Paper ID E18

Potentiality of agroforestry species to climate change mitigation through carbon sequestration

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Abstract

This paper provides information about carbon sequestration potentiality of different agroforestry species in the northern part of Bangladesh to combat with the pessimistic impact of climate change. Agroforestry as a land-use system is receiving wider recognition not only in terms of agricultural sustainability but also in issues related to climate change. The potentiality to sequester carbon by agroforestry species (*Albizia lebbeck, Leucaena leucophala and Melia azedarach*) in sub-tropical regions like Bangladesh is promising. The carbon sequestration potential of three agroforestry species under the study ranges from 115-135 Mg $Cha^{-1}Y^{-1}$ at the age of seven years after plantation. Among the multipurpose tree species, *Leucaena leucophala* (135 Mg $Cha^{-1}Y^{-1}$) sequestrate maximum amount of carbon while *Albizia lebbeck* (115 Mg $Cha^{-1}Y^{-1}$) sequestrate less amount of carbon from the atmosphere and *Melia azedarach* sequestrate 120 Mg $Cha^{-1}Y^{-1}$. Therefore, carbon sequestration potentiality of the studied agroforestry species may be ranked as *Leucaena leucocephala*>*Melia azedarach*>*Albizia lebbeck.*

INTRODUCTION

Bangladesh is among one of the most vulnerable countries resulting from the negative impact of climate change. Global warming and climate change are mainly the result of CO_2 levels rising in the earth's atmosphere. The concentrations of CO_2 in the atmosphere are increasing at an accelerating rate from decade to decade. The upper safety limit for atmospheric CO_2 is 350 parts per million (ppm). Atmospheric CO_2 levels have stayed higher than 350 ppm since early 1988 [1]. In May, 2012 concentration of atmospheric CO_2 was 396.78 ppm. Deforestation in the tropics and fossil fuel burning in temperate regions contribute to the largest flux of CO_2 to the atmosphere. So, this huge amount of carbon in the atmosphere should be removed. Carbon sequestration involves the removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, vegetation, or soils) through physical or biological processes [2]. Conceptually trees are considered to be a terrestrial carbon sink [3]. The integration of trees, agricultural crops, and/or animals into an agroforestry system has the potential to enhance soil fertility, reduce erosion, improve water quality, enhance biodiversity, increase aesthetics and sequester carbon [4, 5, 6 and 7].

The incorporation of trees or shrubs in agroforestry systems can increase the amount of carbon sequestered compared to a monoculture field of crop plants or pasture [8, 9]. The area of the world under agroforestry will increase substantially in the near future. Undoubtedly, this will have a great impact on the flux and long-term storage of C in the terrestrial biosphere [10]. Agroecosystems play a central role in the global C cycle and contain approximately 12% of the world terrestrial C [11, 12]. The IPCC Report estimated the area currently under agroforestry worldwide is 400 million ha with an estimated C gain of 0.72 Mg Cha^{-1} yr^{-1}, with potential for sequestering 26 MMTC (million metric ton C) per year by 2010 and 45 $MMTCyr^{-1}$ by 2040[13]. Consistent with this, average stock of C in the Indonesian Pekarangan is 107 Mg C ha^{-1}, with about 98 per cent in tree biomass and soil [14]. The study therefore, has compiled the data on C sequestration potential of different multipurpose trees (*Leucaena leucocephala, Melia azedarach, Albizia lebbeck*) grown in sub-tropical climate of Bangladesh.

