Dynamics of soil organic carbon stocks in the Guinea savanna and transition agro-ecology under different land-use systems in Ghana

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Abstract: This study was to assess and predict soil organic carbon stocks (SOCS) under the major land use/cover types in Kintampo North Municipal located in the Guinea savanna through the transition agro-ecological zone of Ghana. Random field sampling was done on 34 plots and 24 sample points at depths 0–10 cm, 10–20 cm and 20–30 cm per plot with soil corer. Soil bulk density, pH, particle size distribution and SOC were determined using standard laboratory procedures and computations. Results were subjected to both statistical and Geo-statistical analyses. The SOCS in each land use decreased with depth. The mean SOC for the five land-use systems studied were 11.33 t/ha, 7.95 t/ha and 6.08 t/ha at 0–10 cm, 10–20 cm and 20–30 cm, respectively. The vertical variability in SOC distribution across the considered land use/cover types was statistically significant (p < 0.05) but the statistical difference amongst land use/cover types was insignificant. The determined mean SOCS were 30.02 (±13.20) t/ha for savanna woodland as the highest and 22.01 (±8.92) t/ha for cashew plantation as the lowest at total depth (0–30 cm). The spatial distribution of SOC stocks ranged between 12 t/ha to about 33 t/ha.

Subjects: Agriculture; Environmental Management; Environmental Sciences; Forestry; Soil Sciences

Keywords: soil organic carbon stocks; land use/cover types; geostatistical kriging; Kintampo North Municipal

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Research discipline of authors includes climate change assessment and adaptation, soil and land use engineering, irrigation and water resources management, integrated agriculture, conservation agriculture, postharvest engineering, irrigation and drainage, agricultural water management, soil mechanics applications, rural water supply, hydrological modelling, soil macro and micro nutrient assessment, remote sensing applications, carbon dioxide assessment, performance evaluation of agriculture machinery amongst others. This research is a part of the climate change adaptation and mitigation via adapted land use for carbon dioxide control under the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) Project. Other aspect of this project is the relation of climate change to water resources, energy, human security, biodiversity, agriculture and west African climate systems.

PUBLIC INTEREST STATEMENT
This study was to determine how savanna woodland, cropland and tree plantations affected soil organic carbon stocks (SOCS) in Kintampo North Municipal located in the Guinea savanna through the transition agro-ecological zone of Ghana. Soil samples were picked on 34 plots at depths 0–10 cm, 10–20 cm and 20–30 cm to see how soil organic carbon varies with depth. The types of tree plantations considered in the study were cashew, teak and mango. savanna woodland had the highest SOCS as a land cover and cashew plantation had the lowest amount of SOCS. Running spatial distribution of SOCS in ArcGIS gave values between 12 t/ha to about 33 t/ha all over the municipal. It implies that soil in Kintampo North Municipal stores moderate amount of organic carbons which is vital for climate change mitigation if land use change and soil preparation by ploughing are controlled.
1. Introduction
The largest emission of CO₂ from soils result from land use change and especially drainage of organic soils (Houghton & Goodale, 2004) however, drainage plays an important role to improve soil quality in agriculture (Callesen et al., 2003; Valipour, 2014). Land use change in controlling CO₂ emissions in sub-Saharan Africa may be more critical than in other regions and have been discovered to be an uncertain component in global carbon cycle for the continent (Grieco, Chiti, & Valentini, 2012). The most typical example of incomplete estimates in sub-Saharan Africa is as a result of inadequate and reliable data for various carbon pools. Adu-Bredu, Abekoe, Tachie-Opong, and Tschakert (2010) studied carbon stocks under four land-use systems in three different ecological systems in Ghana. They reported that soils have the highest carbon stocks in Bawku, which is in the Sudan savanna zone with mean values of 34.05 MgCha⁻¹, 32.02 MgCha⁻¹, 32.14 MgCha⁻¹ and 23.64 MgCha⁻¹ for fallow, cultivated land, natural forest and teak plantation, respectively. The results from the study show that soils in the savanna zone and forest zone in Ghana have the highest soil carbon content.

