Chapter

Carbon Sequestration in Agroforestry Technologies as a Strategy for Climate Change Mitigation

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Abstract

Worldwide agroforestry has been recognized as a potential greenhouse gases mitigation strategy under Kyoto protocol. And this is due to its potential in carbon sequestration. There are several agroforestry technologies with different rate in carbon sequestration. In that respect carbon sequestration can depend on type of technology, climate, time since land use change and previous land use. Our knowledge in this topic from the tropical countries such as Tanzania is how ever very limited. To address this challenge this study was undertaken in Kilombero District where the local community are practicing various agroforestry technologies. The objective of this study was to understand the carbon sequestration in different trees species in agroforestry technologies and also to understand which agroforestry technology provide the greatest benefit in term of carbon sequestration. Ecological survey was conducted and a total of 90 plot engaged in different agroforestry technologies were randomly selected from three villages of different altitudinal range. Pivot table was used in analysis and allometric equation was used for computing biomass and carbon. The result shows that *Mangifera indica* contributed highest carbon over all the tree species encountered during ecological survey with 189.88 Mg C ha^{-1}. Home garden, Mixed intercropping, Parkland and Boundary with 19 514.19 $MgCha^{-1}$, 648.44$MgCha^{-1}$,144.79 $MgCha^{-1}$ and 139.29 Mg C ha^{-1} respectively were the agroforestry technology practiced in Kilombero. From the results Home garden contributed more to carbon sequestration and this study results can be used to inform practitioners and policy makers on the most effective agroforestry technologies for carbon sequestration since agroforestry technologies are expected to play important role as climate change mitigation strategy.

Keywords: agroforestry technology, carbon sequestration, mitigation, climate change, carbon stock

1. Introduction

Agroforestry have been considered as a viable alternative to prevent and mitigate the climate change. Using trees as means of mitigating climate change have been achieved by maintaining the existing once on farm land and or by increasing the plantation of short rotation or increasing fast growing trees on the farm fields [1]. Mitigating climate change through increased carbon sequestration in the soil can particularly become useful especially when addressed in combination with other challenges that affect the people livelihood such as reverting land degradation and ensuring food security [2, 3].

Usually potential in carbon sequestration may occur in different land uses including Agricultural land use and forest land through improved land use management and convention to land use with higher carbon storage in harvested product [4]. On other hand IPCC recognized agroforestry having high potential for sequestering carbon under climate change mitigation strategies [1]. Within agroforestry carbon can be stored above and below ground biomass [5]. In that respect agroforestry practices accumulate more carbon than forest and pasture because they have both forestry and grassland sequestration and storage pattern active [6, 7] but, sequestration potential of agroforestry depend on plant characteristics, tree species, age, crop, biodiversity and tree density. Also depend on structural arrangement, management factor such as fertilization, residual, and harvesting regime. This factors together with agroecological condition as well as soil characteristics in the area where the agroforestry is implemented influence the above and below ground carbon sequestration [5, 8–10]. Jose and Bardhan [8] also pointed that if the agroforestry technologies is to be used for climate change mitigation through carbon sequestration, then better information is required about above and below ground biomass and carbon stock. The aim of this study was to determine the carbon stock in different agroforestry technologies and also to determine which technology has the best potential for long term carbon sequestration.

2. Material and methods

2.1 Description of the study area

2.1.1 Geographical location

The study was conducted in Kilombero District located in Morogoro Region between 08° 00′ 16” South and 36° 04′ 364″ East with elevation ranging from 262 m to 550 m above the sea level, See. Administratively, Kilombero District has five divisions, 19 wards and 46 villages. The district is bounded by Kilosa District in the North, South East by Ulanga district, South west by Iringa region as well as in the West and the East by Lindi Region [11].

2.1.2 Climate

The climate in the study area is marked by wet and dry seasons which are further categorized into four sub seasons, hot wet season from December to March, cool wet season April to June, cool dry season July to August and hot dry season September to November. The area receives between 1 200 and 1 800 mm of rainfall per year and temperatures ranging from 26 to 32°C [12].

2.1.3 Land use

Generally, the land use is categorized as village land, reserved land and general land as defined in the Village Land Act 1999 [13]. Meanwhile, Kilombero is considered as one of the fertile spots in Tanzania. The main economic activities in the area include cash crops, food crops, petty trading and fishing in Kilombero River [11]. Overall cereals of the Coast, such as rice, millet, and maize, are grown widely. Also, vegetables such as sweet potatoes, yams, ground-nuts, melons, pumpkins and cucumbers, and many other excellent articles of food. Tobacco is grown very abundantly, sugar-cane, the castor oil plant, cocoa and cotton, are also cultivated [14].

