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Soil carbon store and storage potential as affected by human activities in the natural forest-savanna zone of Northern Ghana

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Anthropogenic activities have the potential to thwart efforts towards enhancing the full carbon (C) sink potential of savannas in the context of mitigating the effects of global warming. The understanding of the induced effects of human pressures on the carbon budget of forest-savanna ecosystems is therefore a valuable tool to better evaluate and predict the current and future effects of human activities on the potential of these forests to sequester carbon in the context of the fight against the global warming. In line with this, the objective of this study was to compare the soil organic carbon stock changes between three well protected forests and three neighbouring unprotected forests which are prone to human pressures (except farming and settlements) in the natural forest-savanna of Northern Ghana. Three study zones, namely Wungu, Serigu and Mognori were used for the study. For each forest type 30 m × 30 m random plots and 1 m × 1 m random subplots were used to generate data for the comparative analysis. A total of 160 random soil samples (0 to 50 cm depth), 96 random samples of aboveground live biomass, and the same number of litter and root biomass samples were collected in both forest types of each study zone to make composite samples for the determination of plant and soil organic carbon contents. The results of the study showed that total plant C (C in live biomass + litter + roots) was three times higher in the protected forest sites than the unprotected across the three study zones. Soil organic carbon stores were significantly ($P < 0.01$ and $P < 0.05$) higher in the protected forest sites than the unprotected. Across the three study zones, soil C store was in general twice greater in the protected sites than the unprotected. The present study indicates the need for employing ecologically and socio-economically sustainable management plans for savanna woodland resources in the region, in collaboration with local communities, so as to sustain communities' livelihoods, besides preserving the full potential of this forest-savanna to sequester C in the context of the fight against the global climate change.

Key words: Anthropogenic activities, climate change, forest-savanna.

INTRODUCTION

The current threats to the terrestrial carbon cycle from human-controlled land-use changes and greenhouse

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gas emissions are increasingly gaining concern (Clark, 2004). The global carbon cycle is being altered in response to human interference; for instance land-use changes in the tropics are estimated to contribute about 23% to human-induced CO_2 emissions (Houghton, 2003). It is established that anthropogenic carbon dioxide (CO_2) emission into the atmosphere plays a vital role in driving the global climate change (Petit et al., 1999; Falkowski et al., 2000), which in turn affects the productivity of terrestrial ecosystems (Nemani, 2003). Apart from the burning of fossil fuel, land-use conversion is considered to be having a significant impact on global carbon balance by profoundly altering land cover biota, and biogeochemical cycles (Houghton et al., 1999). In the biosphere, terrestrial ecosystems contain almost three times more carbon than the atmosphere (Schimel, 1995), and the amount of carbon stored is twice or three times higher than in living vegetation (Post and Kwon, 2000). Because of the significant capacity for carbon storage, soil has been the focus of increasing efforts in assessing the carbon sequestration associated with land-use change and ecosystem succession (Post et al., 1982; Degryze et al., 2004). The patterns and controls of soil organic carbon (SOC) storage are critical for our understanding of the biosphere, given the importance of SOC for ecosystem processes and the feedback of this pool to atmospheric composition and the rate of climate change (Raich and Potter, 1995). Our capacity to predict and ameliorate the consequences of climate and land cover change depends, in part, on a clear description of SOC distributions and the controls of SOC inputs and outputs.

Studies have demonstrated that changes in land-use are inevitably followed by changes in carbon stores (Canadell, 2002). Besides, changes in land-use can affect soil organic matter contents and fertility and also atmospheric $C0_2$ concentrations and global warming (Ross et al., 1999). Hence, unlike the burning of fossil fuel, the anthropogenic carbon emission could be reversible through management of lands in favour of sustainable long-term carbon stores. Indeed, terrestrial carbon sequestration is proposed by scientists as an effective mitigation option because it combines mitigation with positive effects on environmental conservation and soil fertility (Smith et al., 2007). Soil carbon sequestration is the process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other organic solids, and in a form that is not immediately reemitted. This transfer or "sequestering" of carbon helps off-set emissions from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term productivity (Alan et al., 1996).

