Woodlot Agroforestry in the Lower Volta Basin, Ghana: Contribution of Tree Species Admixture to Aboveground Carbon

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Abstract

With current interest in obtaining financial rewards from sequestered **C** in tree plantation-management, it has become critical to begin examining many tropical wood species and their characteristic qualities to site-specific rainfall and drought issues which together influence growth performance in relation to 'leakage' avoidance, a potential for carbon marketing under CDM or REDD/REDD+. This paper presents a plot-level assessment of four different woodlot agroforestry establishments in relation to above ground carbon stocking. Based on the two regression equations for dry to moist conditions for estimating biomass, tree allometric-measure analysis were carried out on 3–4 ha woodlot agroforestry establishments at Bakpa-Agboglakope, a rural community in the North Tongu District of the Volta Region. The study site constitutes part of the post dam floodplains of the lower Volta river now prone to severe drought. Results of the aboveground wood biomass (including necromass) measure for four-to-five sampled wood specie mixtures planted on a hectare plot ranged between 119.92–204.28 kg, which corresponds to approximately 59.96–102.14 tons **C** ha^{-1}. In addition, due to the number of woodlots established, it is certain that among the sampled districts, the enthusiasm towards tree-planting is no doubt likely to increase. If these efforts are sustained and supported across all other agroecological zones in Ghana, the agroforestry policy, in particular, woodlot management once encouraged as part of CDM or REDD/REDD+ could be successful.

Introduction

Over the last century, a quarter to a third of the excess CO_2 in the atmosphere is noted to come from land use change and, according to Niu & Duiker (2006), above ground carbon stock from agroforestry plantations alone are also noted to account for about two-thirds of total C-sequestration potential. Certainly, the only clarion call that can provide a solution and buffer against the climatic change impacts been experinced in recent times is to put in place mechanisms and policy strategies that can reverse such annual C-emissions through sustainable land management (SLM) practices (Lal *et al*., 2007; IPCC, 2007). SLM, through appropriate conservation practices targets mainly cropland and pasture, as well as forestry and agro-forestry management, for reducing C-emissions. With this potential for mitigation of CO_2 in many land use/cover types, different conventional methods for quantifying carbon stocks have been developed. However, a major challenge is how to substantiate the benefits and, or put tangible value on such practices of carbon accounting.

So far, in the literature, there are only few such carbon accounts that have been reported. Detailed assessments comprise the estimation of above and below ground biomass of trees, shrubs, palms, saplings and many other parameters as well as the herbaceous layer on the forest floor, including the dead parts in debris and litter. Although dataset gathering of these parameters do not usually present logistic problems yet the accuracies of measure are usually contentious. Nonetheless, assessments based on the afore-mentioned ecosystem components provide reliable estimates. For example, for soil carbon stock (SCS), samples of soil are analysed to estimate percent soil organic carbon from which subsequent carbon turnover is obtained. Similarly, on individual tree above ground biomass (AGB), a number of different allometric models relating diameter at breast height (dbh), height, wood density and basal area to individual AGB can be compared to empirical data using linear or non-linear regression techniques (Petrokofsky *et al*., 2012). Thus, SCS estimation methods differ from those of tree level AGB estimation.

Petrokofsky *et al.* (2012) indicated that the effectiveness of AGB estimation methods are evaluated using empirical data from the same individuals. Additionally, model fits can be used to assess multiple and, or adjusted R^2 (multiple R^2 penalized by sample size and the number of variables in the model), with some estimate of the error between observed along with the predicted values. Thus, more than one model could be fitted to any one dataset and reported for in each study. This means that no one model is considered perfect to which others are compared (Petrokofsky *et al*., 2012). In order to make cross-comparison of many such SLM project derived values, the technique for assessment will depend on the land use type, the phase of project cycle, the expertise and whether resources are available (Petrokofsky *et al*., 2012).

In line with such challenges and as part of the post-Kyoto arrangements, over the past years, ready to use carbon inventory tools were developed (Brown, 1997; Brown, 2002; Ravindranath & Ostwald, 2008). However, difficult issues including non-permanence, leakage and additionality of carbon gains, as well as other uncertainties, were to be considered in SLM project-based carbon inventory (Ravindranath & Ostwald, 2008). Secondly, to provide a safe and sound reasoning, Geographic Information Systems (GIS) involving Satellite Imagery/Remote Sensing Analysis were proposed to be used to conduct a plot-level to landscape-wide above ground wood biomass assessments, in order to quantify aboveground C storage towards REDD/REDD+.

