RESEARCH ARTICLE

'Islands of fertility': Effects of different forest covers on the distribution of soil carbon stock in a tropical savanna ecosystem.

Ebenezer Djaney Djagbletey[1,2], *H. O. Tuffour[1], A. Abubakari[1] and G. D. Djagbletey[3].
1. Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.
2. Ghana Forestry Commission, Cape Coast, Ghana.
3. Forestry Research Institute of Ghana, Kumasi, Ghana.

Manuscript Info

Abstract

Soil is a vital component of the terrestrial ecosystems with key functions of water and nutrient storage and transmission. Previous studies have shown that soil organic carbon (SOC) stocks vary with land-cover and land-use change, with significant losses occurring through disturbance and cultivation. With regards to the fact that the potential of forest reserves and other land use systems as C sinks is becoming evident, this study was conducted to investigate the levels of C stocks in soil and vegetation, and soil nutrient characteristics of selected forest reserves in the fragile Guinea Savanna Agro-ecological zone of Ghana. Thus, this study sought to investigate the potential of grasslands as potential carbon sinks in reducing the current rapid increase in atmospheric CO_2 concentrations. The study also revealed that the highest SOC concentrations were recorded in the 200% distance from the base of tree, drip line zone and sub-canopy zone for Kenikeni, Sinsablegbinni and Klupene forest reserves, respectively.

Introduction:-
The recent increasing levels of atmospheric CO_2 has raised concerns about C stocks in the soils of the world and to their roles as both sources and sinks of C (Eswaran et al., 1993; Sombroek et al., 1993; Batjes, 1996). Changes in land use patterns have a marked effect on topsoil C storage. One of the main issues of concern relating to the effect of land use changes on soil carbon balance is the effect of the conversion of tropical forest to agricultural and grazing lands (Houghton et al., 1991; Lugo and Brown, 1993; Detwiler, 1996) and such conversion affected 200 million hectares between 1980 and 1995 (FAO, 1997). Currently, studies on carbon stocks (mainly on vegetation or above ground carbon) are concentrated in the High Forest Zone in Ghana. However, quality data on the soil carbon stocks in the savanna ecosystems (which forms two-thirds of Ghana's landmass) are lacking, Savanna zones, in particular, being areas that are starved of quality data on climate change. In view of these, the current study was conducted to determine the distribution of soil carbon stocks under different forest stands in the Guinea Savanna zone of Ghana.

Material and Methods:-
Location of study areas:-
The study was carried out at the Kenikeni, Sinsablegbinni and Klupene forest reserves in the Guinea Savanna agro-ecological zone of Ghana. The Guinea savanna zone is restricted to the northern portion of Ghana, and it covers nearly two-thirds of the country with an approximate area of 147,900 km^2. It is characterized by a unimodal rainfall pattern spanning 5-6 months (commences in April/May) with a period of 6-7 months of pronounced drought annually. The average annual rainfall, temperature, relative humidity, wind speed, sunshine hours and solar radiation are in the order of 1,033 mm, 28.1^{o}C, 61%, 138 km/day, 7.3 hours and 19.6 MJ/m^2/day, respectively. Potential

evaporation is 1720 mm per annum and the annual aridity index is 0.60 (EPA, 2003). The zone is gently undulating and low in relief with slopes of 3% to 4%. Most of the area lies between 153 and 244 m above sea level.

Description of study areas:-

The Kenikeni site is an intact forest reserve that is located in the Bole forest District (Bole Political District in the Northern Region). It lies between Longitude 1° 53' and 2° 30' West and Latitude 9° 06' and 9° 20' North with an area of 515.98 km^2 and 122.92 km as its perimeter. The Sinsablegbinni forest reserve represents a moderately degraded forest reserve in the Tamale forest District (Tamale Metropolis). It stretches from Latitude 9° 26' to 9° 33' North and from Longitude 0° 32' to 0° 45' West with an area of 72.72 km^2 and 37.18 km as its perimeter. The Klupene forest reserve is a degraded forest estate in the Yendi forest district (Yendi Municipality). It stretches from Latitude 9° 27' to 9° 29' North and on Longitude 0° 00' to 0° 15'. It has an area of 2.31 km^2 and 6.62 km as its perimeter.