Carbon exists as inseparable components of biomass and soil organic matter. Its storage in soil organic matter is important in mitigating global climate change and improves the livelihood of resource-poor farmers. It increases land productivity through improved soil properties such as nutrient supply and moisture retention (van Keulen, 2001). Degradation and deforestation have impacted negatively on both vegetation and soil carbon stock. Soils in Africa have been reported to lose 136 gigatonnes of carbon between 1850 and the late 1990s (United Nations Environment Programme, 2012). About 33% of carbon lost in Africa soils within this period was attributed to land degradation and soil erosion. Soil organic carbon (SOC) is also an energy source for organism decomposition (Melillo et al., 2002) and can be lost through increased soil respiration (Conant et al., 2008). Soil Carbon sequestration alone is surely not the only way to fight climate change but it is realistic to link climate change with soil carbon conservation, as soil carbon sequestration is cost competitive, of immediate availability, does not require the development of new and unproven technologies, and provides comparable mitigation potential to that available in other sectors (Schils et al., 2008).

SOC is one of the largest and active carbon pools. Globally, the estimates of SOC storage range from 1,200 to 1,600 Pg in the top 1-m soil depth, inorganic component amounts to 695–930 Pg down to the same depth (Batjes, 1996; Sombroek, Nachtergaele, & Hebel, 1993), which is mostly stored in arid and semi-arid regions (Díaz-Hernández, Fernández, & González, 2003). To mitigate global warming, carbon sequestration, which redistribute carbon from the air to other pools would help to reduce the rate of atmospheric CO₂ release (Soil Science Society of America, 2001; Tieszen, 2000). Other parameters affecting organic matter behaviour in soils include moisture status, temperature, oxygen supply (drainage), acidity, nutrient supply, clay content and mineralogy. Erosion, decomposition and leaching are important soil processes causing carbon concentrations to decrease in the soil (Lal, 2003). Land-use systems conserve, sequestrate, or release carbon into the atmosphere directly or indirectly. United Nations Framework Convention on Climate Change (UNFCCC) reported in 2000 that agricultural soils could be made into a net sink of carbon dioxide. As much as 0.9 ± 0.3 Pg of carbon could be absorbed by agricultural soils annually through improved management practices designed to increase agricultural productivity (Lal, 2004). Proven and documented management practices that will sequester carbon in the transition zone will contribute immensely to the fight against global carbon release from soils (Hedlund, 2015; Woomer, Touré, & Sall, 2004). Batione, Kihara, Vanlauwe, Waswa, and Kimetu (2007) reported that surface disturbance from cultivated systems decreases soil carbon contents because tree cover is reduced and mineralisation takes place faster. Soil organic matter (SOM) increases soil structural stability and resistance to rainfall impact; rate of infiltration and fauna activities (Batione et al., 2007) and 58% of soil organic matter is made up of SOC (Natural Land & Water Resources Audit, 2008).

It has been reported that temperatures in the tropics, including the savanna zone of Ghana are increasing (Nutsukpo, Jalloh, Zougmore, Nelson, & Thomas, 2012). This has led to instability in precipitation and increased food insecurity as well. Increased temperatures in the tropics leads to increased decomposition rates reducing carbon stored as organic matter in the soil. Increased soil
respiration as a result of increasing temperature would release a higher concentration of CO₂ into the atmosphere due to carbon loss from the soil (Melillo et al., 2002). Therefore, this study was to assess and predict soil organic carbon stocks (SOCs) under the major land use/cover types (cropland, savanna woodland, teak plantation, mango plantation and cashew plantation) in the Guinea savanna and transitional agro-ecological zone of Ghana.

2. Materials and methods

2.1. Study area

Kintampo North Municipal where the study was done is located between latitudes 8°45’ N and 7°45’ N and longitudes 1°20’ W and 0°1’ W. It is surrounded by five districts in the country namely Central Gonja District to the north; Bole District to the west; East Gonja District to the north-east (all in the northern region); Kintampo South District to the south and Pru District to the south-east. The municipality has a surface area of about 5,108 km², and occupies about 12.9% of the total land area of Brong Ahafo Region (Strategic Environmental Assessment, 2010). In terms of location and size, the municipal is strategically positioned at the centre of the country as shown in Figure 1. It is the transit point between the northern and southern sectors of Ghana. The municipal comes under the interior wooded savanna or tree savanna and transitional agro-ecology. Every transitional zone is believed to have once existed as forest. Its current transformation is attributed to prevailing savanna conditions resulting from man’s activities. This is evident by the existence of riparian forest where anthropogenic activities are limited.

