A Seminar Paper on

Potential of Agroforestry Practices in Carbon Sequestration for Climate Change Mitigation Option

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Potential of Agroforestry Practices in Carbon Sequestration for Climate Change Mitigation Option

ABSTRACT

Agroforestry, an ecologically and environmentally sustainable land use system, offers a great promise to sequester carbon (C) to mitigate climate change problem. The potential of C sequestration under different agroforestry practices like riparian buffers forest, Multipurpose tree species, and silvopasture are 241.7, 135, and 9.40 Mg C/ha/year, respectively (1 Mg=10^6 gram). Establishment of alley cropping could sequester another 8.27ton C/ha/year. The traditional systems have high C stock in their biomass and soil, but has little potential for sequestering additional C; on the other hand, improved systems have low C stock, but high sequestration potential. For the standard size of live fence (291 m) and fodder bank (0.25 ha), the calculated net present values (NPV) were $ 96.0 and $158.8 without C credit sale, and $109.9 and $179.3 with C sale, respectively. From the C sale perspective, live fence seemed less risky as well as more profitable than fodder bank. Carbon credit sale is likely to contribute to the economic development of the subsistence farmers throughout the world.

Keywords: Agroforestry practices, Carbon sequestration, Climate change and Carbon trading.

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CHAPTER I

INTRODUCTION

Bangladesh is one of the most vulnerable countries resulting from the negative impact of climate change. Global warming and climate change are mainly due to the result of CO_2 levels rising in the earth's atmosphere. Global anthropogenic emissions of carbon dioxide to the atmosphere increased to about 9.7 Pg carbon(C) (1Pg=10^{15} gm) in 2012 mainly due to an increase in the fossil fuel combustion (Peters *et al.*, 2013). However, not all of emitted CO_2 stores in the atmosphere as land-based sinks take up significant amounts, i.e., about 28 % of anthropogenic CO_2 emissions were taken up on average between 2002 and 2011 (Peters *et al.*, 2012). Managing more efficiently the carbon (C) flows in agricultural systems can particularly reduce anthropogenic CO2 emissions (Smith *et al.*, 2008). The clean development mechanism (CDM) under the Kyoto Protocol allows industrialized countries with a Green House Gas reduction commitment to invest in mitigation projects in developing countries as an alternative way to what is generally costlier in their own countries. Forest conversion and land-use change are major factors leading to losses in carbon stocks and increasing the concentration of greenhouse gases in the atmosphere. Agricultural practices lead to the reduction in ecosystem carbon stocks mainly due to removal of aboveground biomass as harvest with subsequent burning and decomposition, loss of soil carbon as CO_2, and loss of soil C by erosion. Tropical deforestation contributes as much as 25% of the net annual CO_2 emissions worldwide (Schlamadinger *et al.*, 2003). Globally, forestry has taken a center stage as one of the options to mitigate CO_2 climate change.

Agroforestry refers to the practice of purposeful cultivation of trees and crops and/or animals, in interacting combinations, for a variety of benefits and services such as increasing crop yields, reducing food insecurity, enhancing environmental services, and resilience of agroecosystems (Nair *et al.*, 2012). Both agriculture and forestry are combined into an integrated agroforestry system to acquire maximum benefits by a greater efficiency in resource such as nutrients, light and water capture and utilization (Kohli *et al.*, 2008). Agroforestry systems are called as an integrated approach for sustainable land use aside from their contribution to climate change adaptation and mitigation (Cubbage *et al.*, 2013). Some agroforestry practices, in particular, have received increased attention regarding their net C sequestration effect by their ability to capture atmospheric CO_2 and store C in plants and soil (Nair *et al.*, 2012). Carbon sequestration potential of agroforestry practices has attracted attention from both industrialized and developing countries in recent years following the recognition of agroforestry as a greenhouse gas (GHG) mitigation strategy under the Kyoto Protocol to the United Nations Framework Convention on Climate Change. Growing agroforestry biomass for bio power and biofuels and thereby replacing fossil fuel has also a potential to reduce increases in the atmospheric CO_2 (Jose *et al.,* 2012). Thus, agroforestry has been recognized as having the greatest potential for C sequestration of all the land uses analyzed in the land-use, land-use Change as well as Forestry.

The potential of agroforestry systems for C sequestration depends on the biologically mediated uptake and conversion of CO_2 into inert mater, long-lived, C-containing materials, a process which is termed as bio sequestration (U.S. DOE 2008). Bio sequestration temporarily removes C from active cycling process. More generally, C sequestration can be defined as the uptake of C-containing substances and, in particular, CO_2 into another reservoir with a longer residence period (IPCC 2007). However, it has become customary for the term C sequestration to imply a contribution to climate change mitigation problem (Powlson *et al.,* 2011). Agroforestry offers an attractive economic opportunity for the subsistence farmers in the developing countries, the major practitioners of agroforestry, for selling the sequestered carbon through agroforestry activities to industrialized countries; it will be also an environmental benefit to the global community at large as well (Albrecht *et al.,* 2009).

