Fig. 2 Map showing the locations of research plots in Wulugu area.

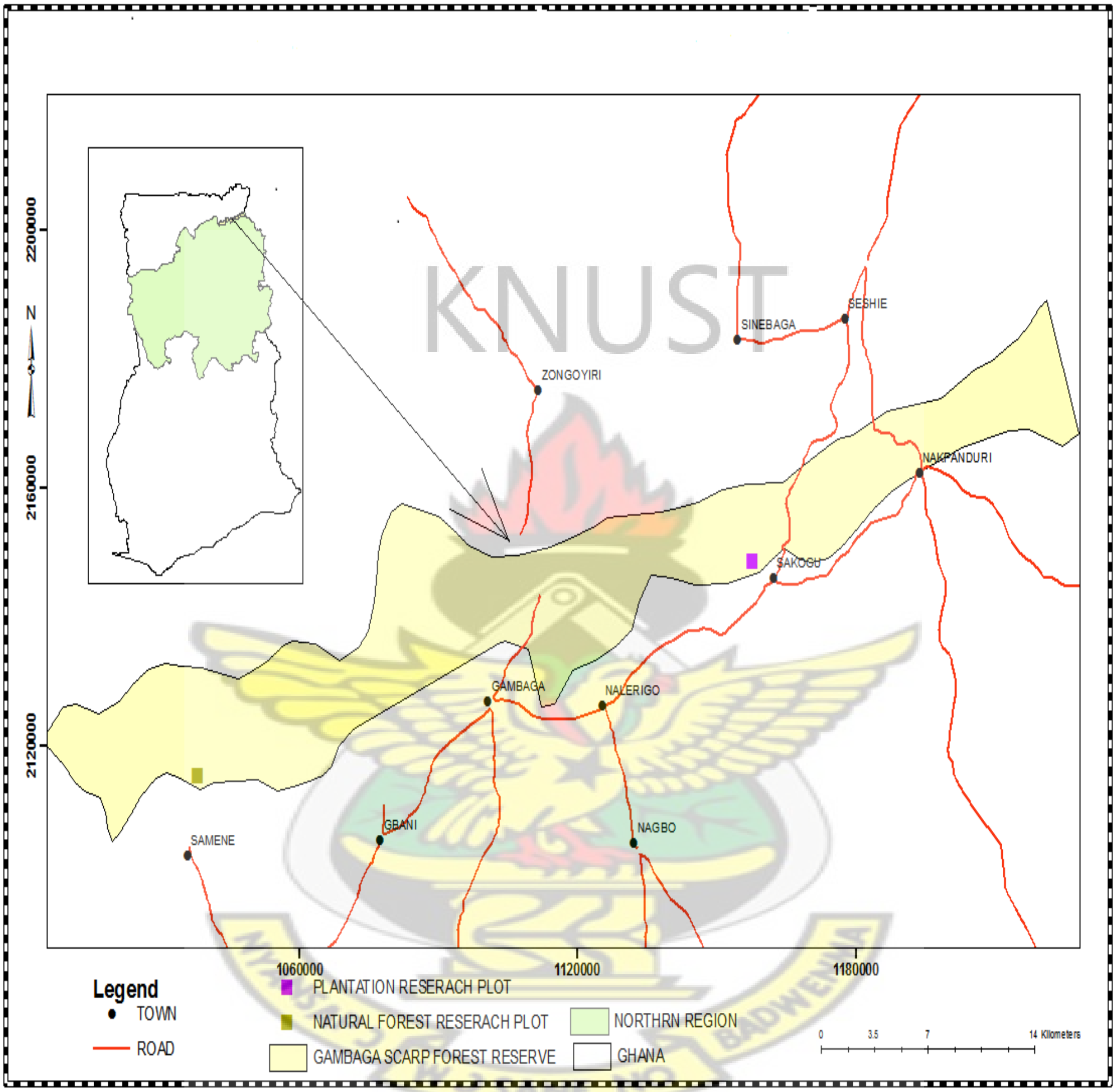

Fig. 3. Map showing location of research plots in Gambaga Scarp East Forest Reserve.

3.1 STATISTICAL ANALYSIS

The results were analysed using Analysis of Variance (ANOVA) and mean difference was located using Post Hoc Least Square Difference (LSD) in Statistical Package for Social Scientist (SPSS)

Plate 1 Teak plantation in the Gambaga Scarp Forest Reserve.

Plate 2 Natural Forest in the Gambaga Scarp Forest Reserve

4.0 RESULTS

4.1 CARBON CONTENT

The average carbon content of litter, herbs and wood was in increasing order of 30.2% ±3.906 (SD), 35.01%±4.095 (SD) and 45.43%±2.110 (SD), respectively (Table. 4). There was significant difference in carbon content among the various plant functional type (P<0.05) as seen in Table 5. Post Hoc Least Square Difference (LSD) test revealed that there was statistically significant mean difference in carbon content among the various plant functional types, thus wood versus herb, wood versus litter and herb versus litter (Table 6). Figure 4 shows graph of mean plot of carbon content among the various plant functional types.

