International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 27 No. 2 Sep. 2019, pp. 591-598

http://www.ijias.issr-journals.org/

IMPACT OF CASHEW PLANTATION ON CARBON STOCK IN THE FOREST-SAVANNA TRANSITION ZONE (NORTH-EAST COTE D'IVOIRE)

AKPA YOU LUCETTE[1-2], DIBI N'DA HYPPOLITE[2-3-4], KYEREH BOATENG[5], and KPANGUY KOUASSI BRUNO[3-4]

[1]WASCAL Graduate Research Program in Climate Change and Land Use, Kwame Nkrumah University of Science and Technology, Ghana

[2]Centre Universitaire de Recherche et d'Application en Télédétection, CURAT, Université Félix Houphouët Boigny, Côte d'Ivoire

[3]Centre National de Floristique, Université Félix Houphouët Boigny, Côte d'Ivoire

[4]Laboratoire de Botanique, UFR Biosciences, Université Félix Houphouët Boigny, Côte d'Ivoire

[5]Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology, Ghana

ABSTRACT: The increasing world demand for cashew (*Anacardium occidentale L.*) nuts and by-products generates rapid expansion of cashew cultivation across West-African countries especially in Cote d'Ivoire. This has created wealth for many smallholders. This is not to mention the pressure on forest-savanna transition zone. The aim of this study is to assess the impact of cashew production on carbon stocks. Vegetation inventory and soil sampling (0-20cm and 20-40cm) were done to estimate the above and below ground as well as soil carbon for savanna, forest and cashew plantain at different growing stages. The total carbon stocks in Mg C ha^{-1} were low in cashew plantations, where mature stands had 21.826 ± 3.23 (Mean ± SE), young 25.927 ± 6.53 and juvenile 16.732 ± 2.96 compared with natural vegetation (forest/woodland 64.375 ± 12.43, tree savannas 23.94 ± 3.3 and tree/shrub savannas 21.012 ± 10.12). There was no significant difference in soil organic carbon and total soil carbon stocks under different land use types, except between forest (24.67 ± 5.37 Mg C ha^{-1}) and tree/shrub savanna (8.92 ± 1.57 Mg C ha^{-1}). This implies that cashew expansion is of higher threat to more woody vegetation which has serious implication in terms of conservation and carbon sequestration. There is therefore a need for a more sustainable management approach to cashew agriculture practices to ensure optimum production for farmers, while conserving the forest-savanna ecosystem.

KEYWORDS: aboveground and belowground biomass, cashew plantation, forest savanna transition, soil carbon stock, Cote d'Ivoire.

1 INTRODUCTION

The change in land use and land cover through agriculture is responsible for the depletion of carbon stocks in vegetation and soil, and this contributes to the emission of carbon into the atmosphere [1] And the net flux of carbon from land use and land cover change accounted for 12.5% of anthropogenic carbon emissions from 1990 to 2010 [2]. The tropical forest conversion contributes as much as 25 % of net annual CO2 emissions globally [3]. The level of disturbance (i.e. land use and cover change) affects biomass and soil carbon at different rates.

The net contributor of vegetation carbon stock comes from primary forest ecosystems with an average of 300 t C ha^{-1} and that of logged or managed forests which ranged from 93 Mg C ha^{-1} in Indonesia to 228 t C ha^{-1} in Cameroon [4]. In Kenya, [5] estimated at 450 t C ha^{-1} the total biomass pools in indigenous forest whilst old plantations (pine, cypress, eucalyptus) recorded 197 to 242 t C ha^{-1}. In Ghana, [6] observed that the carbon stocks between various land use systems in different ecological zones (moist evergreen forest, dry semi deciduous forest and savanna) showed an increasing order from cultivated land (30.87 to 75.12 t C ha^{-1}), fallow land (39.36 to 95.46 t C ha^{-1}), teak plantation (51 to 138.33 t C ha^{-1}) and the natural forest (51 to