Objectives:

The specific objectives of this review paper are:

(1) To highlight the potential of different agroforestry practices in carbon sequestration to mitigate climate change problem,
(2) To review the economic potential of agroforestry in carbon sequestration through carbon trading.

CHAPTER II

METHODOLOGY

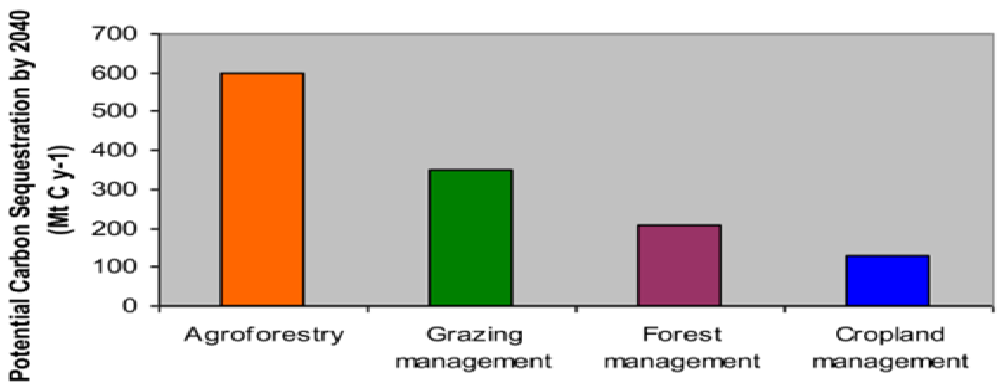
This Seminar paper is exclusively a review paper, so all of the information has been collected from the secondary sources. During preparation of this paper I went through various relevant books, journals, proceedings, reports, publications etc. Findings related to my topic have been reviewed with the help of the library facilities of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU). I have also searched related internet web sites to collect information. I got valuable suggestion and information from my major professor and course instructors. After collecting all the available information, I myself compiled and prepared this seminar paper.

CHAPTER III

REVIEW OF FINDINGS

Potential of Agroforestry Practices in Carbon Sequestration

Adoption of agroforestry practices has greater potential to increase C sequestration of predominantly agriculture dominated landscapes than the monocrop agriculture (Morgan *et al.*, 2010). In the tropics, (Palm *et al.*, 2010) report that agroforestry practices helped to regain 35 percent of the original C stock of the cleared forest, compared to only 12 percent by cropland and pastures (Figure 01). Agroforestry system can sequester 600 Mt C/year compared to cropland management system, which can sequester only 100 Mt c/year.



(Source: Palm *et al.*, 2010)

Figure 01. Carbon sequestration potential of different systems.

Total carbon emission from global deforestation currently estimated at the rate of 17 million ha yr^{-1} is 1.6 Pg. Assuming that one ha. of agroforestry could save 5 ha. from deforestation and that agroforestry practice could be established in up to 2 million hectares in low latitude (tropical) regions annually, a significant amount of carbon emission caused by deforestation could be reduced by establishing agroforestry systems.

There are some Agroforestry practices by which it will help in sequestrating carbon in mitigating climate change. They are:

Alley Cropping

Alley cropping also called hedgerow intercropping. It is a modern agroforestry practices. It includes growing crops in between the hedgerows of some fast growing and high biomass producing plants for the improvements in environmental quality, microclimate, C sequestration, economic returns, and wildlife benefits (Figure 02). In these systems, tree/shrub and crop row configuration, differences in C input into soil, decomposition rate, previous crop and land management, and associated soil micro fauna determine C sequestration (Bambrick *et al.*, 2010).

(Source: www.common.wikimedia.org)

Figure 02. Alley cropping systems.

A study was conducted on 2-year old Jatropha based alley cropping system at the Central Mindanao University, Musuan, Philippines. The treatments were as follows: Treatment 1: Control (No Fertilizer), Treatment 2: Organic Fertilizer, Treatment 3: Inorganic Fertilizer.

Findings **(**Table 01**)** showed that the above ground carbon stocks did not show significant difference both for the two cropping period. Result, however, revealed that the below ground carbon stock showed significant difference in the first cropping while highly significant difference was shown in second cropping. Organic fertilizer treatments had the highest carbon stocks both in the first and second cropping patterns. The inorganic and no fertilizer treatments, on the other hand, were not significantly different (Marine 2016).

Table 01. Total carbon sequestered in Jatrofa based alley cropping system

Treatments	**First cropping**			**Second cropping**		
	AGC	BGC	TC(ton/ha)	AGC	BGC	TC(ton/ha)
No Fertilizer	2.38	3.84^b	6.22^b	2.58	3.73^b	6.31^b
Organic Fertilizer	2.60	5.68^a	7.79^a	2.70	5.08^a	8.27^a
Inorganic Fertilizer	2.62	3.83^b	6.45^b	2.76	3.77^b	6.53^b
Level of Significance	ns	*	*	ns	**	*
CV(%)	10.14	12.08	10.86	10.48	6.16	6.87