TABLE 4. CARBON CONTENT OF PLANT FUNCTIONAL TYPE

Sample	Wood(%)	Herbs(%)	Litter(%)
1	43.66	28.68	30.66
2	44.68	29.98	33.7
3	46.7	40.35	35.26
4	47.8	36.2	26
5	45.78	41.34	28.2
6	42.3	33.79	25.14
7	42.8	36.1	25.2
8	47.06	34.05	30.3
9	48.53	36.96	32.96
10	45.01	32.66	34.6
AVR	45.43	35.01	30.20

Table 5. Analysis of Variance for carbon content

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	139.2114	9	15.46794	1.492218	0.224244	2.456281
Columns	1212.255	2	606.1277	58.47418	1.34E-08	3.554557
Error	186.5832	18	10.36573			
Total	1538.05	29				

Table 6. Carbon content (%)
Post Hoc LSD

(I) Plant Functional Type	(J) Plant Functional Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Wood	Herb	10.42100*	1.55348	.000	7.2335	13.6085
	Litter	15.23000*	1.55348	.000	12.0425	18.4175
Herb	Wood	-10.42100*	1.55348	.000	-13.6085	-7.2335
	Litter	4.80900*	1.55348	.005	1.6215	7.9965
Litter	Wood	-15.23000*	1.55348	.000	-18.4175	-12.0425
	Herb	-4.80900*	1.55348	.005	-7.9965	-1.6215

*. The mean difference is significant at the 0.05 level.

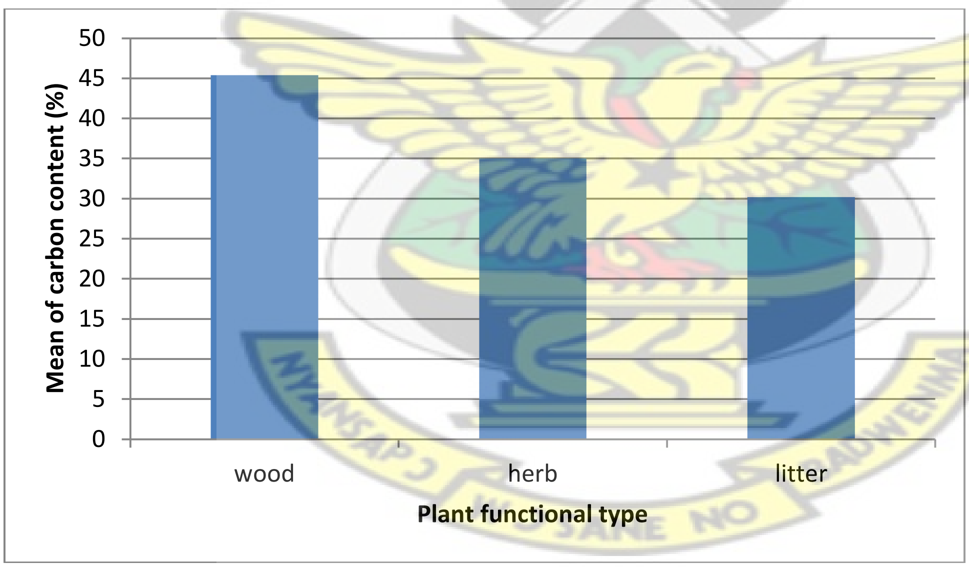

Figure 4. Mean plot of carbon content of plant functional type

4.2 SOIL CARBON

The total soil carbon stock (0-40cm) was 36.35 ±1.964, 34.02±2.196, 30.78±0.902 and 22.90±0.1826 Mg C ha^{-1} for natural forest, fallow land, cultivated land and teak stand respectively (Table 7).

TABLE 7. TOTAL SOIL CARBON CONTENT OF THE VARIOUS LAND-USE TYPES

Sample	Nat. For.	Fallow land	Cultivated Land	Teak Stand
1	33.81	37.10	30.33	23.00
2	35.91	34.00	30.60	23.10
3	37.33	32.10	30.10	22.70
4	38.34	34.02	32.10	22.80
STDV	1.964	2.196	0.902	0.1862

At $P<0.05$, there was significant difference in total soil carbon among the various land-use systems (Table 8). The mean difference between natural forest versus cultivated land, natural forest versus teak plantation, fallow land versus teak and cultivated land versus teak plantation was found to be statistically significant (Table 10).