The basic concept of REDD/REDD+ is for rich north industrial countries to be able to reward poor south governments, companies or forest owners for keeping their forests instead of cutting them down while at the same time benefitting payments. Thus, the acronym REDD stands for reduced emissions from deforestation and forest degradation (UNFCCC, 2005; Angelsen *et al*., 2012). But, the plus in REDD+ points to three other related concerns; conservation of forest carbon stocks, sustainable management of forests and enhancement of forest carbon stocks.

Actually, payments for REDD/REDD+ is not just for keeping forests but for reducing emissions since deforestation, for example, logging an area of forest opens up the possibility for forest degradation. Therefore, a trade-off for emissions is compensated for by practicing tree plantation management. This idea of making payments, therefore, is to discourage deforestation and forest degradation. This was one of the very important discussions in the negotiations leading to the Kyoto Protocol on climate change and its related adaptation and mitigation strategies. But, it was rejected because of four fundamental challenges; leakage, additionality, permanence and measurement (UNFCCC, 2005). The first and last challenges constitute why this study is of relevance. Particularly because, with the construction of the two hydroelectric dams at Akosombo and Kpong in 1963 and 1975 respectively, the annual floods of the Volta river became consequently controlled. No more natural irrigation of the Tongu District lands is now possible.

The communities have since then experienced sudden and dramatic disruption in their socio-cultural and economic activities (Ayivor & Kufogbe, 2001). In particular, domestic energy needs became problematic. In the light of the difficulties and, for purposes of improving the energy needs of the communities, agroforestry practices introduced by the Forestry Services Department (FSD) in 1987–89 was warmly embraced by the local communities. This initiative led to the establishment of woodlots in many parts of Ghana. Apparently, different wood species with better adaptability to local conditions were selected in many plantation-management across the country.

The objectives of the study, therefore, were to (1) provide a preliminary test of Brown (1997and 2002) method for measuring above ground wood biomass in agroforest plantations using participatory field techniques, (2) use derived allometric measures to evaluate the quality of wood species managed in agroforest plantations, (3) evaluate the participatory approach to above ground carbon stock measurement in tree plantation management since that is critical for examining financial rewards for socially poor and vulnerable communities if they must benefit from CDM or REDD/ REDD+.

Material and methods

A number of methodological approaches were adopted in conducting this study. These included study site selection, literature search, preliminary satellite image analysis, focus group discussions and direct field measurements of the vegetation characteristics using allometry.

Study site

The woodlot agroforest plots sampled are located at Bakpa-Agboglakope on latitude 6° 3' 0" N and longitude 0° 30' 0" E, a small rural community in the North Tongu District of the Volta Region. Bakpa (yellow bookmark) is about 2.5 km from Adidome the district capital. The entire study site constitutes part of the pre-and-post dam floodplains of the lower Volta river in southern Ghana (Fig. 1).

Literature search

Literature search involved secondary data gathering (i.e., theses from University of Ghana, reports from District Agriculture and Forestry Office, etc.) on past and present climate and agroforestry activities, etc.

Satellite image analysis

Aster, 2007, Landsat TM 19985, Landsat ETM+ 2000 and GoogleEarth 2009 maps respectively, were explored to assess the forestry and agro-forestry status of the study area and sample sites.