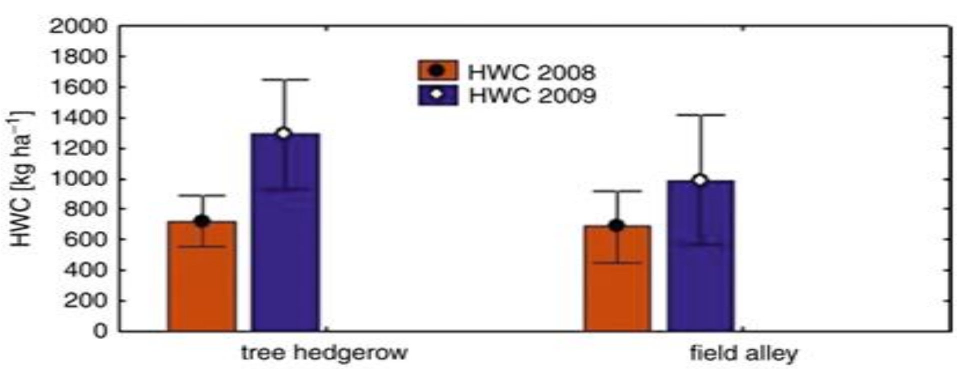
(Source: Marin, 2016)

*Means followed by the same letter in a column are not significantly different at 5%.

Legend: AGC: Above Ground Carbon, BGC: Below Ground Carbon, TC: Total Carbon.

In total carbon stocks, significant difference was shown in the two cropping system. Organic fertilizer treatment had shown the highest carbon stock at 7.79-ton /ha and 8.27ton/ ha for the first and second cropping, respectively. No fertilizer treatment shown the lowest with 6.22 in the first cropping while 6.31 in the second cropping. Its difference with the inorganic fertilizer, however, was not significant. Yan and Gong (2010) reported that utilization of organic fertilizer increased SOC (soil organic carbon) and soil fertility and consequently resulted in a larger yield trend when it compared to a balanced chemical fertilizer. Their model simulation and pot experimental results also revealed that soils with higher SOC had a higher root/shoot ratio such that the long-term use of organic fertilizer not only directly increases SOC, but indirectly contributes to carbon sequestration by favoring root development.

In a study of hybrid poplar leaves and branches had C stocks of 1.3 and 5.5 Mg C ha^{-1} when trees were 13 year-olds (Peichl *et al.*, 2007). After 13 years the tree component of this system added 14 Mg C ha^{-1} in addition to the 25 Mg C ha^{-1} added by litter and fine root. The total C sequestration was 39 Mg C ha^{-1} after 13 years and the system could potentially can sequester significantly more C at the end of a 40-year harvest cycle. Organic carbon in the surface (0–30 cm) soil, 1 year and 2 years after establishing an alley cropping system, in a mining reclamation landscape was considerably higher in tree hedgerow than field alley in 2009 compared to 2008(Figure 03).



(Source: Peichl *et al.*, 2007)

Figure 03. Organic carbon in the surface (0–30 cm) soil, 1 year and 2 years after establishing an alley cropping system, in a mining reclamation landscape.

Riparian Buffer Forest

Riparian areas are the green zone along rivers, streams and wetlands lakes. Trees grows rapidly in riparian zones because of the favorable moisture and nutrient condition. Forest buffers help protect rivers, streams, wetlands, and improve water quality by capturing eroded soil and preventing sedimentation, filtering nutrient runoff, protecting and enhancing the stream environment, and buffering against floods and droughts (Figure 04).

(Source: www.forestasyst.org)

Figure 04. Riparian buffer forest.

A study was carried out in Coastal Plain of North Carolina by the Department of Biology of East Carolina University showed that, the carbon stock of riparian zone cover/condition types ranged from 17.9 Mg C/ha for annual row crop agriculture to 241.7 Mg C/ha for mature forest (> 50 y old) (Table 02).

Table 02. Mean stored carbon (Mg C/ha) of living and detrital components for condition types in a riparian buffer forest

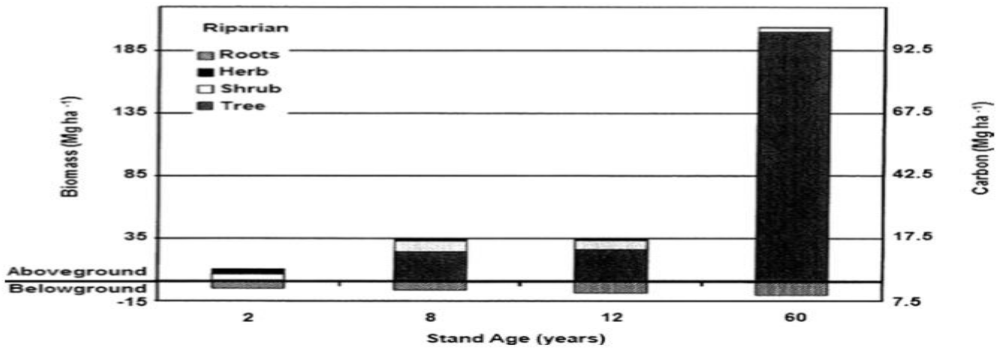
Condition Type (n)	Total Live	Total Detrital	Total C Stored (Mg C/ha)
Mature Forest	156.3	85.4	241.7
Young Forest	60.1	68.2	128.4
Regenerating Forest	61.3	41.0	102.3
Recently Clear-cut	2.2	80.3	82.5
Perennial Herb	6.1	29.8	35.8
Shrub Sapling	3.6	25.3	28.9
Annual Row crop	0.8	17.1	17.9

Mature forest (> 50 y old), Young Forest (26-50y), Regenerating Forest (5-25y), Recent Clear cut Forest (0-5 y).