326.75 t C ha^{-1}), thus revealing a dependency in terms of land use and also in terms of environmental conditions. More recently, plantation forests and other agroforestry practices were encouraged in the afforestation, reforestation and climate mitigation measures to enhance carbon sequestration and to maintain *in situ* carbon [5]. Several studies were conducted to assess carbon stocks of forest and perennial plantations for instance, rubber trees plantations [7] [8] [9], palm oil plantations [10] [11] [12] [13] [14]), for cocoa [15] [16]. However few studies assessed and monitored the amount of carbon stored in cashew (*Anacardium occidentale L.*) plantations. Cashew is a perennial crop that thrives under different soil and climatic conditions [17]. Identified as an agroforesty system, cashew plantations are likely to contribute in the current climate change mitigation process through its carbon sequestration potential [18]. Cashew is also said to have a positive effect on land restoration and soil conservation (because it slows down erosion, one of its qualities acknowledged by West African countries). Recently, there is an important expansion of cashew in West Africa countries mainly driven by a high demand of cashew nuts and kernel at world level [19] [20]. Cashew production has then contributed to improve livelihoods of farmers and even to the national economy in some countries. Moreover, projections suggest that this demand will continue increasing by 2020. The world cashew kernel demand is expected to grow by 5.9% per annum and the cashew demand would increase with a percentage growth of 4.6% [21]. There is therefore a need to assess its contribution in the global carbon storage process. Thus the aim of this study is to assess the impact of cashew production on carbon stocks in the forest-savanna transition zone. The hypothesis was that the conversion of natural vegetation to cashew plantation would lead to a decrease in carbon stocks.

2 MATERIALS AND METHODS

2.1 STUDY AREA

The study area is located within the forest-savanna transition ecological zone (latitudes 8˚26 N and 7˚20 N and longitudes 3˚32 W and 3˚28 W) (Figure 1). The average rainfall is between 800 mm and 1400 mm per annum, and average temperature ranging from 26˚C to 27˚C [22]. The mean monthly temperature is between 24˚C and 28.6˚C, with the highest value (more than 27 ˚C) occurring during the long dry season. The relative humidity has a unimodal curve going from 82% during the rainy periods to the minima of 50% in January. The vegetation, reflecting its geographical and climatic position, is mainly made up of savanna woodlands, tree savanna and shrub savanna. The site which is under lateritic deposit is close to the Comoe National Park [23] . Many riparian forests are observed along the rivers whilst dense forest islands are scattered mainly on hilltops. Soils are mainly acrisols (82%) followed by luvisols and cambisols according to the FAO classification. that the soils are mainly disturbed or typical with hard ground (at middle or low depth) and with some eutrophic brown soils.