Study site showing sample woodlots

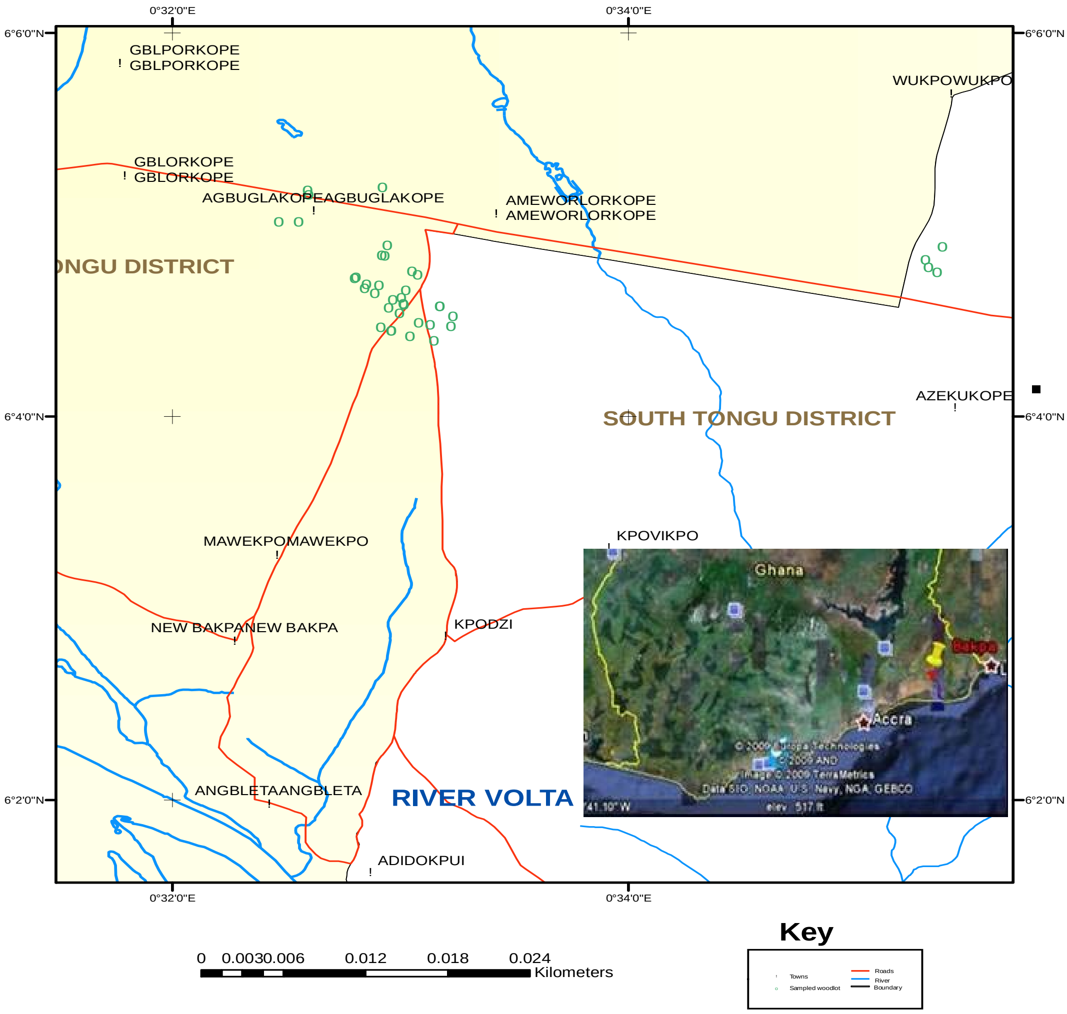


Fig.1. The Lower Volta Basin floodplain of Ghana (insert) showing Woodlot Agro-forests (dotted-ring)

Focus group discussions (FGDs) and direct field measurements (DFMs)

FGDs were held with two woodlot agroforest owners; Messrs Vincent Goka, a prominent retired educationist (now deceased), and Martin Misroame, a peasant farmer. With the consent and participation of these two, field visits were made and plots were selected for sampling. The sampling technique involved field inventory of the selected woodlot agroforest (i.e., tree, shrubs and necromass). In each sample plot, all trees were identified, counted and tagged during DFMs. Woody tree and shrub height (H) and girth (DBH) measurements as well as necromass, were all recorded as shown in Plates 1a-c. The size of each plot sampled was approximately 1 ha. In all, four plots,

Plate 1a. Tree and shrub measure

Plate 1b. Gathering necromass

Plate 1c. Weighing necromass

totalling 4 ha, were sampled by demarcating the boundaries and using the GPS to locate the exact coordinates of the plots. Count numbers, stem diameter and height measurements of woody species in each 1-ha plot were systematically recorded. Additionally, necromass in five 2 m × 2 m nested plots were also randomly harvested in each of the 1-ha plot for weight determination.

