ESTIMATION OF BIOMASS CARBON STOCK AT THREE PLANTATION SITES IN SHER-E-BANGLA AGRICULTURAL UNIVERSITY CAMPUS

A THESIS

BY

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*This is to certify that the thesis entitled "**ESTIMATION OF BIOMASS CARBON STOCK AT THREE PLANTATION SITES IN SHER-E-BANGLA AGRICULTURAL UNIVERSITY CAMPUS**" submitted to the **Faculty of Agriculture,** Sher-e-Bangla Agricultural University (SAU), Dhaka in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN AGROFORESTRY & ENVIRONMENTAL SCIENCE**, embodies the results of a piece of bonafide research work carried out by **MD. SHARIFUL ISLAM, Registration no. 07-02473** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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ABSTRACT

Urban forests play an important role in mitigating hazards evolved due to climate change through sequestering atmospheric carbon dioxide. The study was conducted at three plantation systems in Sher-e-Bangla Agricultural University Campus (SAU) aiming at exploring floristic composition, stand characteristics and biomass carbon stocks. Both purposive (Woodlot and homegarden) and systematic sampling method were followed. A total of 35 genera and 41 tree species that were belonged to 25 families were recorded in SAU campus. Among the three plantation systems, homegaraden was found rich in species composition followed by woodlot and roadside. *Mangifera indica* was found dominant species in SAU (IVI = 17.25 %). Stem density and mean DBH were significantly varied among the three plantation systems ($p < 0.05$), while basal area and biomass carbon (Above - and below ground) was exhibited with insignificant difference ($P > 0.05$). The average biomass carbon stocks for roadside, homegardens and woodlot were 159.18 ± 36 $Mgha^{-1}$, 169.37 ± 34 $Mgha^{-1}$ and 206.19 ± 42 $Mgha^{-1}$, respectively. When three plantation systems considered as whole, the mean biomass carbon, basal area, stem density, mean DBH were 174.24 ± 21 $Mgha^{-1}$, 34.16 ± 3.51 m^2ha^{-1}, 1096.87 ± 121.10, 19.83 ± 1.63 cm, respectively. This study reveals that the urban institutional forest is rich in terms of plant species and carbon stocks and similar work should be extended to other urban green space in order to know the overall carbon stocks in Dhaka City.

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ρ	Wood specific gravity (g/cm³)
AGB	Above-ground biomass
BGB	Below-ground biomass
C	Carbon
CER	Certified emission reduction units
CO_2	Carbon dioxide
O_2	Oxygen
DBH	Stem diameter at breast height (over bark)
GBH	Girth breast height
DW	Biomass dry weight
e.g.	For example

FW	Biomass fresh weight
GHG	Green house gas
GIS	Geographic Information System
GPS	Global Positioning System
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
Mg	Mega gram = 10^6 gram
A/R	Aforestation and Reforestation
et al.	And others
^0C	Degree Celsius
IVI	Importance Value Index
cm	Centimeter
m^2	Square meter

%	Percent
µ	Average
t	Ton
AEZ	Agro-Ecological Zone
AGC	Above ground carbon
BGC	Below ground carbon
UNFCCC	United Nations Framework Convention on Climate Change
CDM	Clean development mechanism
FAO	Food and agriculture organization
REDD	Reducing Emissions from Deforestation and Forest Degradation
SOC	Soil organic carbon

CHAPTER I
INTRODUCTION

Biodiversity conservation and global climate change are the two burning issues those got an immense attention to scientific community and policy makers in the recent decades (Saha *et al.,* 2009; IPCC, 2013). Increasing level of atmospheric CO_2 due to burning of fossil fuels, cement production and deforestation, is the main driver of this climate change. The concentration of CO_2 in the atmosphere has been increasing from starting point of industrial revolution and during the period of 1750-2011, it was raised to 391ppm (IPCC, 2013). A recent prediction reveals that if the rising trend of CO_2 is continue in this manner it would elevate the atmospheric temperature by 2-4.2 °C by the year of 2050 (Anderson and Bows, 2011; IPCC, 2013). It will ultimately induce to melt out of the polar ice which would increase the sea level rise by 5 m and consequently, the coastal region will adversely be affected by saline water particularly in developing countries like Bangladesh (Rahman *et al.,* 2014). Also, the livelihoods pattern will be changed that would cause people to migrate towards Urban Areas (IPCC, 2013). The urban areas has also exhibited with warmer climate than the peri-urban areas due to high level of fossil fuel combustion and elevated proportion of imperious surface (Doygun and Alphan, 2006; Weng and Yang, 2006, Liu and Li, 2012)

Trees in Urban green space provides a multiple benefits to urban dwellers such as lowering temperature, providing shade, aesthetic beauty, reducing sound, giving shelter of diverse birds and other species, act as a air purifier, noise filter and sequester particulate matter etc (Nagendra and Gopal, 2010, Nowak, *et al.,* 2013). Alongside of these ecosystem services, urban green space is playing an important role in sequestering atmospheric carbon dioxide through photosynthesis. However, in the context of global carbon research, a lot of works have conducted in natural forest, afforested and reforested ecosystems outside the urban areas (Myeong *et al.,* 2006; Stoffberg *et al.,* 2010; Zhao *et al.,* 2010; Nowak *et al.*, 2009; Liu and Li, 2012). This was, because of the consideration of natural forest, afforestation and reforestation in UNFCCC's climate change mitigation financial mechanism such as Clean Development Mechanism (CDM), Reduce Emission from Deforestation and Forest Degradation (REDD) (Rosendal and Schei, 2014). However, some recent studies both in developed and developing countries reveals that urban green spaces are rich in biodiversity and also, can store a considerable carbon in above- and belowground (Myeong *et al.,* 2006; Stoffberg *et al.,* 2010; Zhao *et al.,* 2010; Nowak *et al.,* 2010, 2011, 2012, 2013; Liu and Li, 2012).

In Bangladesh, the every district town and the seven divisional towns are rich in biodiversity where the urban forest are designated as roadside plantation, woodlot, homestead, parks, and institutional plantation. However, the quantification of carbon stocks in these diverse urban forests is yet to be done. Therefore, the present study was under taken in Sher-e-Bangla Agricultural University campus as a model of urban institutional forest carbon assessment in Bangladesh where three types of urban forests are available e.g., roadside plantation, woodlot and homegarden.

Objectives:

1. To explore the floristic composition of woody vegetation and stand characteristics of the three plantation sites in Sher-e-Bangla Agricultural University campus.
2. To estimate the amount of biomass carbon stock at three plantation sites in Sher-e-Bangla Agricultural University campus.

CHAPTER II

REVIEW OF LITERATURE

2.1 Carbon sequestration overview

IPCC (2001) reported that climate has changed over the past century and it is very likely that human activities are causing it. The concerns over potential global climate change have reached international level since the first “World Climate Conference” was organized by World Meteorological Organization (WMO) in 1979. In response, WMO and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. Four years later, an international environmental treaty, called United Nations Framework Convention on Climate Change (UNFCCC), was formulated aiming at reducing global greenhouse gas emissions. Article 4 of the UNFCCC requires preventing and minimizing climate change by “limiting anthropogenic emissions of greenhouse and protecting and enhancing greenhouse gas sinks and reservoirs” (United Nations, 1992). While UNFCCC did not specifically mention limits for GHG emissions, the Kyoto Protocol, implemented in 2005, stipulates that for the commitment period of 2008-2012.

D.M. (2011) stated that the contribution to global warming and climate change as discussed in earth summit held in 1992 at Rio De-Janerio, Kyoto protocol signed in 1997 at Japan, Copenhagen conference in 2009 held at Denmark, Kankun conference in 2010 held at Mexico and Darban conference held in 2011 in South Africa. According to UNFCCC (2004) the Kyoto Protocol provides for the involvement of Bangladesh in an atmospheric greenhouse-gas reduction regime under its CDM concept. Through the CDM, carbon credits can be gained from natural forests and afforestation/reforestation activities in developing countries.