Soil organic matter is a major factor in ecosystem functioning and determines whether soils act as sinks or sources of carbon in the global carbon cycle. Under natural conditions the content of organic matter in soil is constant; the rate of decomposition is equal to the rate of supply of organic matter from plants. The equilibrium is disturbed when forests are exposed to human pressures (Young, 1976). Changing patterns of land-use and land-use management practices can have significant direct and indirect effects on soil organic pools, due to changes in plant species, primary productivity, litter quantity and quality and soil structure. Deforestation in the tropics is influencing the climate system by affecting greenhouse gas fluxes. The current Intergovernmental Panel on Climate Change (IPCC) estimate for the annual net release of carbon from the land to the atmosphere due to deforestation and related land use in the tropics is 1 6 ± 1 0 Pg (Melillo et al., 1993). Between 1960 and 1990, Africa and Latin America each lost about 18 percent of their tropical forest cover to deforestation (Food and Agricultural Organization (FAO), 2001).

Tropical forests are globally important because of both their ecological and economic significance. They produce approximately 75% of the world's wood products and likely contain over half of the planet's biodiversity, despite occupying only 7% of the earth's surface (Thomas and Baltzer, 2002). In addition, much of the world's population lives in these regions. Approximately one-fifth of the world's population lives specifically within tropical regions consisting of savanna type vegetation. This results in large pressures being placed on savannas as a result of human activities (Schuttemeyer et al., 2006). Savannas occupy about 40% of Africa. They represent a substantial terrestrial organic carbon pool, which could act as either a net source or sink of atmospheric carbon dioxide in future decades (Atjay et al., 1987).

Over the past century tropical forests have been suffering from exceptional rates of change as they are degraded or destroyed by human activities. Approximately half of the tropical forest that was present at the beginning of the twentieth century has already disappeared, with peak deforestation in the 1980s and 1990s (Wright, 2005). The most important consequence of deforestation is a substantial decrease (well over 50%) in total organic carbon (above and below ground, living and dead) in a deforested site (Vitousek et al., 1981). Therefore, any change in C storage in plants or soils has significant implications for atmospheric carbon dioxide and climate change (Schuman et al., 2001). Consequently, soils and SOC have received attention in terms of the role they can play in mitigating the effects of elevated atmospheric CO_2 and associated global warming (Ross et al., 1999). Assessment of the carbon sequestration potential in terrestrial ecosystems to mitigating the global climate change requires development of a comprehensive database that contains spatially explicit information on carbon stores under various types of land-use, vegetation, and climatic conditions, as well as quantification of changes in carbon stores associated with land-use conversion (Zhiyong et al., 2006). In Ghana, as in many areas in Africa, the guinea savanna woodland plays important roles in servicing the ecological environment and socio-economics of the region (Nsiah-Gyabaah, 1996). However, the persistent exposure of this forest ecosystem to human activities, such as bush burning, overgrazing and logging, constitutes a serious threat to its sustainability and communities' livelihoods (Campbell et al., 2000; FAO, 1998). At the global scale, these activities are a significant source of emitted carbon, contributing to global warming (Ross et al., 1999). Hence, human activities across the natural forest-savanna zones of northern Ghana could highly be detrimental to the carbon sequestration potential of these forests zones and thus thwart efforts towards preserving the full carbon sink potential of these forest ecosystems in the face of the fight against the global climate change.

The problem associated with this situation is related to the fact that there is little information about the impacts of these anthropogenic activities on the carbon budget of the forests being subjected to human pressures across the savanna ecological zone of northern Ghana. There is therefore a need for more research activities so as to better evaluate and predict the current and future effects of these human practices on the soil carbon sequestration potential of the natural forest-savanna zone of northern Ghana in the context of mitigating the effects of the global warming. In view of this, the objective of this study was to compare the soil organic carbon stocks changes between three well protected forest sites and three adjacent unprotected forests which are prone to human activities in the natural forest-savanna of northern Ghana.

MATERIALS AND METHODS

Description of the study area

The study was conducted in the savanna ecological zone in northern Ghana (8° N, to lat. 11° N and longitudes 2° 57' W and 0° 34' E) (Figure 1). The climate in this area is characterized generally as tropical continental or savanna, with a single rainy season, from May to October, followed by a prolonged dry season (FAO, 1998). Average ambient temperatures are high year round (about 28°C) but the harmattan months of December and January are characterized by minimum temperatures that may fall to 13°C at night, while March and April may experience 40°C in the early afternoon. The area is associated with a total annual rainfall of about 1000 to 1300 mm/annum. The rainy season is 140 to 190 days in duration, while the estimated reference evaporation is about 2000 mm/annum, creating a great seasonal deficit every dry season. The peak rainfall period is usually late August or early September. About 60% of the rainfall occurs within the three months (July to September).