Analysis of the measured vegetation characteristics were incorporated into standard allometric models derived for dry and moist tropical forests (Brown, 1997, Pearson *et al*., 2005, Pearson *et al*., 2006) methods for estimating wood quality of species in relation to their potential aboveground carbon stocks. The Brown (1997) allometric regression equations were adopted to estimate biomass of woody species for dry/moist conditions and their respective carbon stock measures derived as follows:

Wood biomass $Y=EXP(-1.996+2.32*\ln D)$ for the dry zone [1]

Wood biomass $Y=42.69-12.8*(D)+1.242*(D^2)$ for the moist zone [2]

Carbon stock = 0.5 * Wood biomass [3]

In addition, the parameters of the standardized allometric relationships (k and c) between stem height (H) and stem diameter at breast height (D); $H = kD^c$ were also determined for the characteristics of individual species recorded per sample plot as a measure of site/wood quality status, where D is the estimated diameter (cm) of tree and shrub species inventoried, and H is the estimated height (m) and, k and c are constants.

Soils

Generally, the soils of Bakpa belong to the Akuse-Ho-Keta series which are heavy textured, sticky and plastic when wet but become very hard and deeply cracked when dry (Asiamah, 1995; Amatekpor, 1997). These soils have low permeability, hence, they are subject to flooding in the rainy season. They are difficult to cultivate but suitable under irrigation. Other soil types of alluvial origin often light-textured and well drained are also prevalent. These light-textured types have a higher permeability and are either suitable for cultivation or agroforestry.

Climate

Bakpa falls within one of the driest zones in Ghana. The pattern of rainfall is bimodal (i.e. occurs twice in the year) with the peak season of 2½ months duration from mid-April–June while the minor rains occur around mid-September to November (Fig. 2). Rainfall averaging 889.0 mm to 1143.0 mm per annum was experienced in the past (Fig. 3). Currently, decreases as low as 635.0 mm and more in certain portions of the lower Volta basin (i.e., North and South Tongu districts) prevail. Thus, precipitation has generally been inadequate and often unreliable for any meaningful crop cultivation. However, for woodlot agroforestry, the potential is great. Inconsistent or incomplete record keeping in certain years affected statistics on the annual total precipitation of the District (Fig. 3). However, available records in 2007 showed that the annual total rainfall reached 1,400 mm, the highest in 30 years (Fig. 3).

Results

A recent review of the woodlot agroforestry planting scheme promoted at different locations in the two districts (North and South Tongu districts) respectively, of the lower Volta basin are indicated in Tables 1 and 2. While the trend in plantation management in the North Tongu showed increases in a total land area of 6.6 ha per annum, that of South Tongu covered 9.9 ha per annum (Tables 1 and 2). In all, eight wood specie mixtures, made up of *Acacia* sp., *Adansonia digitata*, *Azadirachta indica*, *Eucalyptus* sp., *Ficus* sp., *Khaya*

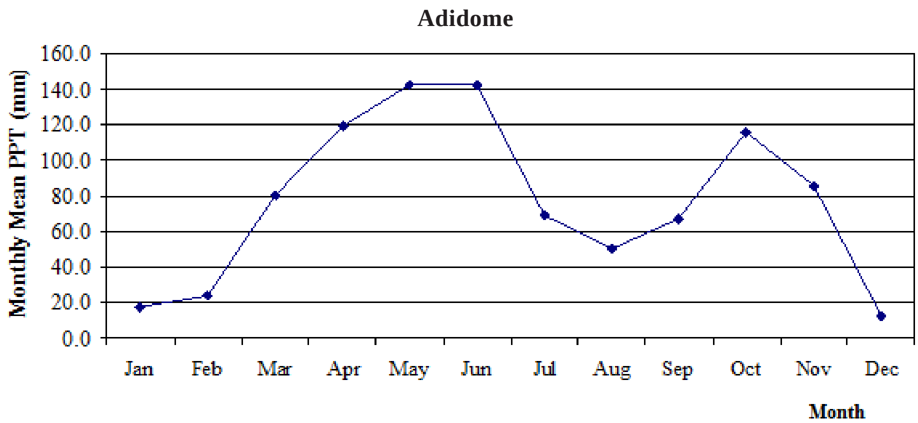


Fig. 2. Rainfall distribution in the North Tongu District.