Unruh *et al.* (1993) reported that Stabilization of CO_2 concentrations in the atmosphere will require large reductions in the use of fossil fuels and rates of deforestation, which is well addressed in Kyoto Protocol, the United Nations’

Kyoto Protocol, intended to slow down the human contribution to emissions of CO_2 and other greenhouse-effect gases to the atmosphere.

UNFCC (2007) stated the recognition of the impacts caused by deforestation in developing countries, in the Conference of Parties (COP 13) in Bali it was agreed that reducing emissions from deforestation and degradation (REDD) should be included in a post-Kyoto mechanism. Burgess *et al.* (2010) reported that recently UN also introduced REDD+ from the original concept of REDD to include emissions from deforestation and degradation of carbon-rich ecosystems. SINO (2005) reported that the global carbon cycle is one of key research issues in the studies of climate change and regional sustainable development as well as one of main subjects for international coordinated research programs on global change.

Jenkins (1999) compared carbon stocks and fluxes in forested and non-forested areas, and concluded that non forested areas (open spaces and agricultural land in intra and peri-urban areas) could add substantially to current estimates of local, regional and national carbon balances. Chiari and Seeland (2004) have highlighted the role of urban forests as a place of social integration as they provide recreation and relief to the urban population from their hectic life.

Gatrell and Jensen (2002) have discussed economical, ecological, and aesthetic benefits of urban forests in detail. The instrumental functions of urban forests have been extensively studied in recent years, few studies conducted in this direction include quantifying CO_2 sequestration by urban forests (McPherson,1998), studies on air pollution reduction by urban trees (Nowak, 2006) and studies on energy saving by trees (Akbari *et al*. 2001).

Watson *et al*. (2000) defined Carbon sequestration as the removal of CO_2 from the atmosphere and store into green plant biomass (sink) where it can be stored indefinitely through the process of photosynthesis. According to IPCC (2005), CO_2 sequestration can be done by terrestrial sequestration or vegetative sequestration, geologic sequestration and oceanic sequestration. Terrestrially, carbon is stored in vegetation and in the soil.

Sampson (1989) studied that trees remove C from the atmosphere through photosynthesis, and store excess C not used in the process as biomass. The C will remain bound until it is released again through respiration, burning or some other chemical transformation.

Brown (1997) reported that carbon quantities are about 50% of the aboveground woody biomass weight.

Dixon (1994); Cannel (1995); Richter *et al*. (1995); Ravindranath *et al*. (1997), Montagnini and Porras (1998); Montagu *et al*. (2005), reported that the assessment of biomass provides information on the structure and functional attributes of trees. With approximately 50% of dry biomass comprises of carbon. Biomass assessments illustrate the amount of carbon that may be sequestered by trees, biomass is an important indicator in carbon sequestration therefore estimating the biomass in trees is the first step in carbon accounting.

Costa (1996) reported plant tissues vary in their carbon storage with stems and fruits having more carbon per gram of dry weight than leaves and that longer-lived trees with high-density wood store more carbon per volume than short-lived, low-density, fast-growing ones.

Canadell and Raupach (2008) reported four major strategies are available to mitigate carbon emissions through forestry activities: (i) increase forest land area through reforestation and afforestaton, (ii) increase the carbon density of existing forests at both stand and landscape scales, (iii) expand the use of forest products that sustainably replace fossil-fuel, and (iv) reduce emissions from deforestation and degradation.

Lu (2006) mentioned three approaches to biomass assessment. These are field measurement, remote sensing, and GIS-based approach. The field measurement is considered to be accurate (Lu, 2006) but proves to be very costly and time consuming (de Gier, 2003).

Cairns *et al.* (2003) reported two methods of measuring sample tree biomass are available: (1) destructive and (2) non-destructive. Direct or destructive method of tree biomass involves felling an appropriate number of trees and estimating their field- and oven-dry weights, a method that is accurate however it is impractical.

De Gier (2003); Ketterings *et al*. (2001) were conducted studies to develop biomass equation that relates dry biomass of trees to its biophysical variables (e.g. diameter-at-breast height (dbh), tree height) and basal area (Murali *et al.,* 2005).

Waston *et al*. (2000); FAO (2005); Sheikh *et al*. (2009) reported that forests are major contributors to terrestrial carbon sink, mitigating climate change and associated economic benefits.

Dixon (1995); Albrecht and Kandji (2003); Montagnini and Nair (2004) investigated that as a leading tree based system, especially in the tropics, agroforestry, afforestation and reforestation has been suggested as one of the most appropriate land management systems for mitigating the atmospheric carbon increase.

Dixon *et al.* (1994a), Dixon (1995), Albrecht and Kandji (2003) mentioned that Agro-ecosystems play a central role in the global carbon cycle and contain approximately 12% of the world terrestrial carbon. DOE (1999), Albrecht and Kandji (2003) noted that Current terrestrial (plant and soil) carbon is estimated at 2000 ± 500 Pg, which represents 25% of global carbon stocks .

DOE (1999) stated that the current terrestrial (plant and soil) C is estimated at 2000 ± 500 Pg, which represents 25% of global C stocks. The analysis of C stocks from various parts of the world showed that significant quantities of C (1.1–2.2 Pg) could be removed from the atmosphere over the next 50 years if agroforestry systems are implemented on a global scale.

Brown *et al*. (1996) investigated that of all the global forests, tropical forests have the greatest potential to sequester carbon primarily through reforestation, agroforestry and conservation of existing forests. Watson *et al*. (2000) reported that the forests are also producing renewable materials in order to substitute fossil fuel.

Strand *et al*. (2008) reported that the roots make a significant contribution to soil organic carbon. Cairns *et al*. (1997) reported that root biomass in ecosystems is often estimated from root-to-shoot ratios. The ratio ranges from 0.18 to 0.30, with tropical forests in the lower range and the temperate and boreal forests in the higher range .with some trees having rooting depths of greater than 60 m, root carbon inputs can be substantial, although the amount declines sharply with soil depth.

2.2 Carbon sequestration potential in urban area

Nowak & Crane (2002) reported that urban trees in the Coterminous USA, store 700 million tonnes of carbon with a gross carbon sequestration rate of 22.8 million t C/yr. Nowak, (1994) indicated that 600 trees in the tropics would fill one acre, which could sequester up to 15 tonnes of CO_2 annually, other statistics include 40 trees will sequester one tonne of CO_2 each year; and that one million trees covering 1,667 acres could capture 25,000 tonnes of CO_2 annually.

Nowak and Crane (2002) reported that urban forests, due to their relatively low tree cover, typically store less C per hectare in trees (25.1 t C/ha) than forest stands (53.5 t C/ha). However, on a per unit tree cover basis, C storage by urban trees and gross sequestration may be greater than in forest stands.

Nowak (1994) reported that due to a greater proportion of large trees in urban environments and relatively fast growth rates due to the more open urban forest structure, on a per unit tree cover basis, C storage by urban trees and gross sequestration may be greater than in forest stand.

Nowak and Crane (2002) studied that individual urban trees, on average, contain approximately four times more C than individual trees in forest stands. This difference is largely due to differences in tree diameter distributions between urban and forest areas.

Brack (2002) reported that about 4,00,000 trees planted in Canberra are estimated to have a combined energy reduction, pollution mitigation and carbon sequestration value of US$20–67 million during the period 2008–2012 in Canberra. Likewise, the City of Tshwane Metropolitan municipality in South Africa has 115,200 indigenous street trees planted during the period 2002–2008.