Table 8. Analysis of variance(summaries) for total soil carbon

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	124.24	31.06	36.51353
Row 2	4	123.61	30.9025	31.88003
Row 3	4	122.23	30.5575	36.73189
Row 4	4	126.12	31.53	41.5788
Natural For.	4	145.39	36.3475	3.855225
Fallow Land	4	136.08	34.02	4.824267
Cultivated L.	4	123.13	30.7825	0.813225
Teak stand	4	91.6	22.9	0.033333

Table 9. Analysis of variance for total soil carbon.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1.95675	3	0.65225	0.220509	0.879759	3.862548
Columns	413.4914	3	137.8305	46.59688	8.3E-06	3.862548
Error	26.6214	9	2.957933			
Total	442.0695	15				

Table 10.Total soil carbon content

LSD

(I) Land-use types	(J) Land-use types	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Natural forest	Fallow land	2.04250	1.05975	.078	-.2665	4.3515
	Cultivated land	5.56500*	1.05975	.000	3.2560	7.8740
	Teak stand	13.44750*	1.05975	.000	11.1385	15.7565
Fallow land	Natural forest	-2.04250	1.05975	.078	-4.3515	.2665
	Cultivated land	3.52250*	1.05975	.006	1.2135	5.8315
	Teak stand	11.40500*	1.05975	.000	9.0960	13.7140
Cultivated land	Natural forest	-5.56500*	1.05975	.000	-7.8740	-3.2560
	Fallow land	-3.52250*	1.05975	.006	-5.8315	-1.2135
	Teak stand	7.88250*	1.05975	.000	5.5735	10.1915
Teak stand	Natural forest	-13.44750*	1.05975	.000	-15.7565	-11.1385
	Fallow land	-11.40500*	1.05975	.000	-13.7140	-9.0960
	Cultivated land	-7.88250*	1.05975	.000	-10.1915	-5.5735

*. The mean difference is significant at the 0.05 level.

4.3 VERTICAL DISTRIBUTION OF SOIL CARBON

The vertical distribution of carbon in soil was also analyzed. For the 0-20 cm layer, the fallow land had the highest soil carbon stock of 20.87 Mg C ha^{-1}. Natural forest, cultivated land and teak stand had soil carbon stock of 20.18, 19.59 and 16.26 Mg C ha^{-1} respectively (Table 11).

Table 11. VERTICAL DISTRIBUTION OF SOIL CARBON (Mg C ha1)

Land-use	Soil C (Mg C ha^{-1})	
	0-20cm	20-40cm
Natural Forest	20.19	16.16
Fallow Land	22.87	11.15
Cultivated Land	19.59	11.19
Teak Stand	16.26	6.64

For the 20-40cm layer, the highest carbon stock was recorded in the natural forest with 16.16 Mg C ha^{-1} whiles cultivated land, fallow land and teak stand had 11.19, 11.15 and 6.64 Mg C ha^{-1} , respectively.

4.4 BIOMASS

The biomass of the trees were determined within the 25m x 25m plot and presented in table 12 below whilst that of the herbs and litter was determined within the 1mx1m quadrats and presented in table 14 and 17 respectively. The biomass was then converted to carbon equivalent and express on area basis (per hectare) and presented in Table 12.

4.5 TREE BIOMASS

Table 12. Tree biomass per plot (Kg)

Plot	Natural For.	Cultivated Land	Teak stand	Fallow land
1	5109.8892	95.8726	5061.2735	87.2227
2	3850.3532	52.7085	4102.6147	186.5521

Table 13. Analysis of variance for tree biomass.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	584296.4	1	584296.4	2.59958	0.205286	10.12796
Columns	39183390	3	13061130	58.10998	0.003717	9.276628
Error	674297.1	3	224765.7			
Total	40441983	7				

As observed in Table 13 there was significant difference in tree biomass among the different land-use systems (P<0.05).

4.6 HERBACEOUS BIOMASS

Table 14. Mass of herbs (Kg)

Plot	**Natural forest**	**Cultivated land**	**Teak stand**	**Fallow land**
1	0.6512	0.4188	0.3998	1.2947
2	0.6789	0.4499	0.4212	1.0988
3	0.6211	0.4420	0.4110	1.3810
4	0.6471	0.3854	0.3712	0.9780

Table 15. Analysis of variance for herbaceous biomass

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.032959	3	0.010986	1.346656	0.31963	3.862548
Columns	1.607935	3	0.535978	65.69728	1.93E-06	3.862548
Error	0.073425	9	0.008158			
Total	1.714319	15				

There was significant difference in herbaceous biomass among the the various land-use systems (P<0.05).

LSD test further revealed that the mean difference between natural forest and cultivated land and teak plantation was not statistically significant at 0.05 alpha (Table 16). The mean difference between cultivated land and teak plantation was not also significant.

However, the mean difference between the natural forest and fallow land, cultivated land and fallow land, and teak plantation and fallow land was statistically significant (Table 16).

Table 16. Mass of herbs(kg)

LSD

(I) Different land use types	(J) Different land use types	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Natural forest	cultivated land	.22555*	.06689	.006	.0798	.3713
	teak plantation	.22555*	.06689	.006	.0798	.3713
	fallow land	-.53855*	.06689	.000	-.6843	-.3928
cultivated land	Natural forest	-.22555*	.06689	.006	-.3713	-.0798
	teak plantation	.00000	.06689	1.000	-.1457	.1457
	fallow land	-.76410*	.06689	.000	-.9098	-.6184
teak plantation	Natural forest	-.22555*	.06689	.006	-.3713	-.0798
	cultivated land	.00000	.06689	1.000	-.1457	.1457
	fallow land	-.76410*	.06689	.000	-.9098	-.6184
fallow land	Natural forest	.53855*	.06689	.000	.3928	.6843
	cultivated land	.76410*	.06689	.000	.6184	.9098
	teak plantation	.76410*	.06689	.000	.6184	.9098

*. The mean difference is significant at the 0.05 level.