The municipality experiences the tropical continental or interior savanna type of climate (Strategic Environmental Assessment, 2010). The mean annual rainfall is between 1,400 mm and 1,800 mm. It occurs in two seasons from May to July as minor and from September to October as major (Strategic Environmental Assessment, 2010). The mean monthly temperature ranges from 30°C in March to 24°C in August with mean annual temperatures between 26.5°C and 27.2°C (Strategic Environmental Assessment, 2010). Kintampo North Municipal is found within the Voltain Basin and the Southern Plateau physiographic regions and is elevated between 60 and 150 m above sea level. Voltain plateau occupies the southern part of the municipal with series of escarpments. About 40% of the surface area is of Voltarian formation rocks and the municipal is covered with 80% of it. Voltarian formation rocks are mainly sedimentary and exhibit horizontal alignments. Examples are sand stone, shale, mudstone and limestone. Two main groups of soils are in the municipal. The first
which is groundwater laterite soils or Plinthosols (FAO) or Plinthaquox (USA, Soil Taxonomy) covers nearly 60% of the municipal particularly in the interior wooded savanna zone. Savanna ochrosols or Alfisols (USDA classification) is the other soil group mostly found in the south and south-western parts. The municipal has 71% of her population in the agriculture sector and land is a very important resource (Strategic Environmental Assessment, 2010).

2.2. Study methods

The municipal is covered by different types of land cover and land use types. However, the land use types considered for sampling were savanna woodland, teak plantation, mango plantation, cashew plantation and crop land (mixed cropping). A measuring tape was used to delineate 50 × 50 m plot (N) and Garmin eTrex 10 GPS device was used to pick location coordinates of sample sites in the middle of the plot. Soil core sampler (5 cm diameter × 5 cm length) was used to collect samples at three (3) points diagonally on each plot at each depth 0–10 cm, 10–20 cm and 20–30 cm (Intergovernmental Panel on Climate Change, 2007; United Nations Framework Convention on Climate Change, 2000), for bulk density determination. This amounted to nine samples per plot. Samples were taken from all six plots for the selected land use/cover types except crop land where sampling was done in 10 plots. Another set of soil samples were obtained by sampling at five points (5 on a die method) on each plot at the three depths as done for the previous sampling. The samples obtained from the five points, for each depth, were thoroughly mixed together to get composite samples for the determination of SOC concentrations, pH and particle size analysis as recommended by World Bank Electronic Institute (WBI) for Clean Development Mechanism (CDM) project (World Bank Electronic Institute, 2014). This amounted to 15 samples per plot. Samples were taken from six plots for all land use/cover types except crop land where sampling was done in 10 plots. On each plot, therefore, a total of 24 samples were collected for the selected land use/cover types in the study area. The limit of the top 30 cm of the soil was chosen because it often represents the limit of the visible humic horizons.

Bulk densities were determined by oven drying at 105°C till constant weight was attained, Walkley–Black wet oxidation method was used for organic carbon concentration determination. The hygrometer method for the particle size analysis and soil–water ratio method for pH determination. Pluske, Murphy, and Sheppard (2014) formula was used for the SOC stocks calculation as follows:

\[
\text{SOC} = 100 \rho_d ZC
\]

where SOC is the soil organic carbon stocks (t/ha); \( \rho_d \) is the soil bulk density (Mg/m³); Z is the soil depth (m); C is the carbon concentration (%).

3. Results

3.1. Dry bulk density

The dry bulk density for all collected samples is shown in Table 1. The mean bulk densities for total depth 0–30 cm across the five land use/cover types increased from 1.34 g/cm³ under mango plantation to 1.46 g/cm³ in cropland. Dry bulk density increased with increasing soil depth for all land use/cover types; this result is consistent with the observation of other works in Ghana (Agboadoh, 2011; Dawoe, 2009; Dowuona & Adjetey, 2010). The decrease in bulk density with increasing soil depth may be due to the decrease in SOC with depth. At depth 0–10 cm, mango plantation recorded the least density of 1.27 g/cm³ and teak and cropland all recording the highest at 1.42 g/cm³. High bulk density means the soil has a high percentage of sand as confirmed by the particle size analysis (Table 2) and therefore is expected to have less nutrient (SOC). Mango plantation had the least dry bulk density 1.35 g/cm³ at depth 10–20 and cashew plantation at depths 20–30 cm recorded 1.40
The largest deviation in values was observed under teak plantation, cashew and mango at ±0.10, ±0.08 and ±0.09 respectively.