Yang *et al*. (2005) investigated that the the air pollutant that was most reduced was PM10 (particulate matter with an aerodynamic diameter of 10ìm), the reduction amounted to 772 tonnes. In addition, the carbon dioxide (CO2) stored in biomass form by the urban forest amounted to about 0.2 million tons .

National Mission for a Green India – document (2009) it is estimated that total carbon stored by the urban trees is 23.8 million tonnes from an estimated 7.79 million ha urban area, i.e. 3.01 tonnes of carbon/ha. Urban forests contribute only 2.21% of the carbon stock against 17.11 tons carbon/ha from overall forest and tree cover. Thus, there is an ample scope to increase contribution of urban forests to overall carbon stocks.

Niranjana K.S and Viswanath. S. (2005) was estimated that a 20-year-old Silver oak shade tree can sequester up to 41.8 Mg/ha of carbon. The study emphasize that when the urban trees are young the standing carbon stock is not substantial, however, the growth of the trees represents a potential increase in biomass and hence carbon sequestration is dependent on the growth rate.

Dwivedi *et al*. (2009) reported that Kerwa urban forest area in Bhopal plays a critical role as a carbon sink with a total storage of about 19.5 thousand tonnes of aboveground carbon.

2.3 Institutional area carbon storage overview

Chavan and Rasal (2007) reported that the above ground biomass for trees as follows: *Ficus religiosa* is 4.27, t/tree, *Ficus Benghalensis* 3.89, t/tree, *Mangifera indica* 3.13, t/tree, *Delonix regia* 2.12, t/tree, *Butea monosperma* 2.10, t/tree, *Peltophorum pterocarpum* 2.01, t/tree, *Azadirachta indica* 1.91, t/tree, *Pongamia pinnata* 1.57 t/tree respectively in selective tree species of University campus at Aurangabad, Maharashtra, India.

Xu & Mitchell (2011); Cox, (2012) reported that KIWI University, California State University, Eastern Illinois University and Auckland University for 4137, 3,900, 4,051, 4,051, and 400 no. of tress Carbon sequestration potential were 1,585, 862, 1,591, and 225.2 tonnes respectively.

Chavan and Rasal (2012) investigate that aboveground and belowground carbon sequestration potential of *Albizia lebbeik* from nine sectors of Aurangabad city was measured. The standing aboveground biomass and belowground biomass of *Albizia lebbek* were 53.73 tha-1 and 13.97 tha-1 respectively, while total standing biomass of *Albizia lebbek* in 2847 hectares area was 67.70 t ha^{-1}. The standing aboveground biomass and belowground biomass of *Delonix regia* were 30.25 t ha^{-1} and 07.86 t ha^{-1} respectively, while total standing biomass of *Delonix regia* in 2847 hectares area was 38.11t ha^{-1}. The average carbon sequestration and carbon dioxide of *Albizia lebbek* intake is 33.85 t ha^{-1} and 124.23 t CO_2 in Aurangabad. The average carbon sequestration and carbon dioxide of *Delonix regia* intake is 19.06 t C ha^{-1} and 63.96 t CO_2 in Aurangabad.

Chavan and Rasal (2011) reported that the total above ground biomass carbon stock per hectare as estimated for *Emblica officinalis* was 33.07 Kg C ha^{-1}, in *Mangifera indica* it was 30.6 Kg C ha^{-1} and in *Tamarindus indica* it was 36.96 Kg C ha^{-1} and in *Achras sapota* were 12.86 Kg C ha^{-1} in *Annona retiaculata* was 83.1 Kg C ha^{-1} and for *Annona squamosa* it was 73.5 Kg C ha^{-1} in University campus.

Chavan and Ganesh (2012) studied that the total standing aboveground biomass and belowground biomass of *Mangifera indica* are 82.83 t ha^{-1} and 21.54 t ha^{-1} respectively, while total standing biomass of *Mangifera indica* in 2847 hectares of Aurangabad is 104.41t ha^{-1}. The sequestered carbon stalk in aboveground and belowground standing biomass of *Mangifera indica* are 44.73 t ha^{-1} and

11.63 t ha^{-1} respectively. While, total sequestered carbon of *Mangifera indica* in 2847 hectares area is 56.36 t ha^{-1}.

Villiers *et al.* (2013) estimated that the 4,139 trees contain 5,809 tonnes of CO_2 on the university's 68 hectare main campus, ignoring smaller trees that sequester very little CO_2. They further estimate the additional CO_2 sequestration over the next 10 years to be 253 tonnes per year.

Pragas and Karthick (2013) observed that the potential of carbon stock sequestered by two different tree plantation types, Eucalyptus plantation (EP) and mixed species plantation (MP) in Bharathiar University campus at Coimbatore, India. Tree density and total biomass were 320 & 468 stems ha^{-1} and 48.05 & 39.64 tonne ha^{-1} at sites Eucalyptus Plantation and Mixed Plantation, respectively. Total carbon stock sequestered by the two plantations was 27.72 and 22.25 t ha^{-1} respectively.

Pandya *et al.* (2013) reported that the maximum carbon storage was 55.95 t C followed by 44.81 t C among 25 species belongs to Gujarat, India. The lowest carbon storage value estimated in 1.77 t C.

Sundarapandian *et al.* (2014) conducted an experiment on biomass and carbon stock of trees in the entire Pondicherry University campus (297 ha). A total of 139 species and 19527 (66 stems/ha) stems of the diameter threshold ≥ 10 cm GBH were recorded in the University campus during the study period (2012-2013). The basal area of adult tree species recorded in the campus was 874.68 m^2 (2.94 m^2/ha). *Acacia auriculiformis* (8780) was the dominant tree species. Above ground biomass of adult trees in the campus was 4438 Mg (14.9 Mg/ha), whereas belowground biomass was 753 Mg (2.5 Mg /ha). *Acacia auriculiformis* was the dominant species in terms of aboveground (1114 Mg) and belowground biomass (200 Mg). The total carbon stock inclusive of both aboveground and belowground of all adult trees in the University campus was 2590.48 Mg (8.7 Mg C/ha) and the highest carbon stock value was observed in *Acacia auriculiformis*.

Ullah and Al-Amin (2012) conducted an experiment to estimate above-ground and below-ground carbon stock in Tankawati natural hill forest of Bangladesh. The Results revealed that the total carbon stock of the forest was 283.80 $t.ha^{-1}$ whereas trees produce 110.94 t ha^{-1}, undergrowth (shrubs, herbs and grass) 0.50 $t.ha^{-1}$, litter fall 4.21 $t.ha^{-1}$ and soil 168.15 $t.ha^{-1}$ (up to 1 m depth).

Akter *et al.* (2013), studied that the plantations of Chittagong University campus can acquire 25.51 m^3/ha volume of economically important tree species, where biomass and organic carbon stock is 222.33 tonne/ha and 107.48 tonne/ha respectively.

2.4 Homegarden as a potential for carbon sequestration

Roshetko *et al.* (2002) studied that the homegardens and other tree-rich smallholder systems offer potential rate of carbon storage in their woody biomass.

Michon and Mary (1994) reported that homegardens production now commonly serves household and market demand, providing families with much needed income.

Kumar (2006) reported that most agroforestry systems are important in respect to carbon sequestration, carbon conservation and carbon substitution, the homegardens perhaps are unique for all above three mechanisms i.e., they sequester carbon in biomass and soil, reduce fossil-fuel burning by promoting wood fuel production, help in the conservation of carbon stocks in existing forests by alleviating the pressure on natural forests.

Henry *et al.* (2009) studied that greater agro-biodiversity of homegardens may ensure longer term stability of carbon storage and the specific management practices that tend to enhance nutrient cycling and increase AGB are particularly relevant in this respect. Kumar *et al*. (1994) Homegarden size and survival strategies of the gardeners are other determinants of biomass and above ground carbon pools.