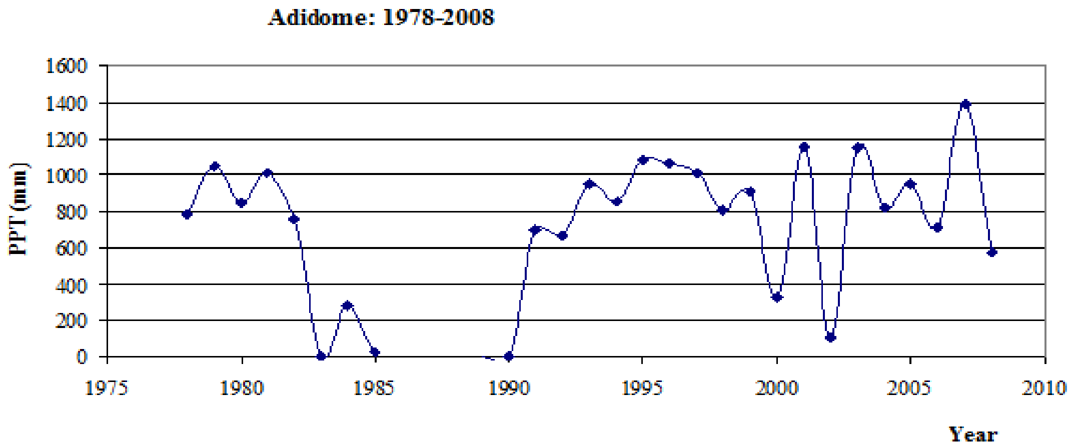


Fig. 3. Variation in 30-years annual rainfall total in North Tongu District

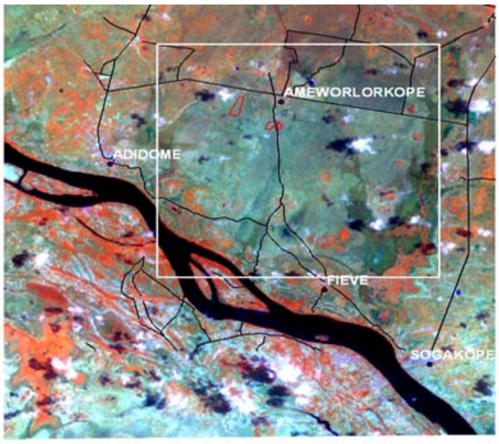
senegalensis, *Leucaena leucocephela* and *Tectona grandi*, were inventoried in the sampled agroforestry plots (Table 3a). On the average, between four and five species mixtures were planted by each agroforester at the plot-level.

Based on the allometric relation $H = kD^c$ for sampled woody tree and shrub species (Table 3a), the coefficient of linear regression (R^2) for each species showed that k and c values derived in most instances were greater than or equal to 0.5. This is indicative that, at the different plot levels, significant differences in structural characteristics of individually sampled species is noticeable. Consequently, each specie is eco-physiologically different depending on its sensitivity to the particular site quality. Thus, the mean k and c values derived for the sampled Bakpa area are 1.20 and 0.93, respectively, at $P < 0.05$ (Table 3b).

Similarly, the wood biomass estimates for these different species per hectare and the corresponding potential amount of aboveground C stock per plot is also indicated (Table 3b). For example, for a sub-total of 3,927 even-aged woody species in the 14–15 year sampled establishment, that is in the first three hectare sampled plots, wood biomass estimated ranged between 119.92–204.28 $kgha^{-1}$ for dry and moist zone scaling respectively per hectare. This accounts for between 59.96–102.14 tons per hectare of above ground carbon stock respectively (Table 4).

The wood biomass and aboveground C stock of the contribution of individual species in the sampled plots (i.e., without necromass) was also determined to assess their respective inputs to that environment; i.e., the dry and moist zones (Table 4). By and large, in other sampled plots, *Eucalyptus* sp. and *Adansonia digitata* were the two species that contributed the highest wood biomass and aboveground C stocks followed by *Acacia* sp., *Tectona grandis* and *Khaya senegalensis* (Table 4). The remaining woody plants, for example *Azadirachta indica*, *Ficus* sp. and *Leucaena* sp. each stored $\leq$ 7.0 tons ha^{-1} of carbon based on Brown (1997) estimates; i.e., for dry and wet regions.