MATERIALS AND METHODS

Carbon sequestration potential of different agroforestry species was evaluated in Agroforestry Research Farm, Hajee Mohammad Danesh Science and Technology University, Bangladesh from 2009-2011. The site was between 25º 13´ latitude and 88º 23´ longitude, and about 37.5 m above the sea level [15]. The experimental site was in a medium high land belonging to the old Himalayan Piedmont Plain Area (AEZ No. 01). The soil texture was sandy loam in nature. The soil pH was 5.1. The experimental site was situated under the tropical climate characterized rainfall only during monsoon and scanty or no rainfall in the rest period of the year. The three agroforestry species includes *Leucaena leucocephala, Melia azedarach* and *Albizia lebbeck*. The trees were selected for the study due to fast growing species and deciduous in nature. Trees were planted earlier in 2005 from saplings collected from the nursery of forest department, government of Bangladesh. The trees was planted with a spacing of 3m × 3m (i.e. 1092 trees/ha) leaving space between the rows for alley cropping. In Agroforestry Research Farm, there were 20 trees of each species among them, 10 species was selected for study. The data collected from the three tree species includes plant height and diameter at breast height (dbh) annually from 2011-2013. Then the data were further interacted through a process for calculation of carbon sequestration potential of agroforestry species. The process for determining carbon sequestration potentiality of the tropical tree species were initiated by a group of teachers and student from university of Nebraska. The process includes determining total (green) weight of the tree, dry weight of the tree, weight of carbon in the tree, weight of CO_2 sequestrated by the tree and finally weight of CO_2 sequestrated by the tree per year. Total weight of the tree was measured by using an algorithm $W = 0.25D^2H$ (when $D<11$), W = Above-ground weight of the tree in pounds, D = Diameter of the trunk in inches and H = Height of the tree in feet. The root system weighs about 20% as much as the above-ground weight of the tree. Therefore, to determine the total green weight of the tree, the above-ground weight of the tree was multiplied by 120% [16]. Then, dry weight of the tree was calculated based on an extension publication from University of Nebraska. According to them, average tree content of 72.5% dry matter and 27.5% moisture. Therefore, dry weight of the tree determined by multiplying the weight of the tree by 72.5% [17]. Generally, carbon content in a tree is 50% of tree's total volume. So, carbon content in the tree was calculated by multiplying dry weight of the tree with 50%. Again, weight of CO_2 sequestrated in the tree was measured from the ratio CO_2 to C which is 3.6663. Thus, CO_2 sequestrated in the tree was measured multiplying weight of carbon in the tree by 3.6663. As a result, CO_2 sequestrated in the tree was divided by the age of the tree for determining CO_2 sequestrated in the tree per year. Finally, all the data were statistically analyzed with the help of the computer package MSTAT. The mean differences were adjusted by the Duncan's Multiple Range Test (DMRT) [18].

RESULTS

Carbon sequestration by different multipurpose trees varies significantly. Among five years old agroforestry species, highest plant height (40.10 ft) was recorded in *L. leucocephala* followed by in *M. azedarach* (39.17 ft) whereas trees with lowest plant height (38.45 ft) was recorded in *A. lebbecck*. On the other hand, maximum diameter (8.43 inch) of the trees was recorded in *M. azedarach*. Again, trees with lowest diameter were observed in *A. lebbeck* which was statistically significant with the diameter of *L. leucocephala*. However, carbon sequestrated by different trees vary diverge significantly at the age of five year. Thus, highest (72.00 Kg) carbon sequestration by the trees per year was recorded in *M. azedarach* followed by in *Leucaena leucocephala* (69.66 Kg) while the lowest (61.53 Kg) carbon sequestration by the trees was recorded in *A. lebbeck*. Consequently, five years old *M. azedarach* sequestrate maximum (78.62 Mg $ha^{-1}Y^{-1}$) amount carbon followed by in *Leucaena leucocephala* (76.07 Mg $ha^{-1}Y^{-1}$) whereas *A. lebbeck* sequestrate minimum (67.19 Mg $ha^{-1}Y^{-1}$) amount of carbon from the atmosphere.

Consequently, at six years old plantation in terms of plant height, trunk diameter and carbon sequestration potentiality similar trends were found like 5th year of plantation. Significantly, highest plant height (43.22 ft) was recorded in *L. leucocephala* followed by in *M. azedarach* (41.71 ft) whereas trees with lowest plant height (40.02 ft) were recorded in *A. lebbeck*. On the other hand, maximum diameter of the trunk (9.08 inch) was recorded in *M. azedarach* followed by in *L. leucocephala* while minimum diameter of the trunk was recorded in *A. lebbeck*. However, maximum (88.97 kg) carbon sequestration by the trees per year was recorded in *M. azedarach* which is statistically significant with *L. leucocephala* (88.70 kg) and minimum (78 kg) carbon sequestration was recorded in *A. lebbeck*. Therefore, highest (97.16 Mg $ha^{-1}Y^{-1}$) carbon sequestration was recorded in *M. azedarach* which is statistically significant with *L. leucocephala* while lowest (78 Mg $ha^{-1}Y^{-1}$) carbon sequestration was recorded in *A. lebbeck*. Furthermore, after seven years plantation of different agroforestry species, diverge character of the species vary significantly in terms of carbon sequestration potential.