(Source: Rheinhardt *et al.*, 2012)

The different functional groups such as trees and grasses in these systems colonize and capture both the above- and below-ground resources more efficiently than the row crop agriculture (Balian and Naiman, 2010).

Below-ground C capture rates were reported by Giese *et al.*, (2003) in South Carolina. The results revealed that 2.5, 3.7, 5.0, and 5.5 Mg C ha–1 below-ground in 2, 8, 12, and 60 year-old riparian buffers, respectively (Figure 05).



(Source: Giese *et al.,* 2003)

Figure 05. Above and below ground biomass and carbon of 2,8,12 and 60-year-old riparian stand in South Carolina, USA.

This study also indicated that fine root biomass in the younger stands was 25–50% of that found in mature stands. In addition to the C sequestered in roots, riparian soils can store C in soil organic matter (SOM). The SOM, which contains about 50% C, was greater in mature riparian stands compared to mono cropped agroecosystems or younger riparian buffers. Riparian systems store C in both above and below ground biomass of the vegetation and in the soil.

Wind Break

Windbreaks are designed with one or more rows of trees or shrubs planted across crop or grazing areas to reduce wind speed and increase microclimate for crop and/ or animal production (Figure 06). Windbreaks have been used throughout the history to protect homes, structures, livestock, and crops, control wind erosion and blowing snow, provide habitat for wildlife and improve landscape (Brandle *et al.,* 2009).

(Source: www.forestasyst.org)

Figure 06. Windbreak system.

For example, hybrid poplar tree sequestered 367 kg C/ tree in above- and below-ground compared to 110 kg C/ tree in green ash**.** In case of conifers, white spruce can sequester 186 kg C per tree where Scot pine can sequester only 107 kg C per tree (Table 03). Like other agroforestry systems, windbreaks also offer great promise for C sequestration (Schoeneberger *et al.*, 2012).

Table 03. Above- and below-ground biomass and carbon for shelterbelt trees

Vegetation type		**Above ground biomass (kg/tree)**	**Below ground biomass (kg/tree)**	**Total Carbon (kg/tree)**
Deciduous	Green ash	161.8	64.7	110
	Maple tree	178.6	71.4	120
	Hybrid poplar	544.3	217.7	367
	Siberian elm	201.9	80.8	140
Conifers	White spruce	286.9	86.1	186
	Scot pine	164.1	49.2	107
	Colorado spruce	202.2	60.7	131

(Source: Schoeneberger *et al.*, 2012).

Windbreaks are also used to reduce evaporation from soil and leaf surfaces. The groundcover under the windbreak can also help to reduce wind erosion and soil detachment by rain drops. The limited literature demonstrated the importance of species selection in maximizing the C sequestration potential of windbreaks. Indirectly, windbreaks reduce fuel utilization for heating and thereby reduce CO_2 emissions.

Multipurpose Trees on Crop Lands

The multipurpose tree species (MPTs) can form an integral component of different agroforestry system interventions in crop sustainability (Figure 07).

The MPTs, besides providing multiple outputs such as fuel, fodder, timber and other miscellaneous products, help in the improvement of soil health and other ecological conditions as well.

(Source: www.forestasyst.org)

Figure 07. Multipurpose tree species in a crop field.

Carbon sequestration through different multipurpose trees varies significantly. Among five years old agroforestry species, highest plant height (40.10 ft) was observed in *L. leucocephala* followed by in *M. azedarach* (39.17 ft) whereas trees with lowest plant height (38.45 ft) was observed in *A. lebbecck* (Table 04).

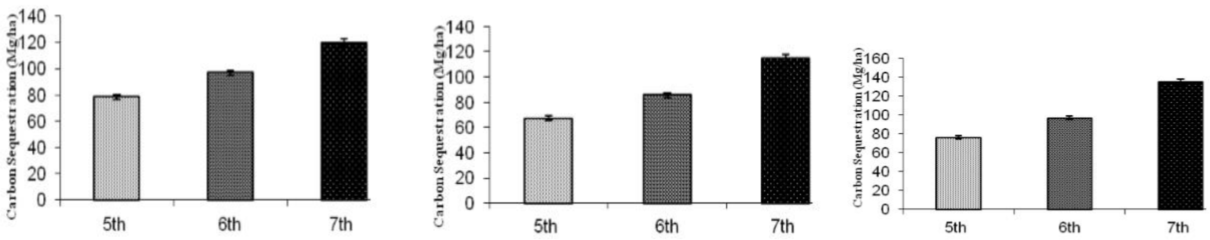
Table 04. Carbon sequestration by different agroforestry species at the age of 5th, 6th and 7th year plantation in Dinajpur, Bangladesh