Jensen (1993) and Roshetko *et al.* (2002) reported that Javanese and Sumatran homegardens aboveground carbon stock values were 58.6 Mg ha^{-1} and 35.3 Mg ha^{-1} respectively.

Dissanayake (2012) studied that the average aboveground carbon stocks of Sri Lankan homegarden were 89.98 Mg ha^{-1} and 103.89 Mg ha^{-1} in Kandy and Matale district respectively.

2.5 Climate change, carbon dioxide and trees

IPCC, (2001) estimated that the level of CO_2 in today's atmosphere is 31% higher than it was at the start of the industrial revolution about 250 years ago. IPCC (2007) reported that the amount of carbon dioxide in the atmosphere has increased from 280 ppm in the pre-industrial era (1750) to 379 ppm in 2005, and is increasing by 1.5 ppm per year. The UNFAO (2003) estimated that since 1980, 25% of all carbon dioxide emissions associated with human activities was a result of tropical deforestation. Waston *et al*. (2000) studied that the deforestation and the burning of forests release CO2 to the atmosphere. According to IPCC, (2000) the estimation of the total global carbon sequestration potential for afforestation and reforestation activities for the period 1995-2050 was between 1.1-1.6 Gt carbon per year and of which 70% will be in the tropics.

Dwyer *et al.* (1992) investigated that worldwide concern about global climate change has created increasing interest in trees to help reduce the level of atmospheric CO_2.

Sampson *et al.* (1992) investigated that forests are the most critical for taking C out of circulation for long periods of time. Of the total amount of C tied up in earthbound forms, an estimated 90% is contained in the world's forests, including trees and forest soils. For each cubic foot of merchantable wood produced in a tree, about 33 lb. (14.9 kg) of C is stored in total tree biomass.

Pandey (2002) reported that forests sequester 1 Gt C annually through the combined effect of reforestation, regeneration and enhanced growth of existing forests.

Funder (2009) reported that Agroforestry systems help to offset the 1.6 billion tons of carbons emited due to deforestration and forest degrafation annually.

2.6 Status of carbon assessment in Bangladesh

Shin *et al.* (2007) reported that diversified forest ecosystems, i.e., wet forest lands, rain forests, moist deciduous forest, semi-arid areas and mangroves, Bangladesh forestry sector is acting as an important carbon sink. It has been estimated that about 5000 species of higher plants with thick foliage and species diversity occur in Bangladesh. On an average, 92 t C ha^{-1} is stored by the existing tree tissues in the forests of Bangladesh. Among them, closed large-crown forests 121 t C ha^{-1}, closed small-crown forests 87 t C ha^{-1}, disturbed closed forests 110 t C ha^{-1} and disturbed open 49 t C ha-1. ESSD (1998) reports that forest soils in Bangladesh store carbon at a rate of 115 t C ha^{-1},100 t C ha^{-1} and 60 t C ha^{-1} in moist, seasonal and dry soils, respectively. Shin *et al*. (2007) commented that due to the over extraction of the forest resources and encroachment in the forests, soil carbon reduce fast. Danesh *et al.* (2011) reported that in the reforested degraded hill forests contain 190 t C ha^{-1} in particular.

In Bangladesh carbon assessment has been carried out by the Forest Department in Sundarbans reserve forest and protected area. The results revealed that the carbon stock in Sundarban reserved forest were105.6 megaton in 4,11,693 ha area, which converts to 256 Mg C ha^{-1}. The carbon stock (above ground and root carbon) in six protected area of Bangladesh namely Dudpukuria-dhopachari wildlife sanctuary, Fasiakhali wildlife sanctuary, Inani national park, Medhakachapia national park, Sitakundo reserved forest, and Teknaf wildlife sanctuary area contained 105.46 Mg ha^{-1}, 110.16 Mg ha^{-1}, 25.99 Mg ha^{-1}, 187.75 Mg ha^{-1}, 22.51 Mg ha^{-1} and 43.08 Mg ha^{-1} respectively.

From the above discussion, it is clear that there is no mentionable research in accounting carbon stock in terms of urban area like as urban green patches, botanical garden, urban roadside, urban park and institutional area etc. in Bangladesh. Therefore, the present study has the immense importance to enlarge the assessment of urban carbon sequestration database as well as it enabled the policy makers to take action plan for national environmental sustainability issues.

CHAPTER III

MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

This study was conducted in Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar, Dhaka-1207, during the period from June, 2013 to May, 2014. The study area was situated at 23°77'N latitude and 90°33'E longitude at an altitude of 8.6 meter above the sea level (Anon., 2004). The campus stands on 86.92 acres (35.2 ha) of picturesque land covered by green plantations with a series of academic, administrative and residential buildings and a number of land for crop cultivation, experimental farms, gardens and other related facilities. The experimental site was shown in the map of AEZ of Bangladesh in Appendix I. The study was carried out to estimate the carbon stock at three vegetation areas in SAU campus. A total of 32 sample plots of 10x10 m^2 size were selected (0.01ha), each were laid out in all the three study sites. The total land area under three vegetation areas was about 40,444 m^2 which was 11.47 % of total land area of SAU campus. These three vegetation areas had distinct tree coverage compared to other sites which had minor tree coverage in SAU campus. For the assessment of above and belowground biomass carbon stock, Sher-e-Bangla Agricultural University campus was divided into three major sites namely roadside (0.78 ha), woodlot (0.73 ha), and homegarden (2.53 ha). These sites were selected as major carbon sequestration pool in the study area.

3.2 Abiotic characteristics

3.2.1 Climate

The climate in Bangladesh is typically tropical; mild winter (October to March); hot, humid summer (March to June); humid, warm rainy monsoon (June to October). The daily average maximum temperatures in Dhaka city is 25°C in January with the average of minimum 10°C, while in June the average maximum temperature is 32°C with a minimum of 25°C. The wettest month in

Dhaka is July with an average rainfall of 367.9 mm while the driest month is December with 8.9 mm precipitation. The climatic data were collected from secondary sources (http://www.myweather2.com) and yearly trends: weather averages & extremes have been presented in Appendix II.

3.2.2 Characteristics of soil

The soil of the experimental site is a medium high land belongs to the general soil type, Shallow Red Brown Terrace Soils under the Agro Ecological Zone (AEZ) 28. The soil texture was silty loam, olive-gray with common fine to medium distinct dark yellowish brown mottles with a pH 5.6. Details of the physical and chemical properties of soil sample are shown in Appendix III. The morphological characters of soil in the experimental plots were indicated by UNDP and FAO (1998).

3.3 Biotic characteristics

3.3.1 Characteristics of vegetation

The total number of plants at sher-e- Bangla Agriculture University belongs to 152 families under 251 genera and 327 species, respectively. Out of all plant species 19 timber species (including 15 genera and 11 families), 42 fruit plant species (29 genera and 17 families), 61 medicinal plant species (55 genera and 34 families), 42 ornamental plant species (35 genera and 25 families), 81 flower plant species (53 genera and 29 families), 41 vegetable plant species (30 genera and 16 families), 13 spices plant species (11 genera and 8 families), 6 fodder plant species (6 genera and 5 families), 5 bamboo plant species (2 genera and 1 families), 3 ficus plant species (1 genus and 1 family), 2 fibre plant species (2 genus and 2 families), 10 palm plants (10 genera and 3 families), 2 rubber plants (2 genera and 1 family) (Sultana *et al.*, 2012)

(a)

(b)

(c)

Plate 1. Over view of plantation sites of Sher-e-Bangla Agricultural University Campus, Dhaka (a = Roadside, b = Woodlot, c = Homegarden).