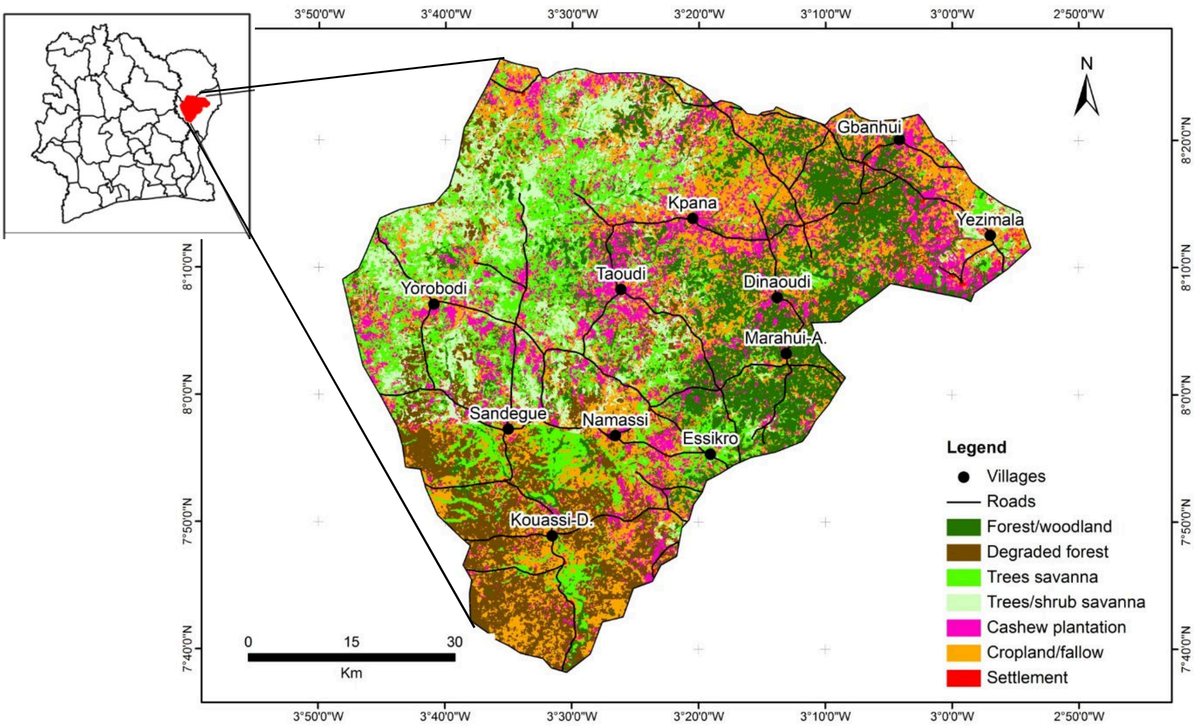

Fig. 1. Land use/cover map of the study area

2.2 SAMPLING METHODS

Several plots were randomly selected and established with size of 20 m x 20 m in cashew plantations along a chronosequence at various stages of growth (0-4 years n=23; 5-8 years n=30 and greater than 9 years n=26) and in other land cover types (forest/woodland n=26; tree savanna n=24 and tree/shrub savanna n=23).

For aboveground biomass (AGB), all trees with diameter at breast height of 1.3 m (DBH) greater than 5 cm were identified and DBH measured. The above biomass was estimated using pantropical allometric regression equations developed by [24] for dry forest.

$$AGB = \rho \, exp^{(-0.667+1.78\ln(DBH)+0.207(lnDBH)^2-0.208(lnDBH)^3} \quad \text{Eq. (1)}$$

Where AGB = above ground biomass (Mg C ha^{-1}); DBH = Diameter at Breast Height (m); ρ = the wood density of three species.

The mass of cashew was estimated from the allometric equation developed for cashew in Northeast Brazil [25 as:

$$AGB = 1.398\,DBH - 0.097 \quad \text{Eq. (2)}$$

And the belowground biomass (BGB) was derived using [26] equation.

$$BGB = 0.345\,AGB^{0.884} \quad \text{Eq. (3)}$$

Where BGB = belowground biomass of tree species (Mg C ha^{-1})

Soil samples were collected at two depth intervals 0-20 cm and 20-40 cm for each land use type (n=10 for 0-4 years plantations; n=9 for 5-8 years; n=10 for greater than 9 years plantations; n=9 for forest/woodland; n=8 for tree savanna; and n=8 for tree/shrub savanna). Samples were air dried for five days and sieved through a 2-mm sieve prior to laboratory analyses. The soil organic content was determined at the laboratory using the wet oxidation Walkley Black. Soils for bulk density were taken in the soil pit for each of the two depth intervals, using the sand replacement method [27]. Each soil samples is a composite of 5 replicate samples. The following equation was used to estimate the soil organic carbon per unit area [28] (Hairiah *et al.*, 2011):

$$SOC = \%C \times BD \times Depth$$

Where: SOC = Carbon stock in soil organic carbon for sample plot (Mg C ha^{-1}); %C = Soil organic carbon concentration for sample plot obtained from laboratory measurement; BD = Soil bulk density of fine (< 2 mm) fraction of mineral soil in sample plot determined in the laboratory (g cm^{-3}); Depth = depth to which soil sample is collected in sample plot (cm).

The overall total carbon for each land use classes was computed by sum of aboveground, belowground and soil carbon.

2.3 STATISTICAL ANALYSIS

Data collected and generated were subjected to the common descriptive analysis and differences between land use classes in terms of carbon stocks were tested using analysis of variance (ANOVA) and LSD fisher tests with a 95% confidence interval. The SPSS 16 package was used.

3 RESULTS

3.1 BIOMASS AND SOIL CARBON STOCKS

The mean value of biomass carbon for each compartment is presented in Table 1. And the ranking system in terms of total biomass carbon followed the same pattern than above ground and below ground biomass: forest/woodland > trees savanna > tree/shrub savanna > Pl 9+ > Pl 5-8 > Pl 0-4.

Table 1. Mean (± SE) of stand biomass carbon pools for various land use/ land cover classes

Land use/ land cover classes	AGB Carbon (Mg ha^{-1})	BGB Carbon (Mg ha^{-1})	Total Biomass Carbon (Mg C ha^{-1})
FOR_WD	62.16 ± 9.01	12.50 ± 1.68	36.17 ± 5.35
TR_SAV	22.63± 2.25	5.37 ± 0.47	13.99 ± 1.37
TR_SHR	19.58 ± 5.14	4.54 ± 1.25	12.06 ± 3.08
Pl 0-4	1.11 ±0.27	0.36 ±0.07	0.74 ± 0.17
Pl 5-8	5.57 ±0.6	1.55 ±0.15	3.56 ± 0.37
Pl 9+	11.34 ±1.24	2.91 ± 0.5	7.12 ± 0.76

ANOVA statistical comparison was used to assess the difference in mean of total carbon between each land use/ land cover class after normality of data was tested. There were significant differences in stand carbon stocks between forest/woodland and the other land use/ land cover classes *($p < 0.05$)* and between tree savanna and juvenile plantation. However, carbon stocks were not significant between tree savanna, tree/shrub savanna, young and mature plantations. Furthermore, tree/shrub savanna was not statistically different from all plantations.