(4a)



Landsat TM Sept, 1985 (RGB 453)

GPS Woodlot Survey, 2008

Note: Woodlots almost non-existent

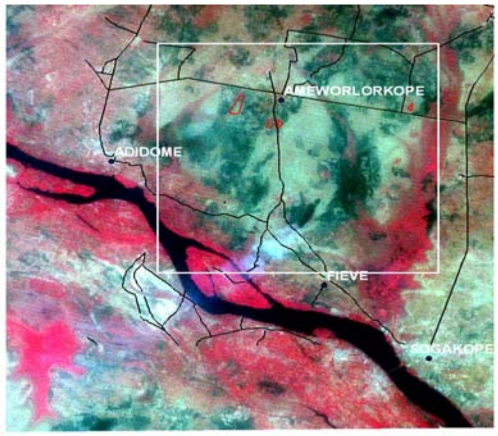
(4b)

Landsat ETM Feb, 2000(RGB 453)

GPS Woodlot Survey, 2008

Note: Woodlots emerging

(4c)



ASTER Jan , 2007 (RGB 413)

GPS Woodlot Survey, 2008

Note: Woodlots clearly evident

Fig. 4a – c: Trends in Agro forestry establishment in the North Tongu District, 1985–2007

Status of land use/cover change in the study site

The different satellite imagery, Landsat TM 1985, Landsat ETM+ 2000 and Aster 2007, show potential land use/cover changes in the study area (Fig 4 a-c). Certainly, there appears to be only little evidence of woodlot development in the early 1980's. However, from the period 2000 to available record date, there certainly has been significant establishment of woodlots (Tables 1 and 2).

Discussion

In this study, promotion of woodlots as an agroforestry practice in the lower Volta basin is clearly evident from satellite imagery (1985–2008). The field surveys also showed that over 20 communities in the lower Volta basin; North and South Tongu districts, are involved in plantation-management, and have

TABLE1

Annual trend of woodlot establishment in the North Tongu District (6.6 ha per annum)

Locality	Year and size -(ha)								
	1989	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*Total*
Adidome		1							1
Kyemfo		1			1.6				2.6
Adidome			0.2		0.3				0.5
Adabakpo				0.5		0.2			0.7
Adidome					0.8				0.8
Kyemfo					1		0.6		1.6
Adidome					2.2	2.1			4.3
Dekpo					1.2				1.2
Adidome						0.5			0.5
Adidome						0.7			0.7
Avakpedome						1			1
Dufor-Adidome						0.2			0.2
New-Bakpa						0.4			0.4
Ahorkope						0.3			0.3
Adabakpo							0.8		0.8
Bakpa-Adzani							3.2		4
Bakpa-Adzani							1.1		2.7
Bakpa-Adzani							1		2.6
Bakpa-Agboglakope	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	11.2
Adabakpo								0.7	0.7
Atitekpo								1.5	1.5
Devime						1.5			1.5
Adidome								1.2	1.2
Avegame								0.5	0.5
Mafi-Dugah								1.7	1.7
Kpenu								1	1
Tsumkpo							0.68		0.68
Dadome							0.56	0.56	1.12
Dadome							0.46	0.46	0.92
Kledeke								0.17	0.17
Kpeyibor								0.66	0.66
Lasivenu								0.62	0.62
Nyatikpo								0.37	0.37
Volo								0.13	0.13
Volo								0.16	0.16
Zormayi								0.68	0.68
Lawekope								0.6	0.6
Aveyime			0.41			0.43			0.84
Aveyime					0.41	0.06			0.47

Source; District Forestry Office, Sogakope, 1997

TABLE 2

Annual trend of woodlot establishment in the South Tongu District (9.9 ha per annum)

Locality	*Year and size -(ha)*										
	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*Total*
Lave	2	2		0.4			0.4				5.8
Bakpo		2.4	2		1.2						5.6
Toklokpo		1.2	0.8	1.6	1.6	0.2					5.4
Agbogbla			1.2	1.2	1.2	0.8					4.4
Akato			1.2	0.8	0.8	2.4	2	1.6	1.6		10.4
Alavanyo			2	0.8	0.8	3.2	0.4				6.4
Avegome				2	2	1.6					5.6
Gbenorkope				0.8	0.8	0.8					2.4
Kpekpo				0.4	0.4	0.4	0.4				1.6
Kudzokope				0.8							0.8
Sahokope				0.8	0.8	0.4					2
Agorhome					0.8	0.8	0.8	0.8	0.8	1.2	5.2
Gamenu					0.6			1.4			2
Agbogbla						0.4	0.4	0.4			1.2
Agorta						0.2					0.2
Agorta						2					2
Agorta						0.15					0.15
Agorta						0.15					0.15
Butuakwe						0.2					0.2
Butuakwe						0.4					0.4
Fieve						0.6					0.6
Agbogbla							1.6	1.6	1.2		4.4
Agorta							0.6	0.2			0.8
Apimkpo							0.8	0.6			1.4
Galotse							4	0.4			4.4
Gbenorkope							0.8				0.8
New-Agave								2.6			2.6
Agorkpo								2	2		4
Anaosukpoe								0.4	0.2		0.6
Tademe								2			2
Dzorgborve								2	2		4
Fieve								1.2			1.2
Fieve								1			1
Lolito								0.6			0.6
Sogakope								0.7			0.7
Agordomi									0.4	0.6	1
Dzebenu									0.6		0.6
Galikope									0.4		0.4
Kpekpo										0.4	0.4
Sogakope										0.9	0.9
Toklokpo									5.4	0.9	6.3
Tove										0.4	0.4
Total	2	5.6	8.2	10.4	12.6	11.9	11.4	19.9	12.6	4.4	99