Plate 2. Measuring plot in the study area

Plate 3. Marking GBH of tree at woodlot area

Plate 4. Measuring GBH of tree at woodlot plantation site

Plate 5. Measuring height of palm species at homegarden area

3.4 Sampling design

Among the three plantation sites, systematic sampling procedure for roadside was selected for primary data collection while purposive sampling were carried out for woodlot and homgardens. In roadside sampling, roadside with continuous plantation was subjected to consider with systematic sampling. All woodlot plantation sites were taken under consideration into purposive sampling procedure due to existence of less woodlot in SAU campus. On the other hand, the homegarden of SAU campus was not well suited in terms of size and tree coverage that's why purposive sampling procedure were carried out for data collection in that area.

3.5 Data collection

The diameter at breast height (DBH) and height are two main biophysical measurement which were considered for each tree sample. But due to lack of DBH tape GBH was measured first and then it was converted into DBH.

3.6 Tree survey

All Individuals ≥ 5 cm in GBH was enumerated at three vegetation site in Sher-e-Bangla Agricultural University Campus. Each sampled area were identified and recorded to species level, or by local name. Every individual of woody species was counted and the tree girth was measured at breast height by using measuring tape. The girth of each individual was converted to tree diameter, dividing the girth by π (3.1416). In some cases especially for palm species measuring pole was used for height measurement.

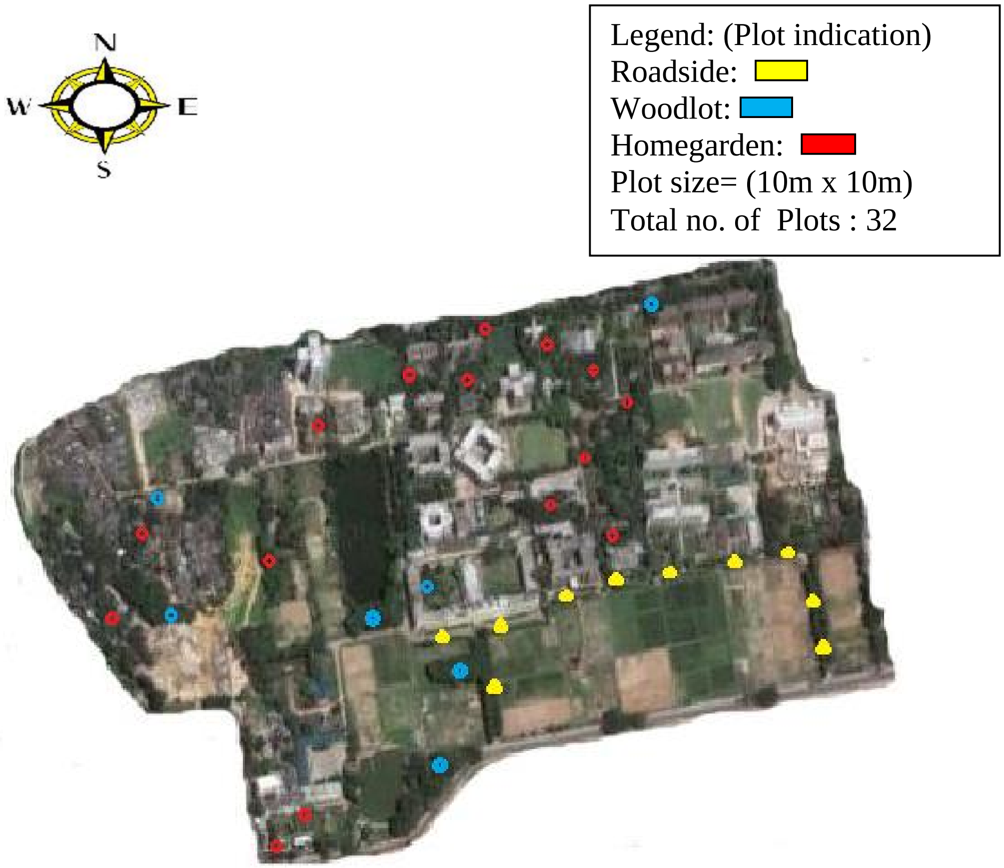

Figure 1. Map of Sher-e-Bangla Agricultural University campus showing vegetation area with respective plot, (Source: Google Earth)

3.7 Allometric computations for above ground biomass (AGB)

3.7.1 Trees

Biomass equations relate DBH to biomass and biomass may differ among species as trees in a similar functional group can differ greatly in their growth form between geographic areas (Pearson *et al.*, 2007). Considering these factors Chave *et al.*, 2005 developed allometric equation for tropical trees that can be used for wide graphical and diameter range.

$AGB = \rho \times \exp(-1.499 + 2.148 \times \ln(DBH) + 0.207 \times (\ln(DBH))^2 - 0.0281(\ln(DBH))^3$ (Chave *et al.*, 2005)

ρ = Wood density (g cm^{-3}); -1.399, 2.148, 0.207 & 0.0281= Constant;

AGB = Above ground biomass; ln = Natural logarithm;

DBH = Diameter at Breast Height (1.37m);

In case of roadside, estimated biomass using allometric equation was multiplied by 0.8 as roadside plants were grown in open ground (Aguaron and

Mcpherson, 2012). Wood density of every species was collected from secondary data such as FAO's list of wood densities for tree species from tropical Asia, (Zanne *et al.*, 2009), Global wood density database and standard average value of tree species (Patwardhan *et. al.*, 2003).

3.7.2 Palms

Usually palm species such as *Cocos nucifera*, *Phoenix sylvestris*, *Areca catechu* are common in home garden of southwestern Bangladesh (Kabir and Webb, 2009). The following equations for palms will be used for AGB calculation:

$AGB = 6.666 + 12.826 \times ht^{0.5} \times \ln(ht)$ (Brown *et al.*, 2001).

AGB = Above ground biomass; ln = Natural logarithm; ht = Height

3.7.3 Below ground biomass estimation

To determine the below ground biomass and carbon, the regression model developed by Cairns *et al*., 1997, which is based on knowledge of above ground biomass was employed. It is the most cost effective and practical methods of determining root biomass.

$$BGB = \exp(-1.0587 + 0.8836 \times \ln AGB)$$

Where; BGB = Belowground biomass, ln = Natural logarithm, AGB = Above ground biomass, -1.0587 and 0.8836 are constant.

3.8 Conversion of biomass to carbon (above ground and below ground biomass):

After estimating the biomass estimating from allometric relationship it will be multiplied by 0.5 as wood contains half percent of carbon of it total biomass.

Carbon (Mg) = Biomass estimated by allometric equation × Wood Carbon Content %

= Biomass estimated by allometric equation × 0.5

The total C was computed by using the following formula :

$$\text{Carbon } (C\ Mg\ ha^{-1}) = \text{Biomass } (Mg\ ha^{-1}) \times \text{Carbon } \%$$

3.9 Measurement of basal area, relative density, relative dominance, relative frequency

For describing floristic composition of species of the study area the basal area, relative density, relative dominance, relative frequency and Importance Value Index (IVI) were calculated (Moore and Chapman, 1986 and Shukla and Chandel, 1980).

The basal area/ha is calculated according to the following formula (Shukla and Chandel, 1980).

$$\text{Ba/ha} = \frac{\sum \frac{\Pi}{4} D^2}{\sum area \quad of \quad all \quad quadrats} \text{X} \quad 10000$$

Basal area $= \pi D^2/4$.

Where, Ba = Basal area in m^2

D = Diameter at breast height in meter

Π = 3.14

Area of individual quadrates = 10 m × 10 m

Following the formulas of Moore and Chapman (1986), Shukla and Chandel (1980) and Dallmeier *et al.* (1992) quantitative structure parameters of investigated trees were calculated.