4.7 LITTER BIOMASS

Table 17. Litter biomass (Kg)

Sample	Natural forest	Cultivated land	Teak stand	Fallow land
1	0.5673	0.2356	0.2612	0.3078
2	0.6012	0.2759	0.2712	0.2960
3	0.5901	0.2598	0.2478	0.3297
4	0.6111	0.2834	0.2354	0.3394

Table 18 Analysis of variance for litter biomass

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.001288	3	0.000429	1.264233	0.343784	3.862548
Columns	0.304884	3	0.101628	299.2782	2.49E-09	3.862548
Error	0.003056	9	0.00034			
Total	0.309228	15				

There was significant difference in the biomass of litter of the various land-use types (P<0.05) as observed in Table 18.

Post Hoc LSD test revealed that except the mean difference between cultivate land and teak plantation, there was significant difference in the means among the other land-use, that is natural forest versus cultivated land, natural forest versus teak, natural forest versus fallow land, cultivate land versus fallow and teak versus fallow land (Table 19). Figure 5 shows the mean plot of biomass of the various land-use types.

Table 19. Mass of litter (Kg)

LSD

(I) Different land use types	(J) Different land use types	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Natural forest	cultivated land	.3287500*	.0134147	.000	.299522	.357978
	Teak plantation	.3385250*	.0134147	.000	.309297	.367753
	Fallow land	.2742000*	.0134147	.000	.244972	.303428
cultivated land	Natural forest	-.3287500*	.0134147	.000	-.357978	-.299522
	Teak plantation	.0097750	.0134147	.480	-.019453	.039003
	Fallow land	-.0545500*	.0134147	.002	-.083778	-.025322
Teak plantation	Natural forest	-.3385250*	.0134147	.000	-.367753	-.309297
	cultivated land	-.0097750	.0134147	.480	-.039003	.019453
	Fallow land	-.0643250*	.0134147	.000	-.093553	-.035097
Fallow land	Natural forest	-.2742000*	.0134147	.000	-.303428	-.244972
	cultivated land	.0545500*	.0134147	.002	.025322	.083778
	Teak plantation	.0643250*	.0134147	.000	.035097	.093553

*. The mean difference is significant at the 0.05 level.

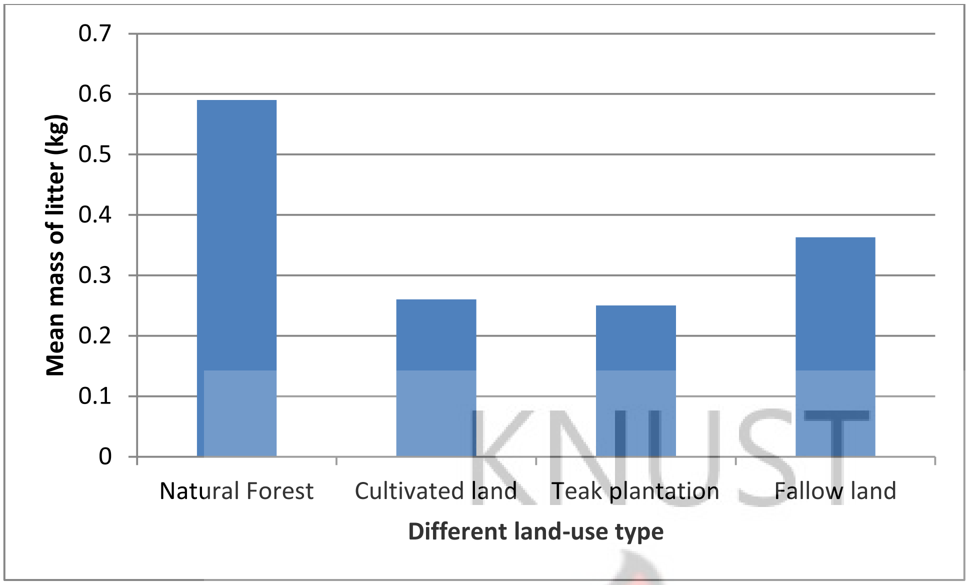

Figure 5. Mean of mass of litter of the various land-use types.

Table 20. BIOMASS CARBON STOCK (Mg C ha^{-1})

Land-use	Trees	Herbs	Litter
Natural Forest	26.052	2.900	3.2900
Cultivated Land	0.864	1.900	1.0200
Teak Stand	26.644	1.795	0.9815
Fallow Land	1.592	5.324	1.2301

The tree carbon stock under the various land-use systems was in order of teak plantation, natural forest, fallow land and cultivated land (Fig. 6).