Most of the geological formations in the area are overlain by a regolith comprising *in situ* chemically weathered material and, to a lesser extent, transported surface material. Typically, this weathered layer consists (from top to bottom) of a residual soil zone (usually sandy - clayey material possibly underlain by an indurated layer) and a saprolite zone (completely to slightly decomposed rock with decreasing clay content with depth) (Carrier et al., 2008). Based on the FAO/UNESCO soil classification system, slightly acid soils with sandy to loamy topsoils and increasing clay content in the subsoil (Lixisols, Acrisols and Luvisols) occur in the savanna zone ecological zone of Ghana (Callo-Concha et al., 2012).

The vegetation cover typical of northern Ghana consists of mixed formations of fire resistant trees and shrubs. Moving northwards, within the savanna region, there is at first densely wooded and vigorous grassland (*Andropogon, spp.)* with fire resistant shrubs, often referred to as woodland savanna or Guinea savanna. Further north, in an increasingly arid environment, grass savanna or sudan savanna is formed, with trees and shrubs either absent or very sparse (FAO, 1998). The total conserved of the northern Ghana savanna area is about 15 million hectares. The reserved forest which was established by the Forest Ordinance of 1910 (Francois, 1995) is made up of 11,590 km² of production forests, 4,323 km² of protection forests and about 1,980 km² of game production reserves. It is estimated that 20,000 hectares per annum of the reserved area is lost to agriculture, or through bush fires and other human activities, such as bush burning, overgrazing, logging and mining (FAO, 1998). The persistent exposure of this forest ecosystem to human activities constitutes a serious threat to its sustainability and communities' livelihoods (Campbell et al., 2000; FAO, 1998).

Site selection and plot demarcation

Three study zones (Wungu, Serigu, Mognori) were used for the comparative study. Each zone was made up of two neighbouring forest types, namely the protected (a forest reserve or sacred grove) and unprotected types. The selection of the study zones was effected based on the distinct ecologies which can be distinguished within the interior savanna, and the level of protection and exposure to human activities of the protected and unprotected forest sites, respectively. The unprotected sites have continuously been subjected to human activities (except farming and settlements) whilst the forest reserves and sacred groves have been well monitored and kept off from human disturbances. The effective monitoring and protection of the forest reserves and sacred groves represents an ideal opportunity to study the effects caused by forest sites long-term exposure to human pressures in the savanna ecological zone of northern Ghana. The study areas were named as follows: WP (Wungu protected forest) and WU (Wungu unprotected forest) for Wungu study site, SP (Serigu protected forest) and SU (Serigu unprotected forest) for Serigu study site, MP (Mognori protected forest) and MU (Mognori unprotected forest) for Mognori study site.

Four 30 m × 30 m random plots were set in both the protected and neighbouring unprotected forest sites of each study zone in late August, 2013 (late peak rainy season) and used for the biomass and soil sampling. Above and Below-ground herbaceous plant biomass was harvested from within four 1 m × 1 m random subplots of each 30 m × 30 m study plots across the three study zones. The biomass sampling was carried out in late August at both sites in all the three study zones, at the time when most grasses had reached their maximum growth (peak biomass) after which senescence starts (Sala and Austin, 1988). The above ground herbaceous plant biomass was collected by clip harvesting all the living tissues of grasses (leaves, stems, inflorescences, and fruits produced in a single year) from the ground surface that occurred in each 1 m × 1 m random subplot of each study plot. Litter was collected from within each 1 m × 1 m subplots of each study plot after the above ground biomass was harvested. Root biomass was collected by soil coring method to 20 cm diameter and 20 cm depth from all the four 1 m × 1 m subplots on each 30 m × 30 m plot demarcated for biomass sampling. Soil samples were collected from within all the four 1 m × 1 m random subplots of each 30 m × 30 m plot by soil coring method using a -5 cm diameter soil core sampler to 50 cm depth and separated into 10 cm layers (0 to 10, 10 to 20, 20 to 30, 30 to 40, 40 to 50 cm). Soil and biomass sampling were conducted