Source: District Forestry Office, Sogakope, 1997

TABLE 3a

Structural characteristics of sampled woodlot agroforest species at Bakpa

Plot ID	*Owner*	*Species / (Count number)*	*Structural characteristics*
1	Mr.Martin Misroame	1. *Adansonia digitata* (2), 2. *Azadirachta indica* (105), 3. *Eucalyptus* sp. (389), 4. *Ficus* sp. (1) and 5. *Tectona grandis* (451)	1.—, 2. $H = 1.7796D^{0.6884}$ ($R^2 = 0.2675$), 3. $H = 0.568D^{1.2083}$ ($R^2 = 0.7077$), 4.— and, 5. $H = 1.522D^{0.7919}$ ($R^2 = 0.5781$)
2	Mr.Martin Misroame	1. *Acacia* sp. (2046), 2. *Azadirachta indica* (28), 3. *Khaya senegalensis* (23) and, 4.*Leucaena leucocephela* (176).	1. $H = 1.3021D^{0.7845}$ ($R^2 = 0.6725$), 2. $H = 1.2458D^{0.8561}$ ($R^2 = 0.7443$), 3. $H = 1.0016D^{0.7600}$ ($R^2 = 0.4907$) 4. $H = 0.8877D^{1.0920}$ ($R^2 = 0.8431$)
3	Mr. Vincent Goka	1. *Acacia* sp. (372), 2. *Azadirachta indica* (183), 3. *Khaya senegalensis* (143) and, 4. *Leucaena leucocephela* (9).	1. $H = 0.7778D^{1.2126}$ ($R^2 = 0.5404$) 2. $H = 0.8026D^{1.1430}$ ($R^2 = 0.4369$) 3. $H = 1.7415D^{0.8626}$ ($R^2 = 0.4323$) 4. $H = 1.5176D^{0.809}$ ($R^2 = 0.7434$)
4	Mr. Vincent Goka	*Acacia* sp., *Azadirachta indica*, *Khaya senegalensis* and *Leucaena leucocephela*.	———

TABLE 3b

Potential aboveground carbon stock scaling in woodlot agroforests at Bakpa

Plot ID	*Plot Owner*	*No. of trees/shrubs*	*Biomass (kg ha⁻¹)*		*Carbon stock (tons ha⁻¹)*	
			Dry	*Moist*	*Dry*	*Moist*
1	Mr.Martin Misroame	947	73.89	119.56	36.95	59.78
2	Mr.Martin Misroame	2,273	29.18	59.11	14.59	29.55
3	Mr. Vincent Goka	707	16.85	25.61	8.42	12.81
4	Mr. Vincent Goka	604	36.91	59.72	18.45	29.86
Total		4,531	156.83	264.00	78.41	132.00

Table 4

Wood biomass and aboveground carbon stocking of individual sampled species

Species	*Wood biomass (tons/ha)Plot-level*				*C-stock (tons/ha)Plot-level*			
	1	*2*	*3*	*4*	*1*	*2*	*3*	*4*
Acacia sp.	8.7–13.6	4.8–6.9	22.3–45.5	–	4.4–6.6	2.4–3.5	11.2–22.7	–
Adansonia digitata	25.0–29.4	–	–	–	12.5-14.7	–	–	–
Azadirachta indica	1.3–3.8	0.7–1.9	2.6–4.3	0.2–0.7	0.7–1.9	0.4-0.9	1.3–2.1	0.1–0.4
Eucalyptus sp.	25.3–43.3	–	–	–	12.7-21.6	–	–	–
Ficus sp.	0.5–1.1	–	–	–	0.3-0.6	–	–	–
Khaya senegalesis	2.9–4.5	13.6-23.8	0.1-0.6	–	1.5-2.3	6.8–11.9	0.1–0.3	–
Leucaena sp.	0.2–0.3	0.2-0.3	2.2-8.0	–	0.1-0.2	0.1–0.2	1.1–4.0	–
Tectona grandis	15.6–21.4	–	–	–	7.8-10.7	–	–	–