Table 1. Carbon sequestration by different agroforestry species at the age of 5th year plantation in Dinajpur, Bangladesh

Agroforestry species	Plant height (ft)	Diameter (inch)	CO_2 $T^{-1}Y^{-1}$ (Kg)	CO_2 $ha^{-1}Y^{-1}$ (Mg)
L. leucocephala	40.10 ^{a}	7.96 ^{b}	69.66 ^{ab}	76.07 ^{ab}
M. azedarach	39.17 ^{b}	8.43 ^{a}	72.00 ^{a}	78.62 ^{a}
A. lebbeck	38.45 ^{c}	7.90 ^{b}	61.53 ^{b}	67.19 ^{b}
$LSD_{(0.05)}$	0.613	0.143	8.80	8.80
CV (%)	0.69	0.80	5.73	5.73
Stad. Deviation	0.87	0.27	0.56	0.56

Table 2. Carbon sequestration by different agroforestry species at the age of 6th year plantation in Dinajpur, Bangladesh

Agroforestry species	Plant height (ft)	Diameter (inch)	CO_2 $T^{-1}Y^{-1}$ (Kg)	CO_2 $ha^{-1}Y^{-1}$ (Mg)
L. leucocephala	43.22 ^{a}	8.91 ^{b}	88.70 ^{a}	96.86 ^{a}
M. azedarach	41.71 ^{b}	9.08 ^{a}	88.97 ^{a}	97.16 ^{a}
A. lebbeck	40.02 ^{c}	8.70 ^{c}	78.48 ^{b}	85.70 ^{b}
$LSD_{(0.05)}$	0.442	0.143	3.093	3.093
CV (%)	0.47	0.73	0.75	1.60
Stad. Deviation	1.40	0.17	5.35	5.35

Table 3. Carbon sequestration by different agroforestry species at the age of 7th year plantation in Dinajpur, Bangladesh

Agroforestry species	Plant height (ft)	Diameter (inch)	CO_2 $T^{-1}Y^{-1}$ (Kg)	CO_2 $ha^{-1}Y^{-1}$ (Mg)
L. leucocephala	45.53 ^{a}	10.24 ^{a}	123.7 ^{a}	135 ^{a}
M. azedarach	43.15 ^{b}	9.92 ^{b}	109.9 ^{b}	120 ^{b}
A. lebbeck	41.13 ^{c}	9.95 ^{b}	105.4 ^{b}	115 ^{b}
$LSD_{(0.05)}$	1.133	0.176	4.744	4.744
CV (%)	0.37	0.77	0.78	1.86
Stad. Deviation	1.92	0.17	8.53	8.53

Thus, highest plant height (45.53 ft) in seventh year was recorded 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*. On the other hand, maximum diameter (10.24 inch) of the trees was recorded in *L. leucocephala* whereas trees with minimum diameter were observed in *M. azedarach* (9.92 inch) which was statistically identical with the diameter of *A. lebbeck*. Again, maximum carbon sequestration (123.7 kg) by the trees per year was recorded in *L. leucocephala* whereas trees with minimum carbon sequestration were observed in *A. lebbeck* (105.4 kg) which was statistically identical with the diameter of *M. azedarach*. Consequently, maximum carbon sequestration (135 Mg $ha^{-1}Y^{-1}$) was recorded in *L. leucocephala* followed by in *M. azedarach* whereas trees with minimum carbon sequestration were observed in *A. lebbeck* (105 Mg $ha^{-1}Y^{-1}$) which was statistically identical with the diameter of *M. azedarach*.

DISCUSSION

Growth of different multipurpose trees varies significantly with time. Among different tree species, maximum plant height was always observed in *L. leucocephala* followed by in *M. azedarach*. On the other hand, minimum plant height was observed in *A. lebbeck*. This is due to the comparatively fast growing nature of the species. But, in case of trunk diameter, maximum diameter was recorded in *M. azedarach* at age of 5th and 6th year while in 7th year maximum diameter was recorded in *L. leucocephala*. Consequently, in three years of observation, minimum diameter of the trunk was recorded in *A. lebbeck*. The height and diameter of trunk of a tree influence the carbon sequestration potential of the species. Maximum height and diameter of a tree represent maximum amount of carbon sequestrated by the species. Although, potential of agroforestry species to sequester carbon varies depending upon the type of the system, species composition, age of component species, geographic location, environmental factors and management practices.

In 5th year of plantation, maximum carbon sequestration was recorded in *M. azedarach* followed by in *L. leucocephala* and minimum carbon sequestration was recorded in *A. lebbeck*. Consequently, in next year maximum carbon sequestration was also recorded in *M. azedarach* while in 7th year maximum carbon was captured by *L. leucocephala* followed by in *M. azedarach*. In a 12-year alley cropping also known as hedgerow intercropping on a Nigerian Alfisol, *G. sepium* and *Leucaena leucocephala* captured maximum amount of carbon compared to sole crops [19]. A 12% increase in SOC (O.23 $MgCha^{-1}$) has also been observed after 5 years of hedgerow intercropping with *Inga edulis* in a typic Paleudult in Peru [20]. Again, in a 6-year-old fallow model found that above-ground *Leucaena* biomass increased from 4 $MgCha^{-1}$ in the first year to 64 $MgCha^{-1}$ in the sixth year [21].