Table 1:- Stand and carbon stock of various components in the three study sites

Forest reserve	Total trees ha^{-1}	Carbon stock (Mg C ha^{-1})			[¶]Total
		Trees	Grass	Necromass	
Kenikeni	178	60.013	0.471	0.090	60.574
Sinsablegbinni	536	26.736	0.109	0.136	26.981
Klupene	169	6.613	0.079	0.291	6.983
Total*	883	93.362	0.659	0.517	
Total[§]			94.538		94.538

*Total Carbon stock for all the three forest reserves; [§]Total Carbon stock for all components; [¶]Total Carbon stock for each forest reserve

Establishment of sampling spots and data collection:-
Soil samples were collected from three spots along a gradient from the dominant tree (herein, *Vitellaria paradoxa*) in each plot. The three spots from the dominant tree were the sub-canopy (SC), drip line (DL) and 200% of the distance from the base of the tree to the drip line (Figure 1).
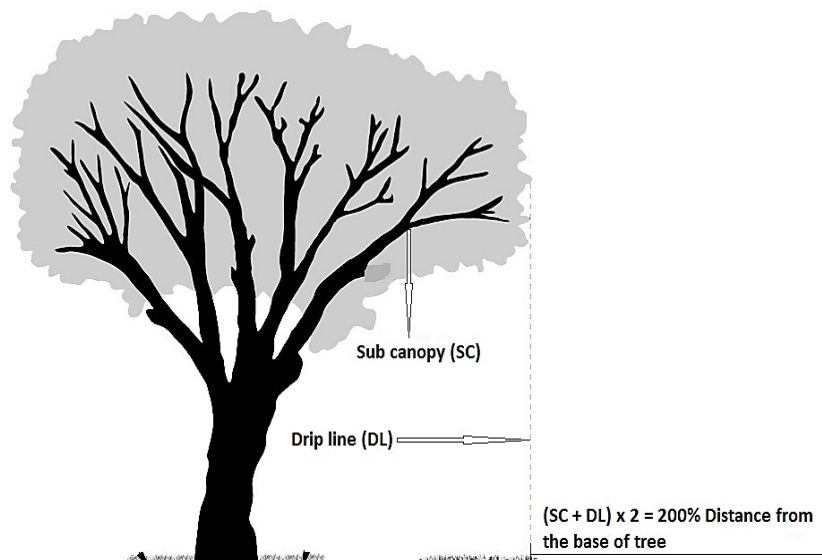

Figure 1:- Diagrammatic representation of soil sampling along the gradient of the dominant tree

Soil organic carbon was determined using the modified Walkley-Black method as described by (Nelson and Sommers, 1982). Soil carbon stock (CS) was calculated as (Guo and Gifford, 2002):

$$CS = SOC \times \rho_b \times D$$

where,
SOC = Soil organic carbon content (g g^{-1})

ρ_b = Bulk density (Mg m^{-3}) and
D = Soil depth or the thickness of the soil horizon (cm)

Statistical analysis:-

Data obtained was subjected to analysis of variance (ANOVA) in order to determine the significant differences among the different sampling classes and differences among the means were separated using least significant difference (LSD) at 5%. The statistical analysis was performed using Genstat statistical package (12th Edition).

Result and Discussion:-

The estimated soil carbon stock for the different forest reserves are presented in Table 2. These estimates comprise soil carbon stocks in the various soil fractions along a concentration gradient from the dominant tree species (i.e., *Vitellaria paradoxa*). Analysis of the soil carbon stock in the respective forest stands shows that the soil carbon pool dominates with the highest stock values across the highly vegetated Kenikeni and Sinsablegbinni forest estates, while the least carbon stock values were recorded for the Klupene forest reserve site. Overall, the soil carbon stock density of the forest reserves was in the decreasing order of: Sinsablegbinni forest, Klupene forest, and Kenikeni forest (Table 2). This implies that land management practices have considerable effects on the content and distribution of SOC under different vegetation covers as reported by (Baritz et al., 2010; Li et al., 2013; 2014; Shang et al., 2014; Zhang et al., 2014). Among the three different forest vegetation covers considered in this study, Kenikeni forest was an intact forest with minimal effects from human activities, however, the SOC concentration was relatively low as compared to that of Sinsablegbinni forest soil. The Sinsablegbinni and Klupene forests were described as degraded forests with different degrees of degradation, which had significantly different SOC distribution patterns. However, the soils under Sinsablegbinni forest reserve had the highest SOC (Table 2) due probably to its high tree stocking density (536 trees ha^{-1}) and secondary succession.