In terms of soil carbon, there was a different trend. Forest/woodland and cashew plantation recorded high value of soil carbon compared to savanna (Table 2). However, the LSD test showed that were no significant variations in the mean of total soil carbon stocks across the six land use classes, except between forest/woodland and tree/shrub savanna ($p < 0.05$).

Table 2. Mean (± SE) of soil carbon parameters under all land use/ land cover classes

	SOC (%)		Bulk density (g cm^{-3})		Carbon stock (Mg C ha^{-1})		Soil Carbon (Mg C ha^{-1})
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20cm	20-40cm	-
FOR_WD	1.56±0.3	0.70±0.2	1.12±0.2	0.85±0.1	21.93±5.8	4.11±1.1	24.67±5.37
TR_SAV	0.79±0.1	0.75±0.2	0.66±0.07	0.70±0.06	7.46±1.26	7.68±3.44	13.22±3.44
TR_SHR	1.59±0.49	0.22±0.02	0.63±0.05	0.63±0.27	7.36±1.68	2.51±0.39	8.92±1.57
Pl 0-4	1.54±0.26	1.19±0.29	0.55±0.18	0.67±0.03	7.74±2.14	8.0±2.77	15.75±5.37
Pl 5-8	1.20±0.2	0.68±0.14	0.571±0.09	0.69±0.04	19.05±6.68	5.132±1.18	23.15±6.48
Pl 9+	1.31±0.29	0.74±0.15	0.62±0.06	0.66±0.29	9.26±2.11	4.86±1.43	13.63±2.72

3.2 TOTAL CARBON STOCKS BETWEEN LAND USE CLASSES

The total carbon stocks (biomass + soil) showed a large contribution of soil carbon for cashew plantations (65 to 90 %) compared to natural vegetations (less than 50%) (Figure 2). Forest/woodland had an average value of 62.21 Mg C ha^{-1}, followed by savannas (29.13 to 21.91) Mg C ha^{-1}) and cashew plantations (27.74 to 21.24 Mg C ha-1). The lowest value was observed in juvenile cashew plantations. Comparing total carbon stock for all the land use/ land cover classes, it can be observed that variations between forest/woodland and the other land use/ land cover classes were statistically significant (savanna and young plantation at $p < 0.05$ and juvenile and mature plantations at $p < 0.01$). There were no significant differences between tree savanna and tree/shrub savanna ($p<0.05$). No statistically significant differences were noted among carbon stocks of the different plantation ages despite the high mean carbon stock of young and mature plantations compared to juvenile plantations. Variation of total carbon stock between savanna and plantation was also not statistically significant at 95% confidence.

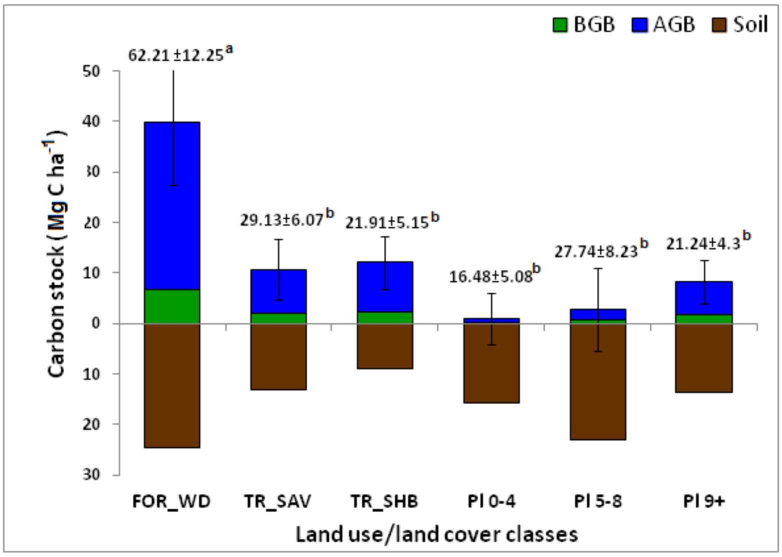

Fig. 2. Mean total carbon stock pools for all selected land use/ land cover classes. Different letters indicate statistically different means (LSD test, P ≤ 0.05)

Thus, taken any natural vegetation as benchmark, loss of carbon stocks from conversion to cashew plantations was analysed. Thus, conversion from forest/woodland to cashew plantation might lead to a progressive total loss of about 75%, 55%, and 65% respectively at juvenile, young to mature growth stages. In the case of tree savanna, the first stage of maturity resulted of about 43% of carbon loss, and then finished at 27% of loss at mature stage. Finally the loss for trees/shrub savanna is about 27 % for juvenile plantation and negligible (less than 5%) for mature plantation.