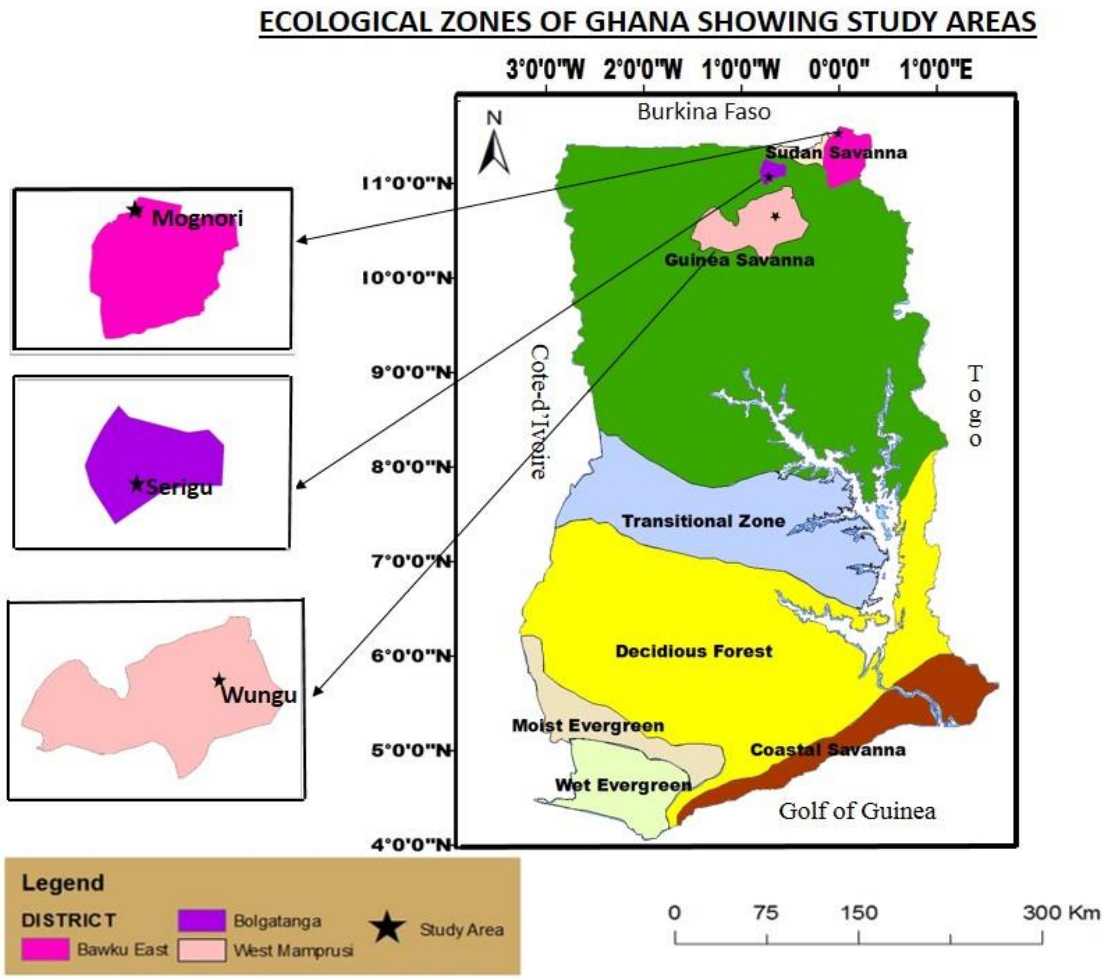

Figure 1. Map of Ghana showing the location of study areas.

concomitantly in all the three study zones.

Harvests consisted of a total of 160 random soil samples (0 to 50 cm depth), 96 random samples of aboveground live biomass, and the same number of litter and root biomass samples collected in both forest types of each study zone to make composite samples for the determination of organic carbon contents in plant and soil materials.