Table 2: Carbon stock (t/ha) distribution under the three forest reserves

Forest reserve	Concentration gradient (Distance from dominant tree)			♠Mean
	Sub canopy	Drip line	200% distance base of tree	
Kenikeni	732	592	798	707
Sinsablegbinni	821	3028	844	1564
Klupene	799	828	598	742
♠Mean	784	1483	747	
Lsd (5%)	*1072.3 ‡1072.3 †1857.3			
CV (%)	46.10			

♠Mean value for reserve; ♠Mean value for distance from dominant tree, *Lsd for forest reserves; ‡Lsd for sampling spot from the dominant tree; †Lsd for the forest reserve/sampling spot interaction

It is obvious that in spatial context, the sub-canopy zone recorded the highest mean soil carbon stock (SCS), followed by the drip line zone, and 200% distance from the base of the dominant tree in all three forest reserves. This observation is a clear evidence of the 'Islands of fertility' phenomenon, which is characteristic of arid ecosystems, wherein soil organic matter (SOM) and nutrient concentrations are considerably higher beneath tree canopies and shrubs than in the intervening spaces (Schlesinger et al., 1996). This phenomenon has been reported to be due to a combination of both biotic and abiotic processes, such as litter fall and decomposition, microbial activity, and atmospheric deposition (Charley and West, 1977; Garner and Steinberger, 1989), surface runoff (Parsons et al., 1992; Schlesinger et al., 1999), stemflow (Whitford et al., 1997), aeolian processes (Li et al., 2008), and livestock, especially cattle grazing and excreta (e.g. dung) from animals taking shelter (from the short wave radiation from the sun) beneath these trees and shrubs (Tuffour, 2012; Allington and Valone, 2014), all of which are factors prevalent in the Guinea Savanna agro-ecological zone.
.
The total soil carbon stocks estimated in this study are considerably higher than those reported by AAS (2012), wherein, the total carbon stock in Dzalanyama forest reserve were in the order of 66.14 and 33.07 t/ha, respectively. The difference between these values and the present study could be due to the number of sample spots used in the study and sampling designs. Whereas concentric sample plots were employed in the study by AAS (2012), in the present study, samples were collected along a concentration gradient (on 25 x 25 m area) from the dominant tree species. Additionally, three distinct sampling points (along a concentration gradient from the most dominant tree

species) were used, while for AAS (2012), only two sample plots were used. This could in some way have overestimated the values in this study. The result is a clear indication that degradation and deforestation have very high impact on both vegetation and soil carbon stock.

Analysis of carbon stock in the respective pools showed that the SOC had highest stock values across the highly vegetated communities. Carbon stock density of the vegetation communities was in the decreasing order of Sinsablegbinni (Moderately degraded forest) > Kenikeni (Intact forest) > Klupene (Degraded forest). This implies that forest degradation would have resulted in much carbon emission into the atmosphere (Jibrin et al., 2014). Assuming the total areas of the three reserves were covered by trees, then large amount of carbon would be stored, which would have pronounced effect on carbon that would be sequestered from the atmosphere. This would consequently allay the effect of CO_2 released from other sources, especially wild fire and farming – practices that are common in the Guinea Savanna zone. It is, thus, clear from the study that carbon balance projects based on forestry would be very effective in mitigating global carbon emissions from land use change and wood consumption over large areas. Conversely, the success or failure of individual projects are controlled by local factors (Watson et al., 2000; Jibrin et al., 2014), since sustainable carbon offset projects depend on both the biophysical potential of an area to sequester more carbon, and on the project's capacity to cater for maintenance of the local people and other stakeholders (Jibrin et al., 2013; 2014).