4 DISCUSSION

4.1 BIOMASS CARBON STOCK

Biomass carbon of forest/woodland was as expected higher than that for both savannas and plantations whilst savannas had higher carbon stocks than plantations. Forest/woodland recorded an average biomass carbon value of 36.17 ± 5.34 Mg ha^1. This amount is low compared to what [6] Adu-Bredu *et al.* (2008) found for dry semi deciduous forest (156 Mg ha^{-1}) and range values for tropical humid forest given by [29] The results are close to weighted mean aboveground carbon ranging from 13.5 ± 2 to 29.8 ± 5 Mg $ha^{-1}$for the Miombo woodland [30] and much closer to carbon stock (9 - 113 Mg ha^{-1}) of the vegetation type called degraded savannas and remnant forest as described by [31. For savannas both tree savanna and tree/shrub savanna were not different in terms of biomass carbon according to the LSD. Savannas within this area were characterised by few trees per hectare because many of them had a DBH < 5 cm probably as a result of high bush fire occurrence that affect smaller trees more severely and retard their growth and recruitment into bigger diameter classes [32], [33], [34] or a combination of fire and grazing [35]). Studies showed that savannas that are highly subjected to fire have trees with smaller size both in height and basal area than other areas less affected by fire and termites [34. Fires reduce considerably woody vegetation and therefore affects biomass production and carbon stocks [36]. This study revealed a low biomass carbon storage capacity of cashew plantations from 1.01 to 7.18 Mg ha^{-1} compared to natural vegetation, but with no significant difference with savannas. Similar studies on cashew are not available for comparison but compared to other trees plantations such as cocoa, oil palm or rubber, cashew can be seen as a poor carbon sink. Therefore conversion from forest/woodland to cashew plantations is likely to reduce biomass carbon stock significantly but less so for savannas. The cashew biomass equation of [37] was based on DBH and wood density however, [38] revealed the importance of litter fall in cashew biomass estimation. In the present study, litter was not taken into account because data were collected at a time when litter had been removed by farmers during weeding.

4.2 SOIL CARBON STOCK

Impact of cashew plantations at different growing stages on soil carbon was assessed at surface and subsurface. Soil organic carbon measured ranged between 1.2 to 1.54 at surface and 0.67 to 1.93 at subsurface with the lowest values associated with young plantations and the highest with juvenile plantations. No significant difference was observed between SOC under natural vegetation and plantations. This implies that in the forest-savanna transitional zone cashew may not have effect on SOC variations. This situation was observed by [39] who did not find any difference between logged forest and 35-year cashew plantation in different soil parameters such as organic carbon, nitrogen, exchangeable calcium and magnesium, and available phosphorus. SOC did not show depth dependency as observed in another study for till agriculture [40]. Changes in land use or land cover agriculture practices are often responsible to change in SOC either positively or negatively. [41] explained that crop removal associated with monoculture agriculture systems during harvesting leads to depletion of carbon available for recycling in the systems. In the current study however, no variations in soil carbon were observed between cashew planted areas and the natural vegetation.