1. Density (stem/ha) =

$$\frac{\text{Total no. of individuals of one species in all the plots}}{\text{Plot area} \times \text{Total no. of plots studied}}$$

2. Relative density (%) =

$$\frac{\text{Total no. of individuals of one species in all the plots}}{\text{Total no. of plots studied}} \text{x } 100$$

3. Frequency (%) =

$$\frac{\text{Total no. of plots in which the species occurs}}{\text{Total no. of plots studied}} \times 100$$

4. Relative frequency (%) = $$\frac{\text{Frequency of one species}}{\text{Sum of frequency of all species}} \times 100$$

5. Basal area (m^2/ha) = $$\frac{\text{Total basal area of individual species } (m^2)}{\text{Sample plot area (ha)} \times \text{Total no. of plots studied}}$$

6. Relative basal area (%) = $$\frac{\text{Total basal area of one species in all plots}}{\text{Total basal area of all species in all plots}} \times 100$$

7. Importance Value Index (%)

= (Relative density + Relative frequency + Relative dominance)/3

3.10 Importance Value Index

Importance Value Index index was used to determine the overall importance of each species in the community structure. In calculating this index, the percentage values of the relative frequency, relative density and relative dominance were summed up together and this value was designated as the Importance Value Index or IVI of the species.

3.11 Data analysis

After the collection of field data the information were processed and compiled by MS Excel 2007 and SPSS-20 software. Aboveground C pools were computed using international standard common tree allometries combined with local tables of wood density by tree species. Regression analyses were used to test the relationship among the variables: total carbon stock Vs basal area, total carbon stock Vs Mean DBH and total carbon stock Vs stem density.

CHAPTER IV
RESULTS

4.1 Floristic composition of the study area

In Sher-e-Bangla Agricultural University campus a total of 351 individuals belonging to 38 tree species in 35 genera and 25 families were recorded from trees of ≥5 cm GBH. Among the three plantation species higher species composition was found in homegarden which belonged to 34 species in 31 genera and 24 families followed by roadside plantation which comprised of 4 species in 4 genera and 4 families, while a total of 7 species belonged to 8 genera and 6 families were recorded from woodlot area (Table 2, 3, 4 and 5).

4.2 Stand characteristics of three plantation sites

Tree Characteristics like mean DBH, Stem density and Basal area of 32 sample plots of three plantation sites with their mean values and standard error were collectively presented (Table 1). The mean DBH (cm), stem density (tree ha^{-1}) and basal area (m^2 ha^{-1}) of homegarden were 14.17 ± 1.46, 1426.67 ± 155.06 and 32.48 ± 5.87 respectively. On the other hand the mean DBH (cm), stem density (tree ha^{-1}) and basal area (m^2 ha^{-1}) of roadside were 27.68 ± 3.08, 480.00 ± 61.10 and 33.80 ± 7.08 respectively. Again the mean DBH (cm), stem density (tree ha^{-1}) and basal area (m^2 ha^{-1}) of woodlot were 20.76 ± 2.34, 1271.43 ± 289.26 and 38.28 ± 2.83 respectively. The mean DBH (cm), stem density (tree ha^{-1}) and basal area (m^2 ha^{-1}) of three plantation sites (homegarden, roadside and woodlot) were 19.83 ± 1.63, 1096.88 ± 121.11 and 34.16 ± 3.51, respectively (Table).

Among the three plantation sites the reported species in roadside, woodlot and homgarden were showed no significant variation ($p > 0.05$) in case of above- and belowground carbon and basal area while stem density and mean DBH showed significant variation ($p < 0.05$) (Appendix IV).

Table 1. Mean DBH, stem density and basal area at three plantation sites in Sher-e-Bangla Agricultural University campus

Species Parameter	Plantation Sites			Average
	Homegarden	**Roadside**	**Wood lot**	
Mean DBH (cm)	14.17 ± 1.46	27.68 ± 3.08	20.76 ± 2.34	19.83 ± 1.63
Stem density (tree ha^{-1})	1426.67 ± 155.06	480.00 ± 61.10	1271.43 ± 289.26	1096.88± 121.11
Basal area (m^2 ha^{-1})	32.48 ± 5.87	33.80 ± 7.08	38.28 ± 2.83	34.16 ± 3.51

4.3 Structural attributes of the species at three plantation sites

A total of 38 tree species were found with stem density of 1096.88 (trees ha^{-1}) from 32 sample plots. The relative density (RD%), relative frequency (RF%), relative dominance (RDo%) and Importance Value Index (IVI) of tree species were recorded from the three study area. When three plantation sites considered as a whole, it was observed that *Mangifera indica* showed the maximum IVI (17.25%) followed by *Swietenia macrophylla* (17.20%), *Artocarpus heterophyllus* (9.76%), and *Polyalthia longifolia* (8.42%) respectively (Table 2).

4.3.1 Structural attributes of the species in roadside

Out of total 38 tree species only four species were found in roadside plantation site from 10 sample plots. The Relative density (RD%), relative frequency (RF%), relative dominance (RDo%) and Importance Value Index (IVI) of tree species were recorded from the roadside plantation. In roadside, it was observed that *Polyalthia longifolia* showed the maximum IVI (43.94%) followed by *Swietenia macrophylla* (27.105%), *Mangifera indica* (17.99%), and *Roystonea regia* (10.97%) respectively (Table 3).

Table 2. Structural attributes of the species at three plantation sites

Sl. No.	Scientific Name	Relative density(%)	Relative frequency(%)	Relative dominance(%)	IVI (%)
1	*Mangifera indica*	16.52	12.90	22.33	17.25
2	*Swietenia macrophylla*	22.22	5.65	23.73	17.20
3	*Artocarpus heterophyllus*	10.26	10.48	8.53	9.76
4	*Polyalthia longifolia*	8.26	5.65	11.35	8.42
5	*Salmalia malabarica*	1.14	2.42	8.44	4.00
6	*Litchi chinensis*	3.70	3.23	4.14	3.69
7	*Garuga pinnata*	2.85	6.45	1.06	3.45
8	*Moringa oleifera*	2.56	4.03	2.80	3.13
9	*Psidium guajava*	4.84	4.03	0.60	3.16
10	*Syzygium samarangense*	2.85	3.23	0.75	2.27
11	*Annona reticulata*	1.99	4.03	0.57	2.20
12	*Samanea samane*	0.57	1.61	3.78	1.99
13	*Citrus grandis*	1.71	4.03	0.31	2.02
14	*Tectona grandis*	2.28	0.81	2.60	1.89
15	*Zizyphus jujuba*	2.56	2.42	0.52	1.83
16	*Cocos nucifera*	0.85	1.61	2.23	1.57
17	*Syzygium cumini*	1.14	2.42	0.53	1.36
18	*Carissa carandas*	3.13	0.81	0.13	1.36
19	*Areca catechu*	1.71	1.61	0.65	1.32
20	*Azadirachta indica*	0.85	2.42	0.53	1.27
21	*Albizzia lebbeck*	0.57	1.61	0.79	0.99
22	*Carpinus caroliniana*	1.14	0.81	0.56	0.83
23	*Averrhoa carambola*	0.57	1.61	0.32	0.84
24	*Roystonea regia*	0.28	0.81	1.21	0.77
25	*Lawsonia inermis*	0.57	1.61	0.04	0.74
26	*Citrus limon*	0.57	1.61	0.02	0.74
27	*Phoenix sylvestris*	0.28	0.81	0.62	0.57
28	*Spondias mangifera*	0.28	0.81	0.28	0.46
29	*Albizzia procera*	0.28	0.81	0.15	0.41
30	*Dillenia indica*	0.28	0.81	0.11	0.40
31	*Vitex negundo*	0.28	0.81	0.08	0.39
32	*Feronia limonia*	0.28	0.81	0.06	0.38
33	*Ficus religiosa*	0.28	0.81	0.03	0.38
34	*Terminalia chebula*	0.28	0.81	0.03	0.37
35	*Terminalia belerica*	0.28	0.81	0.03	0.37
36	*Terminalia arjuna*	0.28	0.81	0.02	0.37
37	*Piper cubeba*	0.28	0.81	0.02	0.37
38	*Areca triandra*	0.28	0.81	0.02	0.37
39	*Diospyros peregrina*	0.28	0.81	0.01	0.37
40	*Punica granatum*	0.28	0.81	0.01	0.37
41	*Nyctanthes arbor-tristis*	0.28	0.81	0.01	0.37