	5th year		**6th year**		**7th year**	
Agroforestry species	Plant height (ft)	CO_2/ha/Y(Mg)	Plant height (ft)	CO_2/ha/Y(Mg)	Plant height (ft)	CO_2/ha/Y (Mg)
L. leucocephala	40.10	76.07	43.22	96.86	45.53	135
M. azedarach	39.17	78.62	41.71	97.16	43.15	120
A. lebbeck	38.45	67.19	40.02	85.70	41.13	115

(Source: Raman *et al.*, 2014)

Five years old *M. azedarach* sequestrated maximum (78.62 Mg ha-1Y-1) amount of carbon followed by in *Leucaena leucocephala* (76.07 Mg ha-1Y-1) whereas *A. lebbeck* sequestrated minimum (67.19 Mg ha-1Y-1) amount carbon from the atmosphere.

Consequently, at six years old plantation in terms of plant height and carbon sequestration potentiality similar trends were found like 5th year of plantation. Significantly, highest plant height (43.22 ft) was observed in *L. leucocephala* followed by in *M. azedarach* (41.71 ft) whereas trees with lowest plant height (40.02 ft) were observed in *A. lebbeck.*



(a) (b) (c)

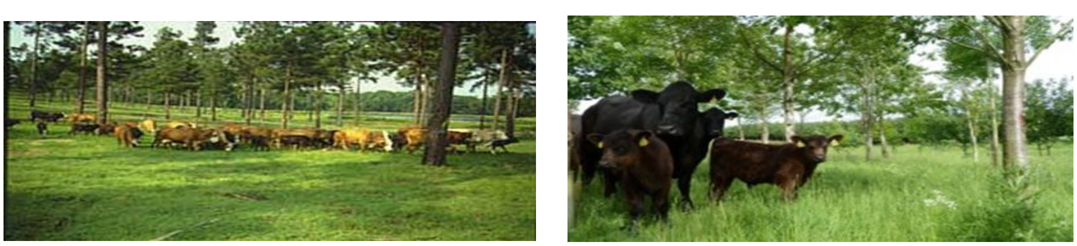
(Source: Rahman *et. al.*,2014)

Figure 08. Carbon sequestration by (a*) Melia azedarach* (b) *Albizia lebbeck* and (c)*Leucaena leucocephala* at the different age after plantation in Dinajpur, Bangladesh.

Therefore, highest (97.16 Mg ha-1Y-1) carbon sequestration was observed in *M. azedarach* which is statistically significant with *L. leucocephala* while lowest (78 Mg ha-1Y-1) carbon sequestration was recorded in A. *lebbeck*. Furthermore, after seven years' plantation of different agroforestry species, diverge character of the species vary greatly in terms of carbon sequestration potential. Thus, highest plant height (45.53 ft) in seventh year was observed in *L. leucocephala* followed by in *M. azedarach* (43.15 ft) whereas trees with lowest plant height (41.13 ft) were recorded in *A. lebbeck*. Consequently, maximum carbon sequestration (135 Mg ha-1Y-1) was observed in *L. leucocephala* followed by in *M. azedarach* (Figure 08).

Silvopastoral Systems

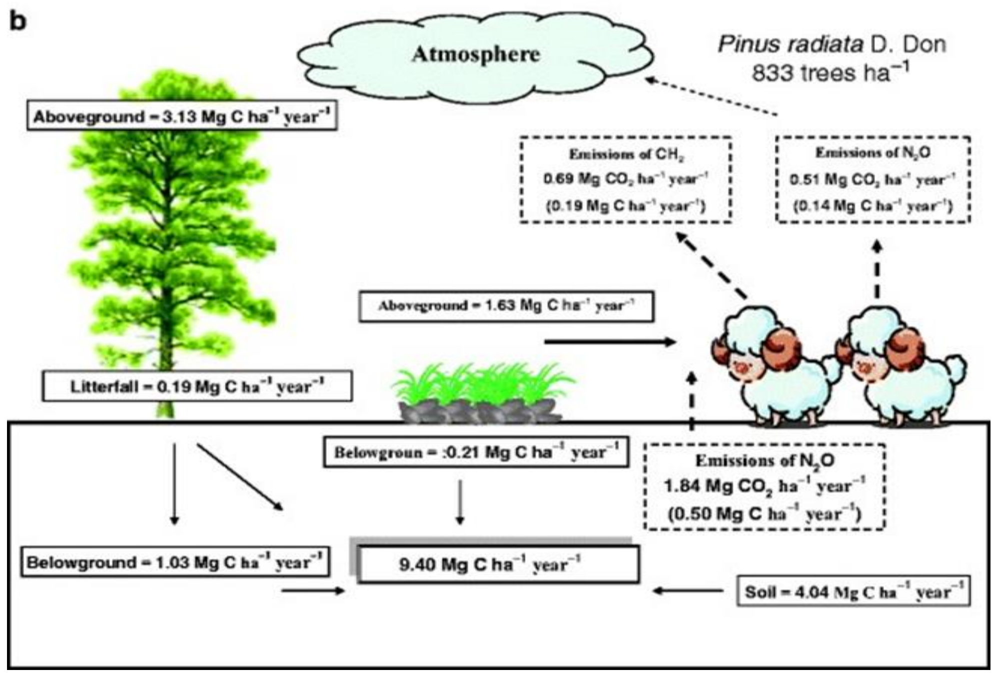
Silvopasture is an agroforestry system that intentionally integrates trees, forage crops, and livestock into a structural and functional system for optimization of benefits from planned biophysical interactions (Nair *et al.*, 2014) (Figure 09).