### 3.2. Soil texture

A summary of the soil texture characteristics and class under the land use/cover types is shown in Table 2. The clay content for all soils was generally low. Clay content was higher under cashew plantation and least in mango with a variation from 3.80% to 6.08%. Residual cover from the leaves of cashew was a major cover for its plantation compared with other land use and therefore has the potential to reduce erosion and eluviation. This might be a major reason for the variation in clay content amongst land use. Sand fractions ranged from 70.14% in savanna woodland to 75.50% in mango plantation. The textural class was Loamy sand for only mango plantation and the remaining land use types were sandy loam. Sand correlated negatively ($R = -0.583, p = 0.00$ for 0–30 cm) with SOC at all depths implying that, where sand is high, clay is expected to decrease resulting in decreased SOCS. Therefore, cashew plantation with the highest clay content was expected to record more SOC content (Figure 2) but was rather the least which might be due to the intercropping of tubers crops with cashew for over 10 years till their canopy cover the spaces between them.

### 3.3. Soil pH

The mean determined pH in the study at the three considered depths is summarised in Table 3. Averagely, cropland measured the lowest mean pH value of 6.69 whilst savanna woodland had the highest mean pH value of 7.10. Intermediate values were recorded by teak, cashew and mango at 6.87, 6.87 and 6.90, respectively. Soil pH increased with soil depth in all land use/cover types. The soil pH correlated positively with clay content ($R = 0.049, p = 0.937$) implying that lower clay content soils should record lower pH. Crop yields are normally high in soils with pH values between 6.0 and 7.5 but most nutrient elements are usually available in the pH range of 5.5–6.5 (Motsara & Roy, 2008). This confirms the study area as a good agricultural land. The range of pH at total depth 0–30 cm at 6.69–7.10 means the soils are neutral (pH approx. 7) and do not need any chemical treatment.
3.4. SOC concentration
The mean SOC concentrations are reported in Table 4 for all three depths by land use/cover type. SOC concentrations decreased from 1.03, 0.64 and 0.48% in savanna woodland to 0.72, 0.47 and 0.38% in cashew plantation at depth 0–10 cm, 10–20 cm and 20–30 cm, respectively. It was only at depth 20–30 cm that cashew plantation and teak plantation recorded the same amount of organic carbon concentration. SOC concentration decreased with increasing depth across all land use/cover types which is consistent with the following studies (Agboadoh, 2011; Dawoe, 2009; Hairiah & van Noordwijk, 2000; Jiao et al., 2010). Savanna woodland and crop land had the widest coverage in the municipal. Therefore, the SOC concentration of these two land uses indicate on average an appreciable stored content which is not protected and can be lost via land use change.

3.5. Soil organic carbon stocks
The SOC stocks distribution for all the land use/cover types ranged between 4.95 and 21.18 t/ha, 3.42 and 16.07 t/ha, 1.38 and 12.74 t/ha and 9.80 and 49.63 t/ha for depths 0–10 cm, 10–20 cm, 20–30 cm and 0–30 cm, respectively.
and 0–30 cm, respectively (Figure 2). All the land use/cover types recorded a decreasing SOC stocks with increasing depth. The mean SOC stocks for all land use/cover types were 11.3, 7.95 and 6.08 t/ha for depths 0–10 cm, 10–20 cm and 20–30 cm, respectively. Savanna woodland measured the highest SOC stocks at all depths and cashew plantation the least. Observations during sampling revealed that soils under plantations were less disturbed after crops are fully grown compared to croplands. Fully grown mango and cashew plantations had the highest cover or litter on top soil and less direct heating of soil from sunshine. It was not so for teak plantation due to the regular bush fires in the municipal. Deviations ranged between ±2.76 and ±4.73, ±2.32 and ±4.33, ±2.48 and ±4.33 and ±7.74 and ±13.20 for depths 0–10 cm, 10–20 cm, 20–30 cm and 0–30 cm, respectively. Savanna woodland recorded the highest variability or deviations at all depths.

Analysis of variance (ANOVA) at 95% confidence indicated no significant difference in SOC stocks amongst the land use types for all the depths ($p = 0.542$ for 0–10 cm, $p = 0.831$ for 10–20 cm, $p = 0.988$ for 20–30 cm and $p = 0.785$ for 0–30 cm) but there was a significant difference ($p < 0.05$) across the three depths under all land use/cover types sampled. SOC stocks correlated positively under the Pearson correlation (Table 5) with clay and finest particles (clay + silt) which indicate that as clay and the finest particles in the soil increases, SOC stocks also increases as confirmed by other studies (Agboadoh, 2011; Hairiah & van Noordwijk, 2000; Jiao, Xu, Zhao, & Yang, 2012). Bulk density and sand content correlated negatively with SOC stocks at all depths showing the inverse proportionality between % sand, bulk density and SOC stocks. High % sand content gives soil higher weight and less % clay therefore bulk density is expected to be higher in all soils with high sand content as SOC will be low in those soils. pH had a positive correlation at all depths except 20–30 cm implying less nutrient at that depth.