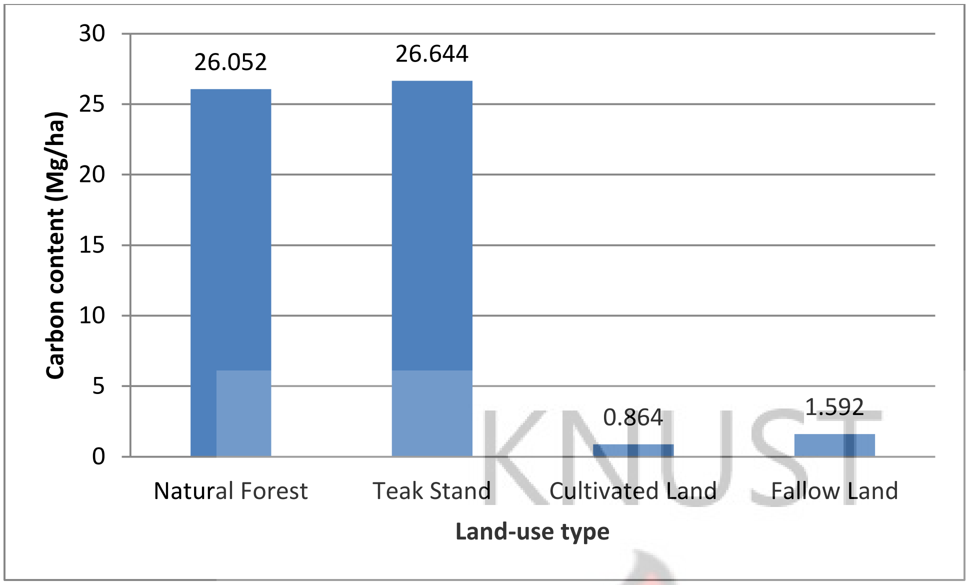

Fig.6 Tree Carbon Stock (Mg/ha)

In terms of herbaceous carbon, the fallow land use system had the highest carbon stock of 5.324 Mg C ha^{-1}, followed by natural forest land-use which had 1.900 Mg C ha^{-1}. Cultivated land and teak stand had similar carbon stock of 1.900 and 1.795 Mg C ha^{-1} respectively (Fig.7).

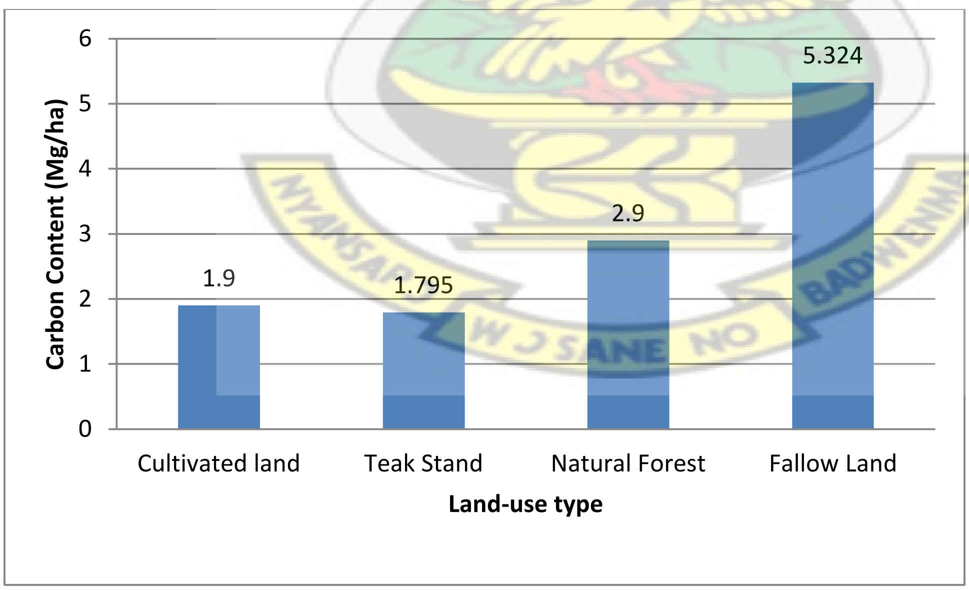

Fig. 7. Herbaceous Carbon Stock (Mg/ha)

The litter carbon content increased from natural forest, fallow land, cultivated land and teak stand with carbon content values of 3.2900, 1.2301, 1.0200 and 0.9815 Mg C ha^{-1} respectively (Fig. 8).