Soil and plant samples preparation and laboratory analyses

Plant materials samples were rid of all debris, weighed to determine the gross weight and air-dried in a ventilated room. Roots were washed and separated from the soil efficiently (Motsara and Roy, 2008). 100 g of each component were subsequently sampled and oven-dried at 70°C to a constant weight to determine the percentage of water content so as to convert material from field (green) weight to dry weight. All soil samples were spread on a drying tray to remove roots and other debris and air-dried for 3 days and ground with a wooden pestle and mortar to loosen the aggregates. After grinding, the soil was screened through a 2 m mesh and mixed thoroughly. The prepared samples were then stored in labelled bags and taken to the laboratory for the necessary chemical analyses. Organic C contents in plant and soil were estimated by wet digestion method using potassium dichromate ($K_2Cr_2O_7$) as oxidant (Motsara and Roy, 2008). Briefly, 1 g of soil and 1 g of plant samples were digested with 10 ml of 0.1667 M $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4 containing Ag_2SO_4 for 30 mn, followed by titration of the solution with standardized 0.5 M $FeSO_4$ solution.

Methods of calculation of plant soil organic carbon

Method of calculation of organic carbon in plant

Calculation of C store in above-ground live biomass: Carbon store in above-ground live biomass (in grams per square meter) was determined using the following formula:

$$C_{ALB}\,(g/m^2)\left[\frac{Dry\ weight\ of\ aboveground\ live\ biomass\left(\frac{g}{m^2}\right) X\,\%\ carbon\ content}{100}\right]$$

Calculation of C Store in Litter: Carbon store in litter (in grams per square meter) was determined as follows:

$$C_{Litter}\,(g/m^2) = \left[\frac{Dry\ weight\ of\ litter\ biomass\left(\frac{g}{m^2}\right) X\,\%\ carbon\ content}{100}\right]$$

Calculation of C store in roots: Carbon store in roots (in grams per square meter) was determined as follows: Amount of C in a root core of 20 cm diameter and 20 cm depth is C_r (g) = % C in roots × total mass of dry roots / 100 corresponding to an area of 3.14 x $(\frac{20}{2})^2\ Cm^2$ or 314 × $10^{-4}m^2$
For an area of $1\ m^2$ C store in roots (g/m^2) = C_r × $10^4 m^2$/ 314.

Method of calculation of organic carbon in soil

Soil organic carbon (SOC) store (in grams per square meter) was estimated using the following formula:
$\mathrm{SOC_{store}}(\mathrm{g}/m^2)$ = $\mathrm{SOC_{density}}$ × S × d

Where $\mathrm{SOC_{density}}$ is the soil organic carbon density, S the total area interested and d the soil depth (50 cm).

$\mathrm{SOC_{density}}(\mathrm{g}/m^2)$ = C × BD, hence $\mathrm{SOC_{store}}$ = C × BD × S × d

Where C is SOC average content (g/kg), BD is the bulk density of soil ($\mathrm{gcm^{-3}}$) at a 50 cm depth.

Statistical analyses of data

The results were subjected to analysis of variances (ANOVA) using the software programme SPSS, ver. 16.0 (SPSS Inc., Chicago, IL, USA) to determine treatment effects (that is, protected versus unprotected forests) for each study zone on collected data. The least significant difference (LSD) test was employed to compare the means for each study zone at 0.05 and 0.01 significance levels.

RESULTS AND DISCUSSION

Carbon store changes in above-ground and root biomass

Carbon store in live biomass was lower in the unprotected forest sites than the adjacent protected forests except for Mognori where the variation between the two sites (MP and MU) was minute (Table 1). Carbon store values were three times and twice higher in the protected site than the unprotected in Wungu and Serigu, respectively. The observed difference between the two forest types was only significant in Wungu (P < 0.05), in contrast to Serigu where no significant difference (P > 0.05) was recorded between the treatment and control sites (Table 2). Carbon store in litter was higher in the protected sites than the unprotected across the three study zones (Table 1). Difference between the two study sites was significant in Serigu (P < 0.01) and Mognori (P < 0.05), while no significant (P > 0.01) difference was observed in Wungu. The variation in C store in litter between the two sites across the three study zones was as follows: Twice greater in WP, and thirteenfold and sixfold greater in SP and MP, respectively (Table 1).