### 3.6 Spatial distribution of SOC stocks

The SOC stocks at 0–30 cm depths were spatially distributed by ordinary kriging in Figure 3. The SOC stocks range majorly between 12 t/ha and about 33 t/ha. The northern part had the least estimates which can be attributed to the limited data collected in that area and also the less SOC stocks measured across agro-ecological zones from the south to the north in the Guinea savanna. The study area is averagely storing about 25 t/ha SOCS. The district has a potential to increase the amount of SOC stocks stored in its soils if sustainable management practices are adopted to increase the sequestration capacity and decrease release from such activities.

| Table 5. Pearson correlation (R) result of SOC stocks with other parameters |
|-----------------------------------------------|-------------|-------------|-------------|-------------|
| Soil organic carbon stocks; R (significance)   | 0–10 cm     | 10–20 cm    | 20–30 cm    | 0–30 cm     |
| Bulk Density                                  | −0.416 (0.014) | −0.248 (0.157) | −0.114 (0.529) | −0.345 (0.045) |
| pH                                           | 0.076 (0.669)  | 0.031 (0.860)  | −0.130 (0.471) | 0.018 (0.919)  |
| % OC                                         | 0.980 (0.000)  | 0.993 (0.000)  | 0.690 (0.000)  | 0.993 (0.000)  |
| % Sand                                       | −0.282 (0.106) | −0.081 (0.649) | −0.297 (0.093) | −0.276 (0.114) |
| % Silt                                       | 0.215 (0.222)  | 0.069 (0.698)  | 0.098 (0.587)  | 0.108 (0.545)  |
| % Clay                                       | 0.268 (0.125)  | 0.321 (0.065)  | 0.446 (0.009)  | 0.454 (0.007)  |
| % Silt + Clay                                | 0.282 (0.106)  | 0.081 (0.649)  | 0.297 (0.093)  | 0.233 (0.205)  |
4. Discussion

The determined values of the dry bulk density suggest that the soil is within the sandy and loam textural classes (Table 2). Bulk density was higher in croplands compared to the report of Agboadoh (2011) which was averagely 1.34 g/cm³ for the top 0–20 cm at Bechem District in the forest zones and lower than 1.65 g/cm³ for cultivated field in Upper East Region of Ghana (Dawidson & Nilsson, 2000). This shows that dry bulk density increases from the southern to the northern part of Ghana. These higher values under cropland over savanna woodland might be as a result soil compaction due to the use of heavy agricultural machinery.

Yao et al. (2010) reported that land use types affect soil texture characteristics and the nutrient availability which confirms the result in this study. Cashew plantation with the highest clay content also recorded the least SOC stocks which is contrary to most findings (Agboadoh, 2011; Hairiah & van Noordwijk, 2000; Su, Xiong, Zhu, Ye, & Ye, 2006). This was due to the continuous intercropping of tuber crops with cashew until they are fully grown and developed closed canopies. Crop yields are normally high in soils with pH values between 6.0 and 7.5 but most nutrient elements are usually available in the pH range of 5.5–6.5 (Motsara & Roy, 2008). This confirms the study area with mean pH range of 6.64–7.15 at depths 0–10 cm, 10–20 cm and 20–30 cm as a good agricultural land. The range of pH at total depth 0–30 cm was 6.69–7.10 implying the soils in Kintampo North Municipal are neutral (pH approx. 7) and do not need any chemical treatment.