Table 3. Structural attributes of the species in roadside plantation

Sl. No.	Scientific Name	Relative density (%)	Relative frequency (%)	Relative dominance (%)	IVI (%)
1	*Polyalthia longifolia*	57.78	54.55	19.50	43.94
2	*Swietenia macrophylla*	35.56	27.27	18.47	27.10
3	*Mangifera indica*	4.44	9.09	40.44	17.99
4	*Roystonea regia*	2.22	9.09	21.59	10.97

4.3.2 Structural attributes of the species in woodlot

Seven species were found out of total 38 tree species in woodlot plantation sites from 7 sample plots. The relative density (RD%), relative frequency (RF%), relative dominance (RDo%) and Importance Value Index (IVI) of tree species were recorded from the woodlot plantation sites. In woodlot plantation it was observed that *Swietenia macrophylla* showed the maximum IVI (51.31%) followed by *Litchi chinensis* (10.98%), *Mangifera indica* (10.43%), *Tectona grandis* (9.14%), *Samanea samane* (5.44%), *Carpinus caroliniana* (5.35%), *Azadirachta indica* (3.71%) and *Albizzia lebbeck* (3.65%) respectively (Table 4).

Table 4. Structural attributes of the species in woodlot plantation

Sl. No.	Scientific Name	Relative density (%)	Relative frequency (%)	Relative dominance (%)	Importance value index (%)
1	*Swietenia macrophylla*	69.66	36.36	47.89	51.31
2	*Litchi chinensis*	6.74	9.09	17.09	10.98
3	*Mangifera indica*	6.74	9.09	15.45	10.43
4	*Tectona grandis*	8.99	9.09	9.35	9.14
5	*Samanea samane*	1.12	9.09	6.09	5.44
6	*Carpinus caroliniana*	4.49	9.09	2.47	5.35
7	*Azadirachta indica*	1.12	9.09	0.90	3.71
8	*Albizzia lebbeck*	1.12	9.09	0.75	3.65

4.3.3 Structural attributes of the species in homegaden

Out of total 38 tree species only 36 species were found in homegarden plantation sites from 15 sample plots. The density (RD%), relative frequency (RF%), relative dominance (RDo%) and Importance Value Index (IVI) of tree species were recorded from the homegarden area. In homegarden area, out of 36 tree species it was observed that *Mangifera indica* showed the maximum IVI (22.46%) followed by *Artocarpus heterophyllus* (16.20%), *Salmalia malabarica* (7.82), *Moringa oleifera* (5.13%), *Garuga pinnata* (5.00%) *and* 4.76% for *Psidium guajava* respectively (Table 5).

Table 5. Structural attributes of the species in homegaden plantation

Sl No.	Scientific Name	Relative density (%)	Relative frequency (%)	Relative dominance (%)	Importance value index (%)
1	*Mangifera indica*	23.36	13.00	31.03	22.46
2	*Artocarpus heterophyllus*	16.82	13.00	18.78	16.20
3	*Salmalia malabarica*	1.87	3.00	18.60	7.82
4	*Moringa oleifera*	4.21	5.00	6.18	5.13
5	*Garuga pinnata*	4.67	8.00	2.33	5.00

6	*Psidium guajava*	7.94	5.00	1.32	4.76
7	*Syzygium samarangense*	4.67	4.00	1.65	3.44
8	*Annona reticulata*	3.27	5.00	1.25	3.17
9	*Citrus grandis*	2.80	5.00	0.69	2.83
10	*Zizyphus jujuba*	4.21	3.00	1.14	2.78
11	*Cocos nucifera*	1.40	2.00	4.91	2.77
12	*Litchi chinensis*	3.27	3.00	0.64	2.31
13	*Carissa carandas*	5.14	1.00	0.28	2.14
14	*Areca catechu*	2.80	2.00	1.43	2.08
15	*Syzygium cumini*	1.87	3.00	1.17	2.01
16	*Samanea samane*	0.47	1.00	2.41	1.29
17	*Azadirachta indica*	0.93	2.00	0.73	1.22
18	*Averrhoa carambola*	0.93	2.00	0.71	1.22
19	*Lawsonia inermis*	0.93	2.00	0.08	1.00
20	*Citrus limon*	0.93	2.00	0.05	1.00
21	*Albizzia lebbeck*	0.47	1.00	1.37	0.95
22	*Phoenix sylvestris*	0.47	1.00	1.36	0.94
23	*Spondias mangifera*	0.47	1.00	0.62	0.69
24	*Albizzia procera*	0.47	1.00	0.33	0.60
25	*Dillenia indica*	0.47	1.00	0.24	0.57
26	*Vitex negundo*	0.47	1.00	0.18	0.55
27	*Feronia limonia*	0.47	1.00	0.12	0.53
28	*Ficus religiosa*	0.47	1.00	0.08	0.51
29	*Terminalia chebula*	0.47	1.00	0.06	0.51
30	*Terminalia belerica*	0.47	1.00	0.06	0.51
31	*Terminalia arjuna*	0.47	1.00	0.05	0.50
32	*Piper cubeba*	0.47	1.00	0.04	0.50
33	*Areca triandra*	0.47	1.00	0.03	0.50
34	*Diospyros peregrina*	0.47	1.00	0.02	0.50
35	*Punica granatum*	0.47	1.00	0.02	0.50
36	*Nyctanthes arbor-tristis*	0.47	1.00	0.02	0.49

4.4 Tree species in roadside plantation site

The tree species comprised of four individuals in 1000 m^2 of total roadside sample plot area in Sher-e-Bangla Agricultural University campus. It was observed that, in roadside total 13.68% of the individual recorded from the total studied individual tree species of three plantation sites. In roadside, stem density varied from 200 to 800 stems per hectare and the ornamental species occupied 62 % of the roadside plantation (Table 6 & Appendix IX).

Table 6. Tree species identified in the roadside plantation site

Scientific Name	**Family**	**Primary use**	**No. of trees**	**% of total**
Mangifera indica	Anacardiaceae	Fruit	2	0.57
Polyalthia longifolia	Annonaceae	Ornamental	26	8.26
Roystonea regia	Arecaceae	Ornamental	1	0.28
Swietenia macrophylla	Meliaceae	Timber	16	4.56

4.4.1 Tree species in woodlot plantation site

The tree species in woodlot was comprised of eight individuals in 700 m^2 sample plot area of the Sher-e-Bangla Agricultural University campus. It was observed that, from woodlot a total 25.36% of the individuals accounted from the total studied individuals tree species of study area. In woodlot, stem density varied from 600 to 2300 stems per hectare and the timber species occupied 86 % of the woodlot plantation. (Table 7 & Appendix IX).