2.1.4 Population

According to the 2012 census the population of Kilombero was 407 880 with male 202 789 and female 205 091 [15]. This area is currently experiencing a doubling of the human population over the years. It has been demonstrated that within Tanzania population growth results in environmental degradation [16]. This increase of population has resulted from migration from various places for cultivation due to soil suitability for farming and livestock keeping migration.

2.2 Methods

2.2.1 Reconnaissance survey

Pre-visiting was conducted to as well as pre-testing of inventory equipment's. This was also conducted so as to familiarize with the study area and observe the nature of the agroforestry farmland.

2.2.2 Study design

The research design for this study was descriptive and cross-sectional. Descriptive design was involved as it gives thorough information concerning agroforestry technologies. Also, cross-sectional design was chosen as data were collected at once without repetitions.

2.2.3 Data collection

A total of 90 farm land were visited in this study. Data for above ground biomass were species, number of trees, Diameter at breast height (DBH), height and diameter at 0.3 m for cocoa trees [17, 18]. A systematic sampling design was expected to be used but during the field all the encountered farms were less than two hectare and there for all the trees within the farmland were all measured and all the farms were considered as a plot [19]. Height were measure using Suunto hypsometer and diameter using calipers.

2.2.4 Data analysis

2.2.4.1 Biomass and carbon stoking

Information obtained from the biophysical survey mainly inventory data was recorded in Microsoft excel for biomass calculation and carbon stock. Allometric equations were used to convert the field measurement attribute mainly heigh and diameter into stand biomass. Since in agroforestry there is diversification of wood perennial, then general allometric model for Cultivated land herbaceous, mixed tree, intercropping and grain crops (for all tree species) was used for the trees without specific equation. Most of these models have been developed for Tanzanian tree species and vegetation types [20]. Carbon stock was computed as the product of Total Biomass and factor of 0.5 [21].

Below are the species specific allometric equations and general allometric equation for computing the above and below Biomass [20, 22]

Tectona grandis

$$\mathrm{AGB} = 0.3356 \times D^{2.1651} \tag{1}$$

$$BGB = 0.0279 \times D^{1.7430} \times Ht^{0.7689} \tag{2}$$

Theobroma cacao

$$AGB = 0.1208 \times d^{1.98} \tag{3}$$

$$BGB = AGB \times 0.25 \tag{4}$$

Cocos nucifera

$$AGB = 3.7964 \times Ht^{1.8130} \tag{5}$$

$$BGB = 13.5961 \times Ht^{0.6635} \tag{6}$$

Cashew nuts

$$AGB = 0.3152 \times D^{1.7722} \times Ht^{0.5003} \tag{7}$$

$$BGB = AGB \times 0.25 \tag{8}$$

For other tree then general allometric equation for Cultivated land herbaceous, mixed tree, intercropping and grain crops (for all tree species) was used.

$$AGB = 0.051 \times \left(D^2 \times Ht\right)^{0.93} \tag{9}$$

$$BGB = AGB \times 0.25 \tag{10}$$

For carbon estimation then for each tree Total Biomass (TB) which is sum of AGB and BGB was computed by the equation below.

$$Carbon\ Stock = TB \times 0.47 \tag{11}$$

where
ABG = Above ground biomass
BGB = Below ground biomass
D = diameter at Breast height
d = diameter at 0.3 m above the ground
TB = total biomass

3. Result and discussion

3.1 Carbon stock in tree species

During biophysical survey total of 37 tree species from 16 families were found in the study area. There were equal species distribution in all villages. Carbon stock per individual tree were computed to identify the tree species which contribute more to the carbon stock in all the agroforestry technology. Over all the Tree species found during the field survey the *Mangifera indica* species were found to have high carbon stock 189.88 Mg C ha^{-1} followed by *Cocos nucifera* 98.44 Mg C ha^{-1}. *Theobroma cacao* and *Vertex doniana* had 0.0013 MgCha^{-1} and 0.0008 MgCha^{-1} respectively which is lesser in the list of all species studied **Table 1**.