The insignificant difference in horizontal distribution of SOC stocks amongst land use/cover types is contrary to the report of Anderson-Teixeira, Davis, Masters, and Delucia (2009) that conversion of uncultivated land to agriculture purposes result in significant SOC stock loss but Yao et al. (2010) however had no significant differences for SOC stocks under 10–year-old teak plantation, cocoa plantation and recurrent fallow. Dawoe (2009) also recorded insignificant difference amongst SOC stocks under forest 3, 15 and 30 years' cocoa plantation in moist semi-deciduous zone of Ghana. The SOC stocks decreased with increasing depth across all land use/cover types as reported in several findings (Agboadoh, 2011; Dawoe, 2009; Follett, Kimble, Pruessner, Samson-Liebig, & Waltman, 2009; Hairiah & van Noordwijk, 2000; Jiao et al., 2010, 2012; Morisada, Ono, & Kanomata, 2004; Sheikh, Kumar, & Bussmann, 2009; Su et al., 2006). Savanna woodland recorded the highest mean of SOC stocks at 30.02 t/ha with a very high variability of 43.97% and cropland followed as the
highest amongst the cultivated lands or systems. This can be attributed to the use of fertilizers as part of the land use management practices by crop farmers as reported by Wang, Zhang, Song, Liu, and Ren (2010). Therefore, the introduction of better land use management practices such as Sustainable Agricultural Land Management (SALM) practices will increase the stored SOC stocks (Verified Carbon Standards, 2014). The relevance of climate, soil type, vegetation, terrain and topography in the study area has no impact on the horizontal variability in SOC stocks due to its homogeneity (Su et al., 2006). Therefore, horizontal variability being insignificant in this study can also be attributed to land use and land cover change. The top 0–10 cm depth recorded the highest SOC stocks under all land use/cover types but varied across land use types because land use management practices have a higher influence at top soil (Post, Izaurralde, Mann, & Bliss, 2001; Su et al., 2006). Savanna woodland recorded 14.30 % SOC stocks over cropland which was second highest and cashew having the least SOC stocks was 14.46 % behind cropland. The SOC stocks is similar to the findings of Dowuona and Adjetey (2010) in the savanna zone of Ghana, ranging between 16.23 and 33.03 t/ha in 2005, 18.08 and 44.89 t/ha in 2007 and 20.85 and 52.54 t/ha in 2009 at depth 0–20 cm under field treatment of maize to sequester SOC stocks. Also, mean SOC stocks values of 30.02 t/ha, 24.31 t/ha and 25.73 t/ha for savanna woodland, teak plantation and cropland, respectively, is comparable with Adu-Bredu et al. (2010) results of SOC stocks in Bawku in the Guinea savanna zone of Ghana. Natural forest recorded 32.14 t/ha, cultivated or cropland was 32.02 t/ha and teak plantation was the least at 23.64 t/ha. The decreasing trend was same in both studies. Tan, Tieszen, Tachie-Obeng, Liu, and Dieye (2008) with General Ensemble Biogeochemical Modeling System also estimated SOC stocks in the transition zone to be 21.2 t/ha at the top 20 cm for the year 2000, which is similar to the findings of this study.

5. Conclusion
From this study, SOC ranged between 4.95 and 21.18 t/ha, 3.42 and 16.07 t/ha, 1.38 and 12.74 t/ha and 9.80 and 49.63 t/ha for the depths 0–10 cm, 10–20 cm, 20–30 cm and 0–30 cm, respectively. Generally, SOC stocks decreased with increasing depth. The study identified savanna woodland which mostly suffers from deforestation as having the highest SOC stocks in the municipal. This is a natural and undisturbed ecosystem at the time of the study. Cropland recording high SOC stocks could be attributed to some land use management practices. This implies the adoption of better management practices like SALM practices which include use of cover crops, returning composted crop residuals to the field, manure management and the introduction of trees into landscapes will increase the carbon storage capacity of soils. It is necessary to consider the SALM concept and disseminate to farmers through the Ministry of Agriculture in order to address both food security and climate change issues. Finally, education on climate change, carbon credit, SALM and their relevance in sustaining livelihood should start in the municipal since carbon sequestration has a higher probability on productivity and further investigate SOCS effect on yield under the land use/cover types considered.

Acknowledgements
Special recognition goes to Ministry of Food and Agriculture (MoFA), Kintampo Municipal for their assistance on the field and to the farmers of the Kintampo North Municipal who participated in the study.

Funding
This work has been funded by the German Federal Ministry of Education and Research (BMBF) through West Africa Science Centre of Climate change and Adapted Land use (WASCAL).

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Citation information
Cite this article as: Dynamics of soil organic carbon stocks in the Guinea savanna and transition agro-ecology under different land-use systems in Ghana, Enoch Bessah, Abdullahi Bala, Sampson K. Agodzo & Appollonia A. Okhimamhe, Cogent Geoscience (2016), 2: 1140319.
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