Conclusions:-
In this study, it was revealed that the distribution of soil carbon stock in the various forest stands showed that SOC pool was dominant in the highly vegetated forest. The SOC concentration along a concentration gradient from three distinct sampling points from the dominant tree in the various forest stands was highest in the coarse fraction in Sinsablegbinni and Klupene, and in the fine fraction in Kenikeni. Further, the trend of the results showed that the distribution of SOC with regards to the spatial distance from the dominant tree followed no definite trend in the various soil fractions, as well as, the vegetation cover. The highest SOC concentrations were recorded in the 200% distance from the base of the tree, drip line zone and the sub-canopy zone in Kenikeni, Sinsablegbinni and Klupene forests, respectively. Clearly, it was observed that soils under the sub-canopy zone of the dominant tree had the highest mean SCS followed by the drip line zone, which was a clear evidence of the existence of the 'Islands of fertility' phenomenon phenomenon. Thus, evidence of distinct spatial pattern of distribution of soil nutrients with higher levels under tree/shrub canopies compared to the interspaces between them has been revealed in this study under forest lands.

From the study, it was realised that carbon stock density of the vegetation communities was in the decreasing order of Sinsablegbinni (Moderately degraded forest) > Kenikeni (Intact forest) > Klupene (Degraded forest). Generally, the study has shown that changes in land use or management practices (including degradation and deforestation) can considerably affect SOC distribution patterns, which could be an essential indicator for the impact of land use changes on SOC dynamics.

The study has clearly shown that reductions in homogenous areas of tropical forests with secondary and primary forest patches play an essential role in the composition of tropical landscapes. This subsequently increases the heterogeneity in landscapes that can store significant amounts of carbon but offer greater challenges such as sampling intensity for their study. It is therefore necessary to consider spatio-temporal variations of the properties, and in the study of global C balance, especially in the tropics as influenced by different forest stands and affected by forest use intensities, as well as agroforestry systems. In addition, a landscape approach to studying the C balance and the hydro-biogeochemistry of tropical forests will facilitate the current ability to address issues about global elemental cycles. Further work may consider decoupling these factors for a better understanding of the mechanisms driving age and management-related patterns of C stock, the changes in species composition and nutritional properties and for improving the ability to model in carbon cycles in these critical biomes.

References:-
1. **AAS. (2012).** Forest resource mapping project under the Japanese grant for the forest preservation programme to Republic of Malawi: Final report for implementation phase, Department of Forestry, Malawi.
2. **Allington, G.R.H. and Valone, T.J. (2014).** Islands of Fertility: A Byproduct of Grazing? Ecosys. 17: 127-141.
3. **Baritz, R., Seufert, G., Montanarella, L. and van Ranst, E. (2010).** Carbon concentrations and stocks in forest soils of Europe. For. Ecol. Manage. 260: 262-277.
4. **Batjes, N.H. (1996).** Total carbon and nitrogen in soils of the world. Eur. J. Soil Sci. 47: 151-63.