4.3 TOTAL CARBON STOCKS

Comparison of natural vegetation to cashew plantations showed that the contribution of soil carbon to the total carbon stocks is higher in plantations. In natural vegetation soil carbon formed between 37 to 50% of the total carbon stocks whereas in cashew plantations, it ranged from 61% to 93.75%. This was the case of *Vittelaria paradoxa* and *Faidherbia albida* parklands, where soil carbon highly contributed to the total carbon stock [4]. [6] also observed an important input of soil carbon in the total stock for cultivated areas. This shows that in the absence of heavy biomass, total carbon stocks are largely determined by amount of carbon stored in the soil. Cashew plantations in the present study had lower carbon stocks compared to the natural vegetation. The average values were about 16 Mg C ha^{-1} for juvenile, 28 Mg C ha^{-1} for young and 21 Mg C ha^{-1} for mature plantations. These values are very low compared to what [42] estimated in Indonesia for cashew using CO_2 Fix Model. Carbon stock was estimated at 33.8 Mg C ha^{-1}, for plantations between 5 years and 10 years, and might get to 74 Mg C ha^{-1}around 25 years. Assessment of the change in carbon stocks when natural vegetation is converted to cashew plantation showed the major loss to occur when forest/woodland is replaced by cashew. Based on the mean carbon stock estimated, nearly 48 t/ha of carbon might be lost from forest at the earlier stage of establishment. During the development process until the mature growth stage, only about 20% of the lost carbon might be recovered by cashew plantation. This represents a total loss of 40 t/ha (80%). This result is comparable to carbon lost when forest is cleared for agricultural purposes in dry semi-deciduous forests [6]. In Brazil cashew orchards are responsible for the loss of carbon during forest conversion and nitrogen emission during cultivation because of the use of fertilizers [43]. On the other hand, cashew plantations established in savanna areas are likely to restore the loss of about 8 t/ha carbon at the mature growing stage. Therefore, the use of marginal lands for cashew plantations is highly recommended to ensure biodiversity conservation and carbon gain

5 CONCLUSION

Forest/woodland had distinctly higher levels of biomass carbon compared to other land use/classes and carbon stocks were generally about 4.5 times higher in natural vegetation than in plantations. Values of soil carbon from plantations at various growth stages did not differ statistically from those for natural vegetation. These soil carbon pools contributed highly to the total carbon of each land/cover classes and influenced the overall pattern of carbon stocks in the landscape. Consequently forest/woodland total carbon was significantly higher than other land use/cover classes whilst carbon stocks in savannas were not statistically different from those of plantations. There was an increase trend of carbon stock in cashew plantation, but it was not plantation age classes-dependent. The conversion of natural vegetation (forest) to cashew as a monoculture system results in a significant reduction in carbon stocks therefore to ensure better management of the transitional zone for carbon stocks enhancement. It is recommended that the policy on the forest savanna transitional zone management should encourage the use of marginal or already degraded lands for cashew establishment to reduce the pressure on areas better stocked with trees.

ACKNOWLEDGEMENTS

The authors are grateful to German Ministry of Science and Education (BMBF) through WASCAL for fully funding this research.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

[1] T. L Sohl, B. M. Sleeter, Z. Zhu, K. L. Sayler, S. Bennett, M. Bouchard, and W. Acevedo, “A land-use and land-cover modelling strategy to support a national assessment of carbon stocks and fluxes,” Applied Geography, vol. 34, pp 111-124, 2012.

[2] R.A Houghton, “Carbon emissions and the drivers of deforestation and forest degradation in the tropics,” Current Opinion in Environmental Sustainability, vol.4, no. 6, pp.597-603, 2012.

[3] C. A Palm,., T. Tomich, M. Van Noordwijk, S.Vosti, J.Alegre, J.Gockowski, and L.Verchot, “Mitigating GHG emissions in the humid tropics: Case studies from the Alternatives to Slash-and-Burn Program (ASB),” Environ. Dev. Sust., vol. 6**,** pp. 145-162, 2007.

[4] O. Takimoto, *Carbon Sequestration Potential of Agroforestry Systems in the West African Sahel: An Assessment of Biological and Socioeconomic Feasibility*. PhD, University of Florida**,** 184, 2009.

[5] L. M. A Omoro, M. Starr, and P. K. E. Pellikka, “Tree biomass and soil carbon stocks in indigenous forests in comparison to plantations of exotic species in the Taita Hills of Kenya”, Silva Fennica, vol 47, issue 2**,** no.18, 2013.

[6] S. Adu-Bredu, M. K. Abekoe, E.Tachie-Obeng, and P.Tschakert, Carbon stock under four land use systems in three varied ecological zones in Ghana. . Africa and the Carbon Cycle Proceedings of the Open Science Conference on “Africa and Carbon Cycle: the CarboAfrica project”. Accra (Ghana) 25-27 November 2008.

[7] V. H. L Rodrigo, E. S Munasinghe,. and U. A. D. P Gunawardena,.. "Development of a simple protocol for in situ assessments of timber, biomass and carbon in the rubber layer". In: N.M. Mathew, C. K. J., M.G.S. Nair, K.K. Thomas, G.C. Satisha, P. Srinivas, A.C. Korah, A.S. Ajitha, L. Joseph (Eds.), Preprints of Papers. (ed.) International Natural Rubber Conference, Rubber Research Institute of India, Cochin (2005), pp. 246-255, 2005.