different tree and species combinations. Of eight plants inventoried, an admixture of 4–5 different woody species were noticed to be managed at the plot-level depending on the domestic energy and other value needs. Approximately 165.0 ha and 267.3 ha, respectively, of sustained plantation-management in the two separate districts, North and South Tongu districts respectively means that, altogether 432.3 ha of tree plantations were successfully achieved between 25–27 and more years in only two districts in this part of Ghana's coastal savanna region.

The relationship of tree height (H) to diameter (D) classes, $H = kD^C$, at the plot-level varied among individually sampled species due to possible eco-physiological differences that influence the site quality, not to talk about possible differences in the planting times. In particular, differences in drought stress are noted to affect the soil conditions in these tree plantations. Notwithstanding, estimated wood biomass including necromass from a three hectare-plot showed that between 119.92 kg/ha and 204.28 kg/ha above ground biomass accounted for about 59.96 tons and 102.14 tons ha^{-1} of above ground carbon for dry and moist zones. However, with an additional 1-ha plot of 604 even-aged woody species, the amount of aboveground carbon stock is likely to increase to approximately 78.41 tons and 132.00 tons ha^{-1} without biomass estimates of the tree crown (canopy).

To acquire sufficient tree information on species and size distribution is time-consuming. Thus, by grouping all specie samples, regression equations with high r^2 generally showed values greater than 0.95, and this measure offers some promise of efficient measure (Brown, 2002). Therefore, using generic regression equations stratified by, ecological zonation or species group for example increases the accuracy and precision of the measures, because they tend to be based on a large number of trees, and span a wider range of tree diameters as indicated in this study.

Currently, the dilemma among the 20 communities in the Bakpa area is about the quality of the wood species as good woodfuel. This is because these species are potentially low in heat yield and tensile strength (pers. comm.). Other species introductions, particularly *Eucalyptus* sp., and *Tectona grandis*, by the Forestry Department are highly undesirable. This implies that there would be less or no leakage since the use value of species are certainly low and, therefore, would not necessarily be exploited to disrupt REDD/REDD+ rules of engagement if incorporated in such schemes. So, therefore, much of the land space can actually be committed to this sort of plantation management in return for financial gains. Indeed, the enthusiasm among communities in establishing and managing woodlots is very high and can be harnessed if they are considered and supported for Clean Development Mechanism (CDM) or REDD/REDD+.

Conclusion

The paper presents a fairly reasonable estimate on the amount of carbon that is likely to be sequestered by mixtures of woody tree and shrub species in agro-forestry management in two districts, North and South Tongu districts respectively in the Lower Volta basin. The plantation management introduced to the lower Volta basin communities by the District Forestry

Department of the Forestry Commission (DFD/FC) as harvestable wood fuel for domestic use were studied to understand how past CDM or recent REDD/REDD+ debate of tree plantation efforts would have contributed to carbon stocking and trading, and in return, provide market benefit to rural communities. Whereas the rate of plantation-management distends a total land cover of 6.6 ha per annum that of the South District is 9.9 ha per annum.

Apparently, the removal of a few trees per hectare (selective logging) or undergrowth by fire or branches and small trees as fuelwood is much more difficult to observe remotely. Indeed, this activity affects the canopy cover only minimally but can affect the accountable wood biomass stock significantly (DeFries, *et al*. 2007), hence, loss of carbon stock through leakage. With the current interest in obtaining rewards for the amount of C-sequestered in the agro-forestry system (in particular woodlot) across all other agro-ecological zones in Ghana means that there is the need to critically address site-specific issues of erratic rainfall and harvesting of fuel wood which are widespread site quality characteristics and others such as leakages due to bushfires. This participatory method of involving stakeholders is particularly acceptable to agro-foresters as a way of assuring them of an equitable benefit sharing mechanism in the event of their projects being approved for payments.

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