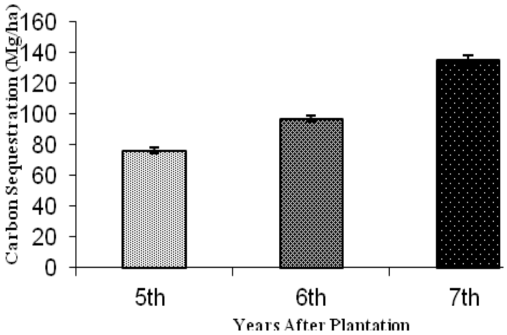

Fig. 1 Carbon sequestration by *Leucaena leucocephala* at the different age after plantation in Dinajpur, Bangladesh

On the other hand, minimum carbon sequestration was observed in *A. lebbeck*. Similar results were observed in India [22]. In India, carbon sequestration potential of 5 and 7 years age *L. leucocephala* in a silvopastoral system were 31.8 $MgCha^{-1}Y^{-1}$ and 32.8 $MgCha^{-1}Y^{-1}$ while highest carbon sequestration was recorded in 70.3 $MgCha^{-1}Y^{-1}$ and 91.8 $MgCha^{-1}Y^{-1}$ in *Acacia auriculiformis*. On the other hand, 9-years old *Ailanthus triphysa* sequestrate maximum amount of carbon from the atmosphere [23].

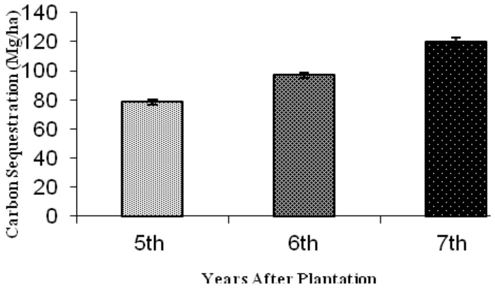

Fig. 2 Carbon sequestration by *Melia azedarach* at the different age after plantation in Dinajpur, Bangladesh

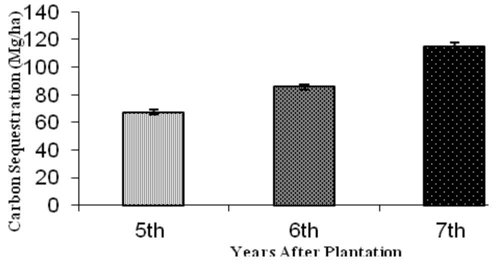

Fig. 3 Carbon sequestration by *Albizia lebbeck* at the different age after plantation in Dinajpur, Bangladesh

Again, if we consider the production system, in United States of America from 154 million ha of total US crop land. The land under alley cropping is 80 million ha with average total carbon sequestration potential of 142 MMTC Y^{-1} [24]. The potential for carbon sequestration through alley cropping could be 73.8 MMTC Y^{-1}. So, alley cropping is richest source of carbon sequestration in United States. However, in India carbon stocks of nine important tropical taxa in the humid tropics of an Indian peninsula ranged from 9.9 to 172 Mg Cha^{-1}, depending on species, age and stand management system [25]. Aboveground C stock was consistently highest for *Acacia*, followed by *Paraserianthes*. Moreover, the highest values for C sequestration obtained are comparable to the stocks of 20 years old teak plantation in Panama (120 Mg Cha^{-1}), 45 year rotation of Australian radiata pine (171 Mg Cha^{-1}) and 30 years rotation of Brazilian Slash Pine (112 Mg Cha^{-1}) [22].

CONCLUSION

Agroforestry system with perennial crop is an important carbon sink. The potential to sequester carbon by agroforestry systems in tropical regions like Bangladesh is promising, as it got worldwide recognition for carbon sequestration potentiality and reducing carbon dioxide emission. However, the type of agroforestry systems and their capacity to sequester carbon vary globally. The findings of this investigation will help the land owners/farmers to take the decision regarding their involvement on the upcoming REDD+ program which will be conducted by the Forest department in collaboration with UNDP and FAO in Bangladesh and they will be benefited. Ipil-ipil tree may be excellent options for farmers to follow Agroforestry practices in their field. Government can also consider this tree in their plantation program in order to mitigate climate change impacts.

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