(Source: www.forestasyst.org)

Figure 09. Silvopastural Systems.

Conversion of pasture land into silvopasture has the potential to increase rooting depth and distribution, quantity, and quality of organic matter input and thereby C sequestration potential. Total carbon pools in a silvopastural system including GHG emissions in a 11 years-old *Pinus radiate* Species is 9.40 Mg C/ha/year (Figure 10).



(**Source:** Fernández Núñez *et al.*, 2010)

Figure 10. Carbon pools in a silvopasture system including GHG emissions in a 11 years-old *Pinus radiate* Species.

These systems could outperform in C sequestration of either forest or pastures as they have both forest and grassland mechanisms of C capture that can maximize C sequestration from both above- and below-ground. Silvopasture is the most common form of agroforestry system in North America (Nair *et al.*, 2012). Pasture and grazed forestland areas in the USA are 237 and 54 million ha respectively. These land areas can be intensively managed for additional C sequestration. According to Nair (2010), the C sequestration potential of silvopasture system in USA was 6.1 Mg C ha^{-1} year^{-1}. Using a sequestration potential of 6.1 Mg C ha^{-1} year $^{-1}$on 10% marginal pasture land (23.7 million ha) and 54 million ha of forests, the total C sequestration potential for silvopastoral land areas in the Unites States could be as high as 474 Tg C year^{-1}.

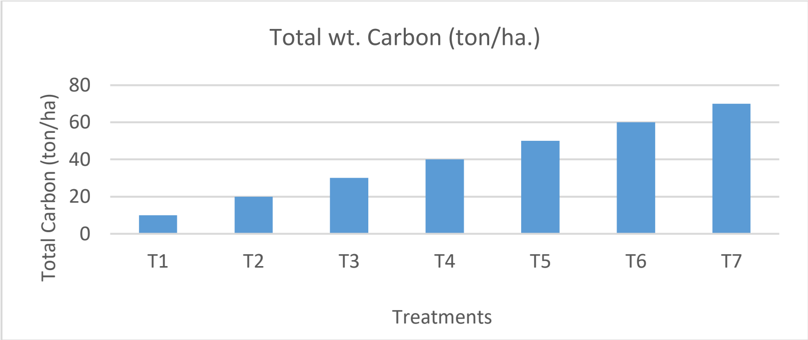
Multistory Agroforestry

Multistory agroforestry is that types of production system where crops are grown under different strata of tree or shrubs where all resources are captured judiciously for maximum production (Figure 11).

(Source: www.forestasyst.org)

Figure 11. Multistory agroforestry System.

A study was conducted in the research field of BSMRAU. Result showed maximum carbon stock was found in treatment T_7 (Aonla+Carambola+Lemon) followed by T_5 (Aonla+Carambola) (Figure 12).



(**Source:** Miah *et al.*, 2015)

Figure 12. Total carbon stock among different treatment in a multistory agroforestry system

T_1= Open field, T_2 = Aonla, T_3 = Carambola, T_4 = Lemon, T_5 =Aonla+Carambola, T_6 = Aonla+ Lemon, T_7 = Aonla + Carambola+ Lemon.

Treatment T_7 contained 15 years aonla and 7 years old carambola and lemon. Leaf litter fall, pruning material, dead organic matter added to soil and started nutrient cycling as well as nutrient pumping. Lowest carbon stocks were found in T_1 as there is no above and below ground biomass.

Carbon Sequestration in Bangladesh

Forestry is an important sector in Bangladesh perspective. There are three major types of forest presents in Bangladesh (Figure 13). According to the report, Sundarbans can capture 56 million tons of carbon and its price is at least Tk 150 billion in the international markets **(**Shin *et al.*, 2007).

(Source: Bangladesh forest department, 2010)

Figure 13. Forest cover map of Bangladesh.

The index estimated that Bain, Passur and Kankra trees can reserve high amount of carbon while Geoa and Keora reserve the least, and Sundari reserves moderate amount of carbon.

Shin *et al.*, (2007) reported that the average carbon sequestration potential in Bangladesh forest is about 92 tC ha^{-1} (Table 05).

Table 05. Carbon density in the forests of Bangladesh

Forest types	**Carbon stock (t C ha^{-1})**
Closed large crowns	11
Closed small crowns	87
Distributed closed	110
Distributed open	49
Average	**92**

(Source: Shin *et al.*, 2007)

An experiment was conducted in Hilly areas by S. K. Barua and S. M. S. Haque related to the impacts of trees on soil characteristics in the degraded hills of Chittagong District. The carbon sequestration potential and the present value of carbon revenue flow was also estimated for the degraded hills of Chittagong under social forestry program using *A. auriculiformis* plantations for the purpose. The results indicated that about 112.88 Mg C could be sequestered in the degraded hill areas of Chittagong District by planting *A. auriculiformis* trees in a 15-year rotation (Table 06).