Botanical name	Local name	Family	Biomass (Mg C/ha)	Carbon (MgC /ha)
Mangifera indica	Muembe	Anacardiaceae	379.7534795	189.8767397
Cocos nucifera	Mnazi	Aracaceae	196.8731288	98.43656442
Persea americana	Mparachichi	Lauraceae	146.1686097	73.08430484
Tectona grandis	Mtiki	Lamiaceae	62.30097903	31.15048952
Ficus stuhlmannii	Mkuyu	Moraceae	60.81134344	30.40567172
Citrus sinensis	Mchungwa	Rutaceae	19.48128997	9.740644984
Elaeis guineensis	Mchikichi	Aracaceae	17.87292025	8.936460123
Bauhinia thonningii	Msegese	Fabaceae	15.35726596	7.678632982
Canica papaya	Mpapai	Caricaceae	10.59125521	5.295627607
Milicia excelsa	Mvule	Moraceae	7.686083716	3.843041858
Psidium guajava	Mpera	Myrtaceae	5.621283726	2.810641863
Annona murcata	Mstafeli	Annonaceae	5.227879976	2.613939988
Cedrella odorata	Msedrela	Meliaceae	4.743090445	2.371545222
Senna siamea	Mjohoro pori	Fabaceae	4.73001597	2.365007985
Sorindeia obtusifolia	Mpilipili	Anacardiaceae	3.060067712	1.530033856
Senna Spectabilis	Mjohoro	Fabaceae	2.749675264	1.374837632
Khaya anthotheca	Mkangazi	Meliaceae	2.231995495	1.115997747
Azadirachta indica	Mwarobaini	Meliaceae	2.200888122	1.100444061
Anacardium occidentale	Mkorosho	Anacardiaceae	1.965061796	0.982530898
Citrus lemon	Mlimao	Rutaceae	1.859403344	0.929701672
Sclerocarya birrea	Mng'ong'o	Anacardiaceae	1.170126345	0.585063172
Citrus reticulata	Mchenza	Rutaceae	1.138515669	0.569257834
Artocarpus heterophyllus	Mfenesi	Moraceae	1.086251846	0.543125923
Averrhoa bilimbi	Mbilimbi	Oxalidaceae	0.938353611	0.469176805
Delonix regia	Mkirismasi	Fabaceae	0.788099951	0.394049976
Olea europeana	Mzaituni	Oleaceae	0.601228169	0.300614084
Cinnamomum zeilanicum	Mdalasini	Lauraceae	0.41427903	0.207139515
Brachystegia boehmi	Myombo	Fabaceae	0.395745497	0.197872749
Citrus autatiifolia	Mndimu	Rutaceae	0.386040111	0.193020056
Syzygium cordatum	Mnyonyo	Myrtaceae	0.359024087	0.179512044
Tamarindus indica	Mkwaju	Fabaceae	0.330284545	0.165142272
Terminalia aemula	Mkulungu	Combretaceae	0.110472679	0.05523634
Syzygium cumini	Mzambarau	Myrtaceae	0.103151497	0.051575749
Saraca asoca	Mwashoki	Myrtaceae	0.102336024	0.051168012
Annona squamosa	Mtopetope	Annonaceae	0.059397123	0.029698561
Theobroma cacao	Mkokoa	Malvaceae	0.002515752	0.001257876
Vitex doniana	Mfuru	Verbenaceae	0.00166612	0.00083306

Table 1.
Biomass accumulated and carbon sequestered in different tree species.

Technology	Total biomass Mg/ha	Total carbon Mg/ha
Boundary	46.43 ± 7.85	23.22 ± 3.92
Home garden	813.09 ± 352.32	406.55 ± 176.16
Mixed intercropping	41.84 ± 10.67	20.92 ± 5.34
Park land	57.92 ± 14.75	28.96 ± 7.38

Table 2.
Average estimated biomass and carbon stock under different agroforestry system.

3.2 Carbon stock in different agroforestry technologies

Also, biomass and carbon stock were computed and presented based on agroforestry technology. Based on agroforestry technology Total biomass average were 46.43 ± 7.85 for Boundary, 813.09 ± 352.32 for Home garden, 41.84 ± 10.67 for mixed intercropping and 57.92 ± 14.75 for Parkland. Carbon stock for agroforestry technologies were also computed and the results shows that Boundary had 23.22 ± 3.92, Home garden 406.55 ± 176.16, Mixed intercropping 20.92 ± 5.34 and Parkland were 28.96 ± 7.38 (**Table 2**)