Carbon store in roots was four times higher in the protected site than the unprotected in Wungu, and approximately twice and three times greater in Serigu and Mognori, respectively (Table 1). The observed difference between the two forest types was significant in Wungu (P < 0.01) and Mognori (P < 0.05) as opposed to Serigu where the difference was not significant (P > 0.05) (Table 2). Total plant C (C in live biomass + litter + roots) was three times higher in the protected forest than the treatment site across the three study zones. However, the variation between the two forest types was not significant (P > 0.05) in Mognori, in contrast to Wungu and Serigu where significant (P < 0.01 and P < 0.05) differences were recorded. The pattern of variation in carbon pools in the three components of plant biomass, that is live biomass, litter, and roots biomass, between the protected and unprotected forests was inconsistent across the three study zones. In Wungu, root and live biomass were the most variable, in Serigu, litter showed the highest variability, and in Mognori, root biomass was the most variable.

Carbon store changes in soil

Soil organic carbon stores were significantly (P < 0.01 and P < 0.05) higher in the protected forest sites than those recorded in the unprotected forests across the three study zones (Tables 1 and 2). Across the three study areas, soil C store was in general twice greater in the protected sites than the unprotected. The variation in soil carbon store between the protected and unprotected forests across the three study zones showed the following rank order Serigu (9432 g Cm^{-2}) > Mognori (7133 g Cm^{-2}) > Wungu (4061 g Cm^{-2}). Consequently, Wungu study site recorded the least variation between the two forest types.

DISCUSSION

It is established that more than three-quarters of the ecosystem organic carbon in woodlands and savannas is in the soil (Scholes and Hall, 1992), and that removal of trees leads to an overall decline in SOC over a period of years (Jones et al., 1990; Vitousek, 1981). It is further indicated that savannas represent a substantial terrestrial organic carbon pool, which could act as either a net source or sink of atmospheric carbon dioxide in future decades (Atjay et al., 1987). In view of these facts, the degradation of the guinea savanna of northern Ghana could adversely affect the carbon storage potential of this forest ecosystem and consequently weaken efforts towards preserving the full role of carbon sink played by forests in the country, more so as the savanna ecological zone of northern Ghana occupies 40% of the country and plays important roles in servicing the ecological environment of the region (Nsiah-Gyabaah, 1996). The persistent exposure of this forest ecosystem to human activities, such as commercial and artisanal logging, large

Table 1. Total amounts of carbon (g/m^2) stored in soil and plant pools as affected by forest management type (Wungu).

Ecosystem components	Forest management system	
	Protected forest	Unprotected forest
Above-ground C	**WP**	**WU**
Live Biomass C	247±111	83±28
Dead Biomass (Litter) C	83±63	42±35
Total Above-ground Carbon C	330±64	125±27
Total roots C		
0 – 20 cm	516±51	124±28
Total Plant C	846±52	249±31
Soil organic C (0-50 cm)	10348±191	6287±375
Above-ground C	**SP**	**SU**
Live Biomass C	140±28	65±6
Dead Biomass (Litter) C	141±15	11±4
Total Above-ground Carbon C	281±23	76±5
Total Roots C		
0 – 20 cm	202±58	115±62
Total Plant C	483±38	191±36
Soil organic C (0-50 cm)	16969±385	7537±395
Above-ground C	**MP**	**MU**
Live Biomass C	23±9	25±6
Dead Biomass (Litter) C	24±11	4±1
Total Above-ground Carbon C	47±10	29±4
Total roots C		
0 – 20 cm	312±49	106±29
Total Plant C	359±30	135±17
Soil organic C (0-50 cm)	15341±413	8208±375

Within rows, means ± S.D. (n = 4).

scale land conversion, fuel wood and charcoal production, slash and burn agriculture, grazing, harvesting of non-timber forest products, hunting and mining, constitutes a serious threat to its sustainability and communities' livelihoods (Campbell et al., 2000; FAO, 2000). Indeed, it is estimated that 20,000 hectares per annum of the reserved area is lost to agriculture, or through bush fires and other human activities (FAO, 1998).