Table 06. Potential carbon sequestration in *A. auriculiformis* plantations in the degraded hills of Chittagong district through social forestry

Crediting Period (Y)	**Storage of organic carbon (Mg ha $^{-1}$)**		
	In Biomass	In soil (10cm)	Total
5	22.29	3.68	25.96
10	65.31	7.53	72.66
15	101.86	11.03	112.88

(Source**:** Shin *et al.*, 2007)

Economic Potential of Agroforestry in Carbon Sequestration Through Carbon Trading

Carbon Credit

A carbon credit is a term in any tradable certificate or permit that representing the right to emit one tone of CO_2 or the mass of another greenhouse gas with an equivalent to one tone of CO_2. Carbon credit and carbon market are the components of national and international attempts to mitigate the increase in concentration of greenhouse gases.

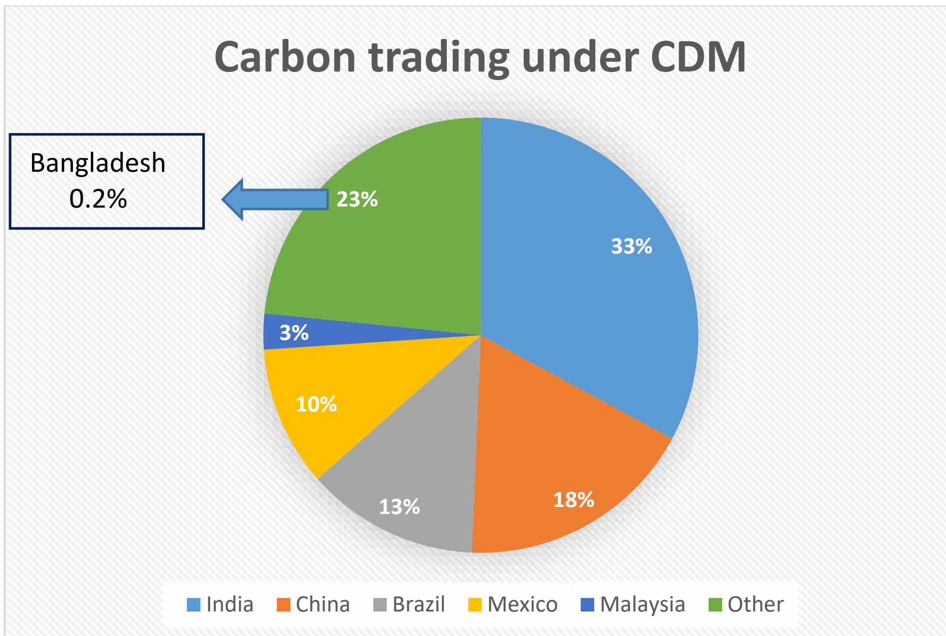
Clean Development Mechanism (CDM)

Clean Development Mechanism (CDM) is an important obligation of the Kyoto Protocol. Clean Development Mechanism known as CDM, which allowed 39 industrialized countries to achieve part of their Green House Gas (GHG) emission reduction target through investment in projects in developing countries that reduce GHG emission specially CO_2 from the atmosphere (IPCC 2007).

Global carbon market in 2005 was comparatively lower than the carbon market in 2008 (Figure 14). In 2005, total carbon market was 10.864 billion US$ and CDM market was only 2.638 billion

US$. Where as in 2008 total carbon market was 92 billion US$ CDM market was 22 billion (Antle *et al.*, 2010).

Clean Development Mechanism project is running in different developing countries to reduce the emission of CO_2 by planting more tree or afforestation. In Bangladesh it is also running in the coastal region of Bangladesh (Figure 14).



(Source: Capoor *et al.*, 2013)

Figure 14. Carbon trading program in developing country.

Newly afforestation in mangrove forest and establishment of coastal green belts are the major areas of this project in Bangladesh to reduce CO_2 emission, ultimately mitigating climate change impact.

Carbon Trading

Carbon markets are considered to be one of many innovative, market-based solutions to global climate change. These markets allowed for the purchase of carbon "credits" by carbon emitters who need to offset their emissions. The emitter can reduce carbon emissions or purchase credit from a seller who is taking some action to reduce carbon emissions or sequester carbon.

Role of Agroforestry in Carbon Trading

Agroforestry is a bright sector for carbon trading through carbon sequestration. Grasses or plants in no-till or strip till or trees in forests are well-known for their ability to sequester carbon from atmosphere. Fodder bank and live fence are another example of agroforestry practices for commercial carbon trading. As plant grows, it accumulates more biomass. This biomass grows incrementally using atmospheric carbon in photosynthesis process. A rapidly growing young forest has large yearly incremental increase in biomass and thus has a large capacity to sequester carbon from the atmosphere. This ability to capture carbon is what makes forests an important source of credits from sequestration projects. Further, carbon captured through no-till or strip till is stored in biomass and in soil. Carbon credits could also be generated when carbon-neutral fuels are substituted for fossil fuels. Agroforestry can be replaced in the place of coal by cultivating bio fuel plant that can be used in electricity generation. This source of credits ensures additional income to landowners for harvest residues and other forest biomass that are used for energy production.