[8] J. C.Yang, J. H.Huang, J. W.Tang, Q. M Pan,. and X. G Han, "Carbon sequestration in rubber tree plantations established on former arable lands in Xishuangbanna, SW China". Acta Phytoecologica Sinica, vol. 29 no. 2**,** pp.296-303, 2005.

[9] J. B.Wauters, S.Coudert, E.Grallien, M.Jonard, and Q.Ponette, "Carbon stock in rubber tree plantations in Western Ghana and Mato Grosso (Brazil)," Forest Ecology Management, vol. 255**,** pp. 2347-2361, 2008.

[10] E. Lamade, and J. P Bouillet, "Carbon storage and global change: the role of oil palm". Oléagineux, corps gras, lipides, vol. 12**,** pp. 154-160, 2005

[11] L.Melling, K. J Goh, C.Beauvais, and R.Hatano, "Carbon flow and budget in young mature oil palm agroecosystem on deep tropical peat", Planter, vol. 84 no. 21, 2008

[12] A. C. Morel, J.B. Fisher, Y.Malhi, "Evaluating the potential to monitor aboveground biomass in forest and oil palm in Sabah, Malaysia, for 2000-2008 with Landsat ETM+ and ALOS-PALSAR". International Journal of Remote Sensing, vol. 33, pp. 3614- 3639, 2012

[13] T. B.Bruun, K.Egay, O.Mertz, and J.Magid, "Improved sampling methods document decline in soil organic carbon stocks and concentrations of permanganate oxidizable carbon after transition from swidden to oil palm cultivation". Agriculture, Ecosystems & Environment, vol. 178 pp. 127-134, 2013.

[14] L. A.Frazão, K.Paustian, C. E. P.Cerri, and C. C. Cerri, "Soil carbon stocks under oil palm plantations in Bahia State, Brazil". Biomass and Bioenergy, 2014.

[15] J.Jacobi, M. I.Pillco, M.Schneider, and S.Rist,. Biomass and Carbon Stocks Related to Ecological Complexity and Tree Diversity in Three Different Cocoa Production Systems. Resilience of agricultural systems against crises. Tropentag , September 19-21 , 2012, Gottingen Kassel/Witzenhausen, 2012.

[16] L.Norgrove, and S.Hauser, "Carbon stocks in shaded Theobroma cocoa farms and adjacent secondary forests of similar age in Cameroon". Tropical Ecology, vol. 54 no. 1, pp. 15-22, 2013.

[17] C. D Dedzoe, J. K Senayah, and R. D Asiamah, "Suitable Agro-ecologies for Cashew (Anacardium Occidentale L.) Production in Ghana". West African Journal of Applied Ecology, vol. 2, 1 p. 6, 2001

[18] S. S.Stephens, and M. R.Wanger, "Forest plantation and biodiversity: a fresh perspective". Journal of Forestry, vol 5, no. 6, p.7. 2007

[19] R. Venkattakumar, "Socio-Economic Factors for Cashew Production and Implicative Strategies : An Overview". Indian Res. J. Ext. Edu., vol. 9; no. 3, p 8, 2009

[20] J. O.Lawal, O. O.Oduwwole, T. R.Shittu, and A. A.Muyiwa, "Profitability of value adistion to cashew farming households in Nigeria," African Crop Science Journal, vol. 19, no. 1, p 6, 2011

[21] S. P.Malhotra, World Edible Nuts Economy, 2008

[22] M Youan Ta, *Contribution de la télédétection et des systèmes d'informations géographiques à la prospection hydrogéologique du socle précambrien d'Afrique de l'Ouest : cas de la région de Bondoukou (Nord-Est de la Côte d'Ivoire)*.Thèse de Doctorat de l'Université de Cocody (Abidjan), Côte d'Ivoire., pp. 259. 2008

[23] A.Fournier, "Contribution à l'étude de la végétation herbacée des savanes de Ouango Fitini (Côte d'Ivoire), les grands traits de la phénologie et de la structure". Candollea vol. 38, no. 38, pp. 237-265, 1983

[24] J.Chave, C.Andalo, S.Brown, M. A.Cairns, J. Q.Chambers, D.Eamus, H.Fölster, F.Fromard, , N.Higuchi, T.Kira, J.-P.Lescure, B. W.Nelson, et al., "Tree allometry and improved estimation of carbon stocks and balance in tropical forests," Oecologia, vol 45, pp.87-99, 2005

[25] R.Avtar, W.Takeuchi, and H.Sawada, "Monitoring of biophysical parameters of cashew plants in Cambodia using ALOS/PALSAR data," Environmental Monitoring and Assessment, May 2012, pp.1-15, 2012