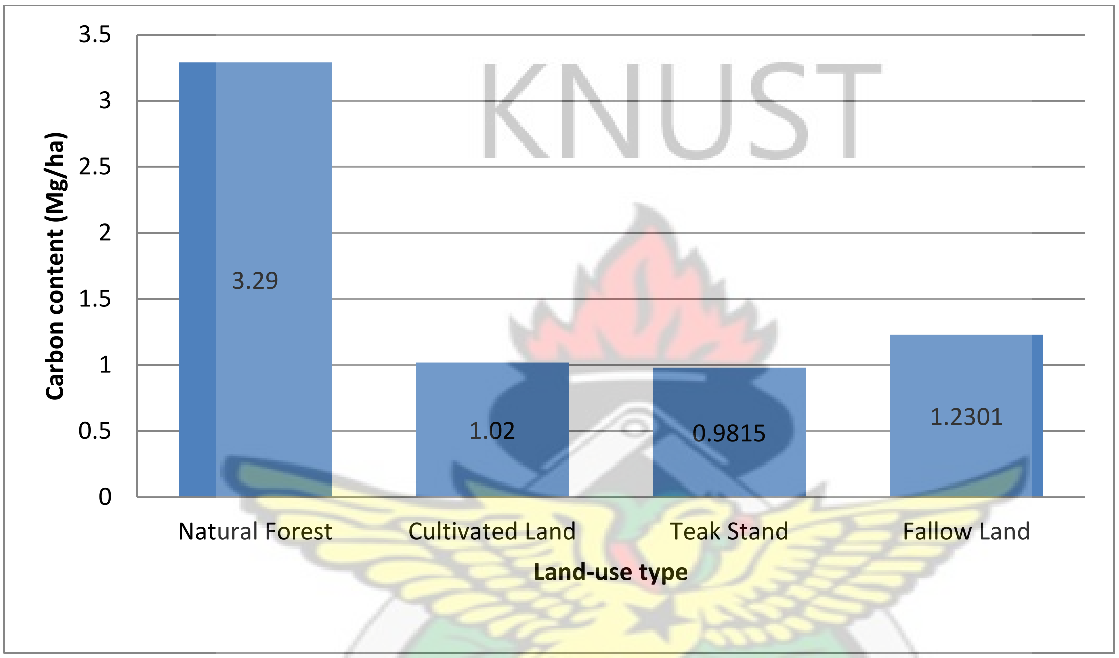

Fig. 8 Litter Carbon Stock (Mg/ha)

Table. 21 SUMMARY OF COMPONENTS OF CARBON STOCK (Mg C ha^{-1})

Land-use	Trees	Herbs	Litter	Soil	Total Carbon
Natural Forest	26.052	2.900	3.2900	36.35	68.592
Cultivated Land	0.864	1.900	1.0200	30.78	34.564
Teak Stand	26.644	1.795	0.9815	22.90	52.3205
Fallow Land	1.592	5.324	1.2301	34.02	42.1661

The natural forest had the highest total carbon stock of 68.592 Mg C ha^{-1} followed by teak stand which has 52.3205 Mg C ha^{-1}. Fallow land and cultivated land had 42.1661 and 34.564 Mg Cha^{-1} respectively (Table 21).

4.8 CONTRIBUTION OF SOIL CARBON TO TOTAL CARBON STOCK

On average, contribution of soil carbon stock to total system carbon stock decreased in the order cultivated land, fallow land, natural forest and teak stand (Fig. 9)

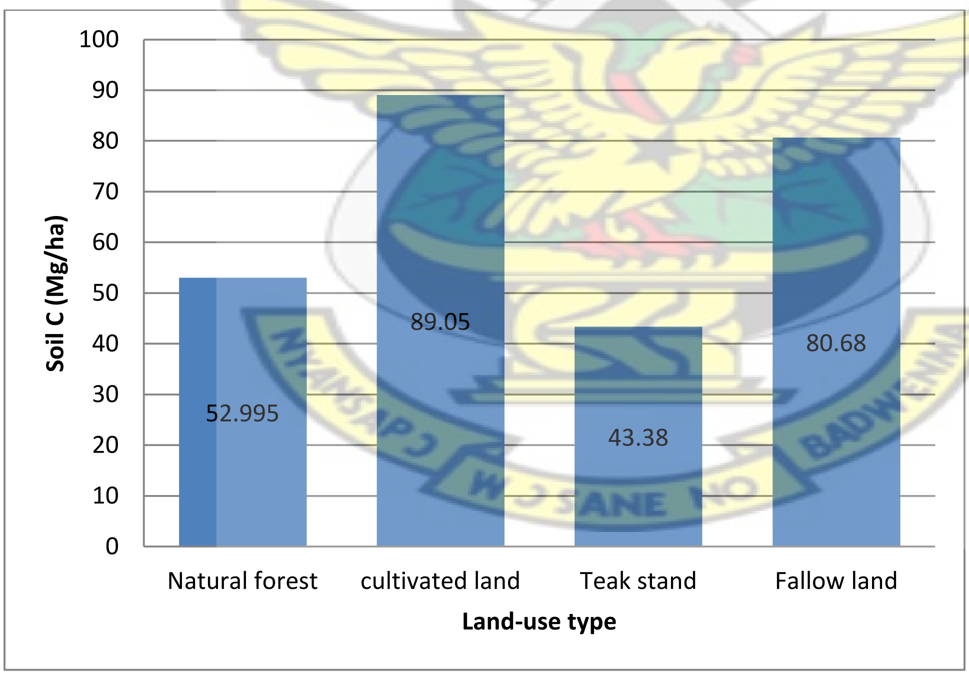

Fig. 9 Contribution of soil carbon to total soil carbon stock (Mg/ha)

4.9 CARBON EMMISSION/GAIN FACTORS

Using the natural forest as a bench-mark, the carbon loss from converting the natural forest to other land-uses was in increasing order from teak stand, fallow land and cultivated land (Table. 22). For instance, the difference in total system carbon between natural forest and teak stand is 16.2715 Mg C ha^{-1} implying that when a one hectare of natural forest is converted to one hectare of teak stand, the carbon loss is 16.2715 Mg C ha^{-1} and when express as a percentage of the carbon stock per hectare in the natural forest (bench-mark), it is about 23.722% (Table 22). Following the same procedure as illustrated above, and this time using teak stand as the bench mark, the carbon gain when converting fallow land and cultivated land to teak stand are 10.1544 and 17.7565 Mg C ha^{-1} representing 19.41% and 33.94% respectively (Table. 23).