In this study, we assessed the extent to which these human activities alter the SOC store and constitute a threat to the carbon sequestration potential of the forest-savanna of northern Ghana in the fight against the global climate change. The study results showed that the anthropogenic activities in the unprotected forests resulted in significantly low ($P < 0.01$ and $P < 0.05$) C stores in plant and soil as opposed to the adjacent protected forest sites. Besides, the C stores in the soils of the unprotected forest sites were below the world's mean of 10.6 kg C/sqm (Post et al., 1982) in contrast to C values recorded in their corresponding neighbouring protected forests. These findings are consistent with those reported by several authors (Schlesinger, 1985; Winjum et al., 1990; Veldkamp, 1994). The relatively low values of C recorded across the unprotected forest sites compared with the high values of C displayed by their corresponding adjacent protected sites could be attributable to low inputs of organic matter in the soils of these unprotected forests as a result of the persistent removal of biomass through burning, overgrazing, logging, and other types of forest products extraction. Besides reducing the carbon sinks potential of the forest-savanna in the region, the effects of human pressures on forests could also lead to soil erosion and loss of soil fertility and productivity, as the abundance of

Table 2. Summary of the analysis of variance (ANOVA) outputs of organic carbon store in soil and plant between protected and unprotected sites at each study zone.

Ecosystem component	F– Value	P – Value	Outcome
Carbon store in live biomass			
Wungu	8.302	0.028	P< 0.05 Significant
Serigu	5.107	0.064	P> 0.05 Not significant
Mognori	0.207	0.664	P > 0.05 Not significant
Carbon store in litter			
Wungu	1.031	0.34	P > 0.05 Not significant
Serigu	95.090	0.000	P< 0.01 Significant
Mognori	9.122	0.023	P< 0.05 Significant
Carbon Store in root biomass			
Wungu	185.225	0.000	P< 0.01 Significant
Serigu	3.439	0.11	P> 0.05 Not significant
Mognori	6.830	0.039	P< 0.05 Significant
Carbon store in total above ground biomass			
Wungu	4.868	0.044	P< 0.05 Significant
Serigu	28.543	0.000	P< 0.01 Significant
Mognori	2.260	0.154	P> 0.05 Not significant
Total plant carbon store			
Wungu	11.061	0.003	P< 0.01 Significant
Serigu	16.272	0.000	P< 0.01 Significant
Mognori	2.352	0.139	P > 0.05 Not significant
Soil organic carbon store			
Wungu	391.695	0.000	P < 0.01 Significant
Serigu	62.825	0.000	P< 0.01 Significant
Mognori	9.842	0.020	P< 0.05 Significant

organic carbon in the soil affects and is affected by plant production and its role as a key control of soil fertility has been established (Tiessen et al., 1994). This situation could take a heavy toll on communities' livelihoods as the savanna woodland of northern Ghana plays important roles in servicing the socio-economics of the region (Nsiah-Gyabaah, 1996). The results of the study are therefore an indication of the fact that differences in forest-savanna management practices affect soil organic matter input, and that best forest management practices in the forest-savanna zones of northern Ghana could be utilized as a significant carbon sink in the context of mitigating global climate change while maintaining adequate productivity for servicing the socio-economic development of the region (Zhiyong et al., 2006).

Atjay et al. (1987) buttressed this climate change mitigation potential by pointing out that savannas could act as a net sink of atmospheric carbon dioxide in future decades. Indeed, the carbon sink potential offered by forest ecosystems corroborates the reason why scientists propose terrestrial carbon sequestration as an effective mitigation option because it combines mitigation with positive effects on environmental conservation and soil fertility (Metz et al., 2007). In the light of this, it is generally believed that recent changes in climatic conditions in Ghana and indeed in the West African sub-region may be due to deforestation occurring in Ghana and neighbouring countries (Francois, 1995). Hence, the study findings substantiate the perspective that proper forest management practices coupled with a holistic approach of addressing social issues that determine the interaction between people and forest resources should be seriously considered by the key stakeholders as the way forward for ensuring environmental sustainability in the region. Mitigation actions in line with this perspective should revolve around the main causes of forest degradation in the savanna ecological zone of northern Ghana, namely bushfires, farming, logging, mining, and over-grazing (Francois, 1995; NSBC, 2002). Also related are issues of lack of effective enforcement of institutional and policy framework for implementing ecologically and socio-economically sustainable management systems for savanna woodland resources, in collaboration with local communities (NSBC, 2002).

Hence this study indicates the need for putting up effective monitoring and regulatory measures and mechanisms to ensure a sustainable conservation and management of the forest-savanna zones in northern Ghana. It further provides information that has practical application that could be used by the local advisory Committee on Climate Change and the Forestry Advisory Service as part of measures and efforts to enhance the full carbon sink potential of the northern savanna woodland in the face of the global climate change.

Conflict of Interests

The authors have not declared any conflict of interests.

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