5. **Charley, J.L. and West, N.E. (1977).** Micro-patterns of nitrogen mineralization activity in soils of some shrub-dominated semi-desert ecosystems of Utah. Soil Bio. Biochem. 9: 357-365.
6. **Detwiler, P.B. (1996).** Ca^{2+} dependence of dark and light adapted flash responses in rod photoreceptors. Neuron. 17: 323-331.
7. **Environmental Protection Agency (2003).** National Action Programme to combat drought and desertification. Accra, Ghana.
8. **Eswaran, H., Van den Berg, E. and Reich, P. (1993).** Organic carbon in soils of the world. Soil Sci. Soc. Am. J. 57(1): 192-194.
9. **FAO. (1997).** Forest harvesting in natural forests of the Republic of Congo, Forest Harvesting Case Studies-07.
10. **Garner, W. and Steinberger, Y. (1989).** A proposed mechanism for the formation of ''Fertile Islands'' in the desert ecosystem. J. Arid Environ. 16: 257-62.
11. **Guo, L. and Gifford, R.M. (2002).** Soil carbon stocks and land use change: a meta-analysis, Global Change Bio. 8: 345-360.
12. **Houghton, R.A., Lefkowitz, D.S. and Skole, D.L. (1991).** "Changes in the landscape of Latin America between 1850 and 1985 I. Progressive loss of forests." For. Eco. Manag. 38(3): 143-172.
13. **Jibrin, A., Musa, I.J., Abdulkadir, A., Yisa, C.L. and Kaura, S.J. (2013).** 'Towards harnessing forestry-based carbon sequestration potentials in Nigeria: Costs and Benefits'. Nig. Geog. J. 9(1): 40-54.
14. **Jibrin, A., Zubairu, S.M. and Kaura, S.J. (2014).** Carbon Sequestration Potential of Kpashimi Forest Reserve, Niger State. Nig. J. Geog. Earth Sci. 2(1): 149-163.
15. **Li, Y.F., Zhang, J.J., Chang, S.X., Jiang, P.K., Zhou, G.M., Fu, S.L., Yan, E.R., Wu, J.S. and Lin, L. (2013).** Long-term intensive management effects on soil organic carbon pools and chemical composition in Moso bamboo (*Phyllostachys pubescens*) forests in subtropical China. For. Ecol. Manage. 303: 121-130.
16. **Li, Y.F., Zhang, J.J., Chang, S.X., Jiang, P.K., Zhou, G.M., Shen, Z.M., Wu, J.S., Lin, L., Wang, Z.S. and Shen, M.C. (2014).** Converting native shrub forests to Chinese chestnut plantations and subsequent intensive management affected soil C and N pools. For. Ecol. Manage. 312: 161-169.
17. **Li. J., Okin, G., Alvarez, L. and Epstein, H. (2008).** Effects of wind erosion on the spatial heterogeneity of soil nutrients in two desert grassland communities. Biogeochem. 88: 73-88.
18. **Lugo, A.E. and Brown, S. (1993).** Management of tropical soils as sinks or sources of atmospheric carbon. Plant Soil. 149: 27-41.
19. **Nelson, D.W. and Sommers, L.E. (1982).** Total carbon, organic carbon, and organic matter. 539-579 p. *In*: A.L. Page (ed.) Methods of Soil Analysis. 2nd Ed. ASA Monogr. 9(2). American Society Agronomy, Madison, WI.
20. **Parsons, A.J., Abrahams, A.D. and Simanton, J.R. (1992).** Microtopography and soil-surface materials on semi-arid piedmont hillslopes, southern Arizona. J. Arid Environ. 22:107-15.
21. **Schlesinger, W.H., Abrahams, A.D., Parsons, A.J. and Wainwright, J. (1999).** Nutrient losses in runoff from grassland and shrubland habitats in Southern New Mexico: I. Rainfall simulation experiments. Biogeochem. 45: 21-34.
22. **Schlesinger, W.H., Raikes, J.A., Hartley, A.E. and Cross, A.F. (1996).** On the spatial pattern of soil nutrients in desert ecosystems. Ecol. 77(2): 364-374.
23. **Shang, S., Jiang, P., Chang, S.X., Song, Z., Liu, J. and Sun, L. (2014).** Soil Organic Carbon in Particle Size and Density Fractionations under Four Forest Vegetation-Land Use Types in Subtropical China. For. 5: 1391-1408.
24. **Sombroek, W., Nachtergaele, F.O. and Hebel, A. (1993).** Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. Ambio. 22: 417-426.
25. **Tuffour, H.O. (2012).** Spatial variability of physical, hydraulic and hydrologic properties of a tropical soil. MSc. Thesis, Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.
26. **Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. and Donken, D.J. (2000).** Land Use, Land-Use Change and Forestry. Special Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, USA. 375pp.
27. **Whitford, W.G., Anderson, J. and Rice, P.M. (1997).** Stemflow contribution to the 'fertile island' effect in creosotebush, *Larrea tridentata*. J. Arid Environ. 35: 451-7.
28. **Zhang, T., Yuan, Y., Wei, W., Yu, S., Zhang, R., Chen, F., Shang, H. and Qin, L. (2014).** A tree-ring based precipitation reconstruction for the Mohe region in the northern Greater Higgnan Mountains, China, since AD 1724. Quat. Res. 82(1): 14-21.