Table 22. CONVERSION OF NATURAL FOREST TO OTHER LAND-USE SYSTEMS (EMMISSION FACTORS)

Land-use	Fallow land	Cultivated land	Teak stand	Natural forest
Mean C (Mg ha^{-1})	42.1661	34.564	52.3205	68.592
C Loss (Mg ha^{-1})	26.4259	34.028	16.2715	
% C Loss	38.53	49.61	23.722	

Table 23. CONVERSION OF OTHER LAND-USES TO TEAK (EMISSION/REMOVAL FACTORS)

Land-use	Fallow land	Cultivated land	Teak stand
Mean C (Mg ha^{-1})	42.1661	34.564	52.3205
C Gain (Mg ha^{-1})	10.1544	17.7565	
% C Gain	19.41	33.94	

5.0 DISCUSSION

5.1 CARBON CONTENT

The carbon content of litter, herb and wood were in increasing order 30.2%, 35.01% and 45.43%, respectively. There was significant difference in the carbon content among the various plant functional type ($p<0.05$). This result is comparable to results by Adu-Bredu *et al.* (2008) where the carbon content of litter was found to be 29.98%, 37.46% and 47.48%, respectively. It is common to regard carbon content as 50% of wood but Pearson *et al*. (2005) as quoted by Adu-Bredu *et al.* (2008) pointed out that local data should be preferred if available and that the Clean Development Mechanism (CDM) Executive Board may recommend local measurement of carbon content in the future. These results together with that of Adu-Bredu *et al.* (2008) show that the carbon content of the various plant functional type may be different and that the 50% carbon content should be used with caution.

5.2 SOIL CARBON

The soil carbon in the natural forest was highest followed by the fallow land, cultivated land and teak stand in that order. This result is fairly the same as that of Adu-Bredu *et al*. (2008) in the savanna areas except that in that research the highest soil carbon was in the fallow land-use system. The total soil carbon stock (0-40cm) was 36.35, 34.02, 30.78 and 22.90 Mg C ha^{-1} for natural forest, fallow land, cultivated land and teak stand respectively. The low carbon value of teak stand was also recorded by Adu-Bredu *et al*. (2008) in the savanna. Adu-Bredu *et al*. (2008) attributed this to the fact that teak leaves decomposed slowly and the intensity of the annual bush fires that sweep through the teak stands burn almost all the litter on the forest floor.

Bruijnzeel (1998) pointed out that loss of soil carbon is affected by fire intensity and ambient weather conditions, as this prevents the incorporation of the litter into the soil through decomposition.

The range of 16.26 to 22.87 Mg C ha^{-1} for the top 20cm soil depth given in this study for the various land-use systems (Tab. 7) is comparable to the average value of 25 Mg C ha^{-1} given by Tiessen et al. (1998) for the semi-arid regions, as well as the value of between 11.7 and 41.3 Mg C ha^{-1} reported by Manley *et al*. (2004b) for various land-use systems with varying crop intensities for the top 20cm depth for the savannah of west Africa.

Adu-Bredu *et al*. (2008) recorded the lowest carbon stock in the cultivated land-use type in both the Dry semi-deciduous forest and the moist evergreen forest but the highest was in the natural forest for the moist evergreen and in the fallow for the dry semi-deciduous forest. But in this research the highest soil carbon was in the natural forest and the least was the teak plantation. The differences could be as a result of the differences in climatic conditions especially rainfall which is the chief determinant of soil carbon accumulation and decomposition.

Allocation of carbon to the 0-20cm soil depth, with respect to the total (0-40cm) was 55.54%, 67.23%, 63.65% and 71.00% for natural forest, fallow land, cultivated land and teak stand respectively. This result agrees to assertion by Vagen *et al*. (2005) that the highest soil carbon stock is concentrated in the top 20cm soil depth.

5.3 BIOMASS CARBON

The highest tree carbon was from the natural forest which was 26.052 Mg C ha^{-1}whiles the cultivated land-use had the lowest of about 0.864 Mg C ha^{-1} which is comparable to Adu-Dredu *et al*. (2008) where there was no tree carbon content recorded for cultivated land-use. Adu-Bredu *et al*. (2008) observed that absence of tree carbon stock in the cultivated land-use system was due to the harvesting of trees as fuel wood in the cultivated land-use system. The low carbon recorded in this study could also be due to the removal of trees to allow for direct light penetration to food crops. The carbon recorded under trees in the natural forest in this study is somewhat different from the value of 15.92 Mg C ha^{-1} recorded for savannah by Adu-Bredu *et al*. (2008). The difference could be that Adu-Bredu *et al*. research for the savannah was conducted around Bawku which is sahel savannah but this research was conducted around Walewale which is sudan savannah. Therefore, one has to use with caution carbon data from the ecological zones as there could be large variations within the same ecological zones. The value for natural forest in this study is also somewhat higher than that of 10.0 Mg C ha^{-1} given by Brown (1997) for the savannah.