[26] M. A.Cairns, S.Brown, E. H.Helmer, and G. A Baumgardner, "Root biomass allocation in the world's upland forests", Oecologia, vol. 111, pp.1-11, 1997

[27] B. C.Punmia, and K.Jain, A. *Soil Mechanics and Foundations*, 2005

[28] K.Hairiah, S.Dewi, F.Agus, S.Velarde, A.Ekadinata, S.Rahayu, and M.van Noordwijk, *Measuring Carbon Stocks Across Land Use Systems: A Manual. Bogor, Indonesia.* World Agroforestry Centre (ICRAF), SEA Regional Office, p.154, 2011

[29] S. Brown, "Estimating biomass and biomass changes of Tropical Forests". FAO Forestry Paper 134, Rome, 1997

[30] D. D.Shirima, P. K. T Munishi, S. L Lewis, N. D.Burgess, A. R Marshall, A.Balmford, R. D Swetnam, and E. M Zahabu, "Carbon storage, structure and composition of miombo woodlands in Tanzania's Eastern Arc Mountains," African Journal of Ecology, vol. 49, pp. 332-342, 2011

[31] P. L. Woomer, , L. L.Tieszen, , G. G.Tappan, , A. Toure, and M.Sall,. Land use change and terrestrial carbon stocks in Senegal. Journal of Arid Environments, 59, 625-642. 2004

[32] K. J.Hennenberg, F.Fischer, K.Kouadio, D.Goetze, B.Orthmann, K. E.Linsenmair, F.Jeltsch, and S.Porembski, "Phytomass and fire occurrence along forest–savanna transects in the Comoé National Park, Ivory Coast," Journal of Tropical Ecology, vol. 22, no. 3, p. 9, 2006.

[33] D.Zida, L.Sawadogo, M.Tigabu, and P. C.Oden, "Dynamics of sapling population in savanna woodlands of Burkina Faso subjected to grazing, early fire and selective tree cutting for a decade," Forest Ecology and Management, vol. 243, pp. 102-115, 2007

[34] A. B. N'Dri, J.Gignoux, S.Konate, A.Dembele, and D.Aıdara, "Origin of trunk damage in West African savanna trees: the interaction of fire and termites," Journal of Tropical Ecology, vol. 27, pp. 269-278, 2011

[35] S. S. H.Biaou, *Tree recruitment in West African dry woodlands: The interactive effects of climate, soil, fire and grazing*. PhD Wageningen University, The Netherlands, 156. 2009.

[36] F.Van Langevelde, C. A. D. M.Van de Vijver, L.Kumar, J.Van de Koppel, N.De Ridder, J.Van Andel, A. K.Skidmore, J. W.Hearne, L.Stroosnijder, W. J.Bond, H. H. T. Prins, and M. Rietkerk, "Effects of fire and herbivory on the stability of savanna ecosystems," Ecology and Society, vol. 84, pp. 337-350, 2003

[37] A. M Rajaona, "Comparative study of allometric parameters of cashew tree (Anacardium occidentale) in North East Brazil," University of Bonn, 2008

[38] S. M. G.Callado, *Environmental Sustainability Analysis of Cashew Systems in North-east Brazil*. Doctor of Agriculture, ULB Bonn, 95, 2008

[39] A. O.Aweto, and M. A.Ishola, "The impact of cashew (Anacardium occidentale) on forest soil," Experimental Agriculture, vol. 30, pp. 337-341, 1993

[40] R. R.Ratnayake, T.Kugendren, and Gnanavelrajah, "Changes in soil carbon stocks under different agricultural management practices in North Sri Lanka," J. Natn.Sci.Foundation Sri Lanka, vol. 42, no. 1, pp. 37-44, 2014

[41] R. R.Ratnayake, G.Seneviratne, and S. A.Kulasooriya, "The effect of cultivation on organic carbon content in the clay mineral fraction of soils," International Journal of Soil Science, vol. 6, pp. 217-223, 2011

[42] H.Iskandar, L. K.Snook, T.Toma, K. G MacDicken,. and M.Kanninen, "A comparison of damage due to logging under different forms of resource access in East Kalimantan, Indonesia," Forest Ecology Management, vol. 237, pp. 83-93, 2006

[43] M. C. B.de Figueiredo, J.Potting, L. A. L.Serrano, M. A.Berreza, V. d. S.Barros, R. S.Gondim, and T.Nemecek, Life cycle assessment of Brazilian cashew. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector, pp. 395-404, 2009