4. Discussion

4.1 Carbon stock in tree species

From the results all the 37 species obtained during biophysical survey *Mangifera indica* had the highest amount of carbon stock on its biomass 189.88 $MgCha^{-1}$ followed by *Cocos nucifera* with 98.44$MgCha^{-1}$. High amount of carbon in this species may be due to its dominance as a result of high demand of mango tree product as well as palm tree products (fruits and coconut juice) both domestic and local market demand [23]. This cannot be explained only by the total number of appearances of *Mangifera indica* which is 178 because there were other species which appeared mostly than *Mangifera indica* but by the superiority of the Dbh than the other species. Study conducted in Philippines on carbon sequestration revealed that *Mangifera indica* can sequester 100.71 $MgCha^{-1}$. This is lower than the amount obtained in this study. In fact, Brown [24] and Gibbs, [25] reported that Dbh is 95% of the total biomass, and in this study *Mangifera indica* present huge biomass and carbon stock which can be due to its high average diameter and height. Other species like *Theobroma cacao* and *Vertex doniana* had lesser carbon stock due to smaller average diameter and height. Age of the tree and number of occurrences of a tree in the plots also can be used to justify the amount of carbon stored in a particular species [26]. Usually, older tree undergone photosynthetic activities with much longer time compare to younger tree and consequently are absorbing and storing more carbon [26]. The top most tree with highest biomass were tree species used for food (*Cocos nucifera*), fruits (*Mangifera indica and Persea americana*), timber production, (*Tectona grandis*) and one mostly used for shade (*Ficus stuhlmannii*). Variety of species documented and observed during the field display the potential for agroforestry to enhance the resilience for farmer for present and future climate risk. For example, farmer in both villages maintain varieties of trees for timber, fruits, animal fodder to support livestock during drought. Similar study conducted in Kenya shows that majority of small holder farmers maintain trees not only for food support but also for the soil and water conservation [27, 28]. There was variable distribution of tree species on different land uses. High tree species diversity was found in home garden where multipurpose trees for various purpose such as shade, timber, and food are grown. For example, the tree with high frequency in home garden were *Mangifera indica*, *Cocos nucifera, Persea americana, Tectona grandis and Ficus stuhlmannii*. Moreover, Kindt *et al*., [29] pointed out that usually high economic values trees are widely spread in a farm land.

4.2 Carbon stock in agroforestry technologies

A number of studies have shown that agroforestry in tropics have high Carbon stock than any crop field or pasture [5, 30]. From the result home garden leads in the carbon sequestration with 19 514.2 Mg C ha^{-1}. This result is highly influenced by the mixture of component of agroforestry such as cattle's, high occurrence of trees and agricultural crops. In other way home garden have been observed as the potential technology for carbon sequestration due to the fact that it sequesters carbon in biomass as well as in soil, reduce fossils fuel burning by encouraging fuelwood production and reduce pressure on natural forest. More ever in home garden there is no complete removal of biomass [31, 32]. Similar study conducted in India shows that home garden of 12-17 years accumulate 55.8-162MgCha^{-1}[33]. Agroforestry technology study conducted in by Kumar [34] showed that based on species composition, soil and climate generally agroforestry can sequester carbon of 68–228 Mg C ha^{-1}. High amount of carbon stock in home garden maybe the progress of carbon sequestration which was estimated to be 391 000MgCha^{-1} by 2010 and 586 000MgCha^{-1} by 2040 [35]. Mixed intercropping which involves wood perennial and herbaceous crop were observed to store 648.44 Mg C ha^{-1}. High carbon within the mixed intercropping is higher than those of from the sole cropping system due to addition carbon pool in tree and increased carbon soil carbon pool as a result of carbon input from litter fall and fine root turn over [36] mixed intercropping can store 121–125 Mg C ha^{-1} and this was explained by the higher growth and assimilation rates [37]. Parkland technology was observed to store 144 MgCha^{-1}. Parkland technology unlike mixed intercropping the trees are not arranged in accordance with crops but some little trees are left on the crop land. Study conducted in Guinea shows parkland carbon stock may also range from 22.22–70.8 Mg C ha^{-1} [38]. Parkland agroforestry are very stable (long standing) and high carbon storage [39]. On boundary agroforestry the tree is planted purposely for indicating the boundary or fencing. In this study boundary agroforestry technology stored 139.29 Mg C ha^{-1}. Study show that Boundary planting have positive effect on both soil character tics, crop production and carbon sequestration [30]. Hooda *et al*., [40] indicate that tree boundary and herbaceous crop can have carbon storage ranging from 18.53–116.29 Mg C ha^{-1}. Other study indicates that greater potential of carbon sequestration was found in the boundary plantation of *Populus deltoides* and Eucalyptus hybrid [41]. In this study the carbon stock was found to be higher compared to other studies conducted in various areas. The difference in the carbon stock can be explained by factors such as allometric equation which could be a limitation resulting in large variation in such estimate [42]. Low cutting of trees in the field could also be the source of high mount of carbon. In the study many trees observed were for various purposes such as food, fruits, shade, wind break and for boundary hence maintained for long time hence sequestering high amount of carbon.

5. Conclusion

Agroforestry technology can have important role in climate change mitigation. This study concludes that there are benefit in term of carbon sequestration form the implementation of agroforestry technologies and these are most relevant in the tropical climate. In this study we also found that carbon stock is determined by the number and average trees found in the farm land. The fruits trees were the most abundant trees suggesting multipurpose use and quick economic benefit. Therefore, understanding the drivers of tree selection can help to meet both local food, fuel and global climate regulation needs. Therefore, we recommend the identification of the benefit provided by different species in different agroforestry technologies and realize its economic benefit. This will establish co benefit of on farm carbon stock from economic value of benefit derived from trees.

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