Adu-Bredu *et al*. (2008) recorded the highest tree carbon in the natural forest and the least in the cultivated land for the dry semi-deciduous forest zone and highest tree carbon was recorded in the natural forest and the least in the cultivated land for the moist evergreen, results which have a similar trend to this study.

Tree carbon stock under the various land-use systems among the ecological zones was recorded by Adu-Bredu *et al*. (2008) in the increasing order of savanna, dry semi-deciduous and moist evergreen. This according to Adu-Bredu *et al*., reflects the climatic gradient of the various ecological zones.

The fallow land had the highest herbaceous carbon stock followed by the natural forest with teak stand having the lowest carbon stock. This trend can be attributed to the fact that the canopy in the natural forest and fallow land is more open in the savannah and this allows light to penetrate to the forest floor resulting in the presence of more abundant herbs. The low carbon stock in the teak stand can be attributed to the fact that bush fire annually runs through the stand due to the slow degradation of the leaves and this does not allow the development of herbs.

Adu-Bredu *et al*. (2008) recorded the highest litter carbon in the fallow land and the least litter carbon in the cultivated land for dry semi-deciduous forest type, a trend which is slightly different from this study. In this study and as explained above, the least litter carbon was in teak plantation and not in the cultivated land by Adu-Bredu *et al*. (2008). The differences in the litter carbon could be as a result of the timing of the research, as litter accumulation may vary for different period in a year.

For the moist evergreen, Adu-Bredu *et al*. (2008) recorded the highest litter carbon in the fallow land followed by natural forest and the least from cultivated land. The relatively high litter carbon content of teak in the moist evergreen recorded by Adu-Bredu *et al*. (2008) and which is different from the litter carbon of this research can be attributed to the fact that the teak plantation in the moist evergreen forest zone hardly get burnt because of the high moisture content in the vegetation for long period in the year (it receives the highest amount of rainfall in the country) unlike the teak plantations in the savanna and dry semi-deciduous zones which experiences annual wildfires.

The highest litter carbon stock was found in the natural forest followed by fallow land with teak stand having the least carbon stock (Fig. 8).

5.4 TOTAL SYSTEM CARBON STOCK

On average, contribution of soil carbon stock to total system carbon stock decreased in the order cultivated land, fallow land, natural forest and teak stand (Table. 10)

The presence of high soil carbon stock in the cultivated land-use implies that soil carbon is critical to cultivated land-use and therefore Adu-Bredu *et al*. (2008) observed that agronomic practices that preserve soil carbon must be practiced. Lal *et al.* 1999; FAO, 2001 as quoted in Adu-Bredu *et al*. (2008) observed that carbon stored in organic matter is important in improving soil properties such as nutrient supply, moisture retention and as a consequence, increase land yield and productivity and crop yields. The natural forest even though exhibited a very high soil carbon compared other land-use systems, the biomass carbon stock was far greater.

5.5 CARBON EMMISSION/GAIN FACTORS

If one is to convert a natural forest of one hectare (like the size of a football pitch) to a teak plantation in the savanna areas (Tab. 10), the carbon loss is about 16.2715 Mg (i.e. about 23.722% loss). If one is to convert a hectare of natural forest into a fallow land (which might be impractical) the carbon loss will be about 26.4259 Mg (i.e. about 38.53% loss). Lastly if one is converting a hectare of natural forest into cultivated land the carbon loss will be about 34.028 Mg (i.e. about 46.61% loss). So if one is faced with a difficult decision to convert natural forest to other land-use, then it is environmentally safer to convert natural forest to teak plantation than fallow and cultivated land because the carbon loss is smaller compared to conversion to other land-uses.

In terms of carbon sequestration, it makes sense to convert a cultivated land to teak plantation than to convert a fallow land to teak plantation. In converting a fallow land to teak plantation, the carbon gain per hectare is 10.1544 Mg representing 19.41% gain but when converting a cultivated land to a teak plantation, the carbon gain per hectare is 17.7565 Mg representing

33.94% gain (Table.11). Therefore in carbon emission trading, this consideration must be must fully considered.

6.0 CONCLUSION AND RECCOMMENDATION

It has been shown that high proportion of carbon is concentrated in the top 20cm of soil. Land-use system also had an influence on the total system carbon and is very critical to cultivated land-use system. It is also shown that conversion of natural forest to other land-use leads to reduction in biomass carbon and subsequently gradual depletion of soil organic carbon.

The scope of this study will however need to be expanded to cover zones in the savannah areas especially the sahel and the guinea savannah areas. This will allow results to be related to environmental variables to enable predictive models of land-use change and its consequences to be carried.

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