Economic Analysis of Carbon Sequestration of Live Fence and Fodder Bank

Live fence referred to planting relatively fast-growing trees with very high density around field plots, orchards, or cultivated land. Trees are planted at 1 m intervals in two lines 1.5 m apart from surrounding the protected land. Five tree species are highly used: Acacia nilotica, Acacia senegal, Bauhinia rufescens, Lawsonia inermis, and Ziziphus mauritiana. Fodder bank is a system of planting exotic and/or native species suitable for animal fodder in relatively high density. ICRAF has introduced an exotic species, Gliricidia sepium, and two indigenous fodder trees, Pterocarpus lucens and P. erinaceus, although these two species did not grow well enough to be harvested in all the experimental plots. The most common size of the fodder bank is 0.25 ha (50 by 50 m) bordered by live fence, and fodder trees are planted 2×1 m in lines.

Benefit Cost Ratio (BCR) of Live fence and Fodder bank

Calculations of the three decision rules Net Present Value (NPV), Benefit Cost Ratio (BCR), and Internal Rate of Return (IRR) for three different conditions (No C sale, C sale with the ideal accounting method, and C sale) have showed that C sale by the ideal accounting method changed all decision rules from the no C sale scenario. NPV of the live fence without C sale is increased from $96.0 to $109.9 with C sale by the ideal accounting method. NPV of the fodder bank was $158.8 without C sale, but $179.3 with C sale by the ideal accounting method (Table 07).

Table 07. Net Present Value (NPV), Benefit Cost Ratio (BCR), and Internal Rate of Return (IRR) of the live fence and the fodder bank projects in the three different scenarios (without C sale, with C sale by the ideal accounting method, and with C sale

	Live fence			**Fodder bank**		
	No C sale	Ideal accounting	Final accounting	No C sale	Ideal accounting	Final accounting
NPV	96	109.94	96.32	158.76	179.26	159.13
BCR	1.53	1.60	1.53	1.67	1.74	1.67
IRR (%)	25.5	27.3	25.5	29.5	31.4	29.5

*Values are in US dollar. (Source: Tschakert *et al.*, 2007)

BCR and IRR was also increased with C sale showing economic profitability of the practice. However, C sale did not increase the three decision rules much from those without C sale (Tschakert *et al.*, 2007).

Sensitivity Analysis of Live Fence and Fodder Bank in Case of Carbon Sequestration

Sensitivity analysis was conducted for five major input variables by varying one at a same time. Two scenarios, with or without C sale, were taken to assess the NPV sensitivity. When the discount rate was changed from 15% to 10 and 20%, the NPV was changed greatly for both live fence and fodder bank projects. Seedling costs change (±50%), on the other hand, did not fluctuate the NPV much compared to other variables in both projects (Table 08). Labor price changes (±50%) has affected the NPV of the live fence project and the fodder bank project differently, causing a large change in the NPV of live fence while causing very little in the NPV of fodder bank.

Table 08. NPV sensitivity of the live fence project and the fodder bank project to the change of an input variable

	Live Fence		Fodder Bank	
	No C sale	**With C sale**	**No C sale**	**With C sale**
Best-guess scenario	96	109.92	158.76	175.26
Discount rate −5%	198.84	215.26	302.61	322.37
Discount rate +5%	38.18	49.96	78.35	92.12
Seedling cost −50%	125.14	139.08	185.17	201.67
Seedling cost +50%	66.86	80.79	132.35	148.85
Labor price −50%	151.22	158.19	161.36	169.61
Labor price +50%	40.78	47.75	156.16	164.41
Yield of harvests +50%	235.15	256.05	272.04	296.79
Yield of harvests −50%	−43.14	−36.17	45.48	35.55
C price +50%		116.90		183.51
C price −50%		102.97		167.01

*Values are in US dollar. (Source: Tschakert *et al.*, 2007)

When the yield (harvest of fodder, live fence products and timber) was examined with ±50%, the range of NPV was largest in both live fence and fodder bank. The NPV values became even negative (meaning: the project is economically not viable) for the live fence project when yield was −50% from the best-guess scenario. C price change (±50%) did not change the NPV of both systems largely, suggesting C price is not an influential factor to change the project's profitability.

CHAPTER IV

CONCLUSIONS

Acceptance of different agroforestry systems like alley cropping, windbreak, riparian buffer, silvopastural system etc. provide a huge potentials of carbon sequestration as because in agroforestry systems, C is located in five main pools, namely, aboveground plant biomass (tree and understory), plant roots (tree and understory), litter, microbial, and soil C.

Improved agroforestry practices such as live fence and fodder bank have a better prospect as C sequestration. Carbon sale is more likely to contribute to economic the well-being of the farmers in the region if C credit market is introduced under CDM. Between these two improved practices, live fence has higher C sequestration potential as well as economically less risky than fodder bank. Adopting these systems on cultivable land rather than on abandoned land is likely to be more profitable.

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