Table 7. Tree species identified in woodlot plantation site

Scientific Name	**Family**	**Primary use**	**No. of trees**	**% of total**
Albizzia lebbeck	Mimosaceae	Craftwood	1	0.28
Azadirachta indica	Meliaceae	Craftwood	1	0.28
Carpinus caroliniana	Betulaceae	Craftwood	4	1.14

Litchi chinensis	Sapindaceae	Fruit	6	1.71
Mangifera indica	Anacardiaceae	Fruit	6	1.71
Samanea samane	Mimosaceae	Craftwood	1	0.28
Swietenia macrophylla	Meliaceae	Craftwood	62	17.66
Tectona grandis	Lamiaceae	Craftwood	8	2.28

4.4.2 Tree species in homegarden plantation site

The tree species in homegarden was comprised of thirty six individuals in 1500 m^2 sample plot area of the Sher-e-Bangla Agricultural University campus. It was observed that, in homegarden total 60.97% of the individual accounted from the total studied individual tree species of three plantation site. In homegarden, stem density varied from 600 to 2600 stems per hectare and the fruit species occupied 79 % of the homegarden plantation (Table 8 & Appendix IX).

Table 8. Tree species identified in the homegarden plantation site

Scientific Name	Family	Primary use	No. of Trees	% of total
Albizzia lebbeck	Mimosaceae	Craftwood	1	0.28
Albizzia procera	Mimosaceae	Craftwood	1	0.28
Annona reticulata	Annonaceae	Fruit	7	1.99
Areca catechu	Palmaceae	Ornamental	6	1.71
Areca triandra	Arecaceae	Ornamental	1	0.28

Artocarpus heterophyllus	Moraceae	Fruit	36	10.26
Averrhoa carambola	Oxalidaceae	Fruit	2	0.57
Azadirachta indica	Meliaceae	Craftwood	2	0.57
Carissa carandas	Apocynaceae	Fruit	11	3.13
Citrus grandis	Rutaceae	Fruit	6	1.71
Citrus limon	Rutaceae	Fruit	2	0.57
Cocos nucifera	Palmaceae	Fruit	3	0.85
Dillenia indica	Dilleniaceae	Fruit	1	0.28
Diospyros peregrina	Ebenaceae	Fruit	1	0.28
Feronia limonia	Rutaceae	Fruit	1	0.28
Ficus religiosa	Moraceae	Wood	1	0.28
Garuga pinnata	Burseraceae	Fence	10	2.85
Lawsonia inermis	Lythraceae	Dye	2	0.57
Litchi chinensis	Sapindaceae	Fruit	7	1.99
Mangifera indica	Anacardiaceae	Fruit	50	14.25
Moringa oleifera	Moringaceae	Vegetable	9	2.56
Nyctanthes arbor-tristis	Oleaceae	Ornamental	1	0.28
Phoenix sylvestris	Palmaceae	Ornamental	1	0.28
Piper cubeba	Piperaceae	Spice	1	0.28
Psidium guajava	Myrtaceae	Fruit	17	4.84
Punica granatum	Punicaceae	Fruit	1	0.28
Salmalia malabarica	Bombacaceae	Cotton	4	1.14
Samanea samane	Mimosaceae	Craftwood	1	0.28
Spondias mangifera	Anacardiaceae	Fruit	1	0.28
Syzygium cumini	Myrtaceae	Fruit	4	1.14
Syzygium samarangense	Myrtaceae	Fruit	10	2.85
Terminalia arjuna	Combretaceae	Medicine	1	0.28
Terminalia belerica	Combretaceae	Medicine	1	0.28
Terminalia chebula	Combretaceae	Medicine	1	0.28
Vitex negundo	Lamiaceae	Medicine	1	0.28
Zizyphus jujuba	Rhamnaceae	Fruit	9	2.56

4.5 Estimation of carbon stock at three plantation sites in SAU campus

The recorded average standing biomass carbon stock of the three plantation sites were 174.24 ± 21 Mg C ha^{-1} (Figure 2). The estimated average biomass carbon stock of the roadside, woodlot and homegarden were 159.18 ± 36 Mg C ha^{-1}, 206.19 ± 42 Mg C ha^{-1} and 169.37 ± 34 Mg C ha^{-1}, respectively (Figure 2

& Appendix VII). It was observed from the study area (roadside, woodlot and homegarden) that the average biomass carbon per tree, above ground carbon (Mg/0.01 ha), below ground carbon (Mg/0.01 ha), total carbon (Mg/0.01 ha), above ground carbon (Mg ha^{-1}) and below ground carbon (Mg ha^{-1}) were 0.17 Mg C $tree^{-1}$, 1.61 Mg C, 0.26 Mg C, 1.87 Mg C, 150.01 Mg C ha^{-1} and 24.23 Mg C ha^{-1}, respectively (Table 9).

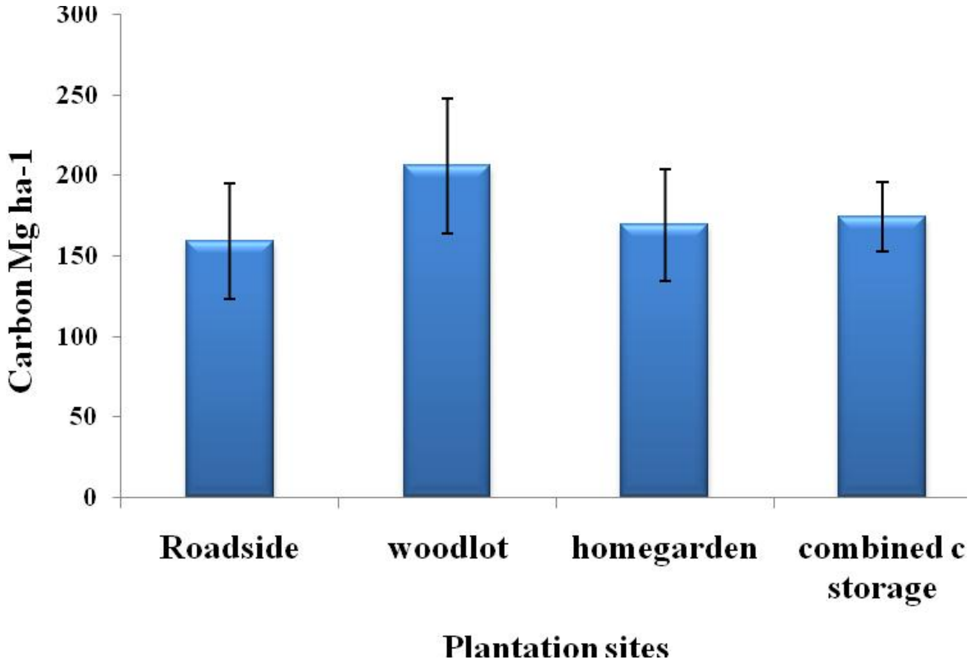

Figure 2. Average carbon stock of different plantation sites in Sher-e-Bangla Agricultural University campus

Table 9. The average carbon per tree, above ground carbon, below ground carbon and total carbon at three plantation sites

Plantation site	C (Mg) $tree^{-1}$	AGC (Mg) (0.01 ha)	BGC (Mg) (0.01 ha)	Total carbon (Mg) (0.01 ha)	AGC (Mg) ha^{-1}	BGC (Mg) ha^{-1}
Roadside	0.42	1.38	0.21	1.59	137.98	21.20
Woodlot	0.16	1.77	0.30	2.06	176.52	29.66

Homegarden	0.12	1.46	0.24	1.69	145.66	23.71
Average	0.17	1.61	0.26	1.74	150.01	24.23

In roadside area, the average carbon per tree, above ground biomass carbon (Mg/0.01 ha), below ground carbon (Mg/0.01 ha), total carbon (Mg/0.01 ha), above ground carbon (Mg ha^{-1}) and below ground carbon (Mg ha^{-1}) were 0.42 Mg C $tree^{-1}$, 1.38 Mg C, 0.21 Mg C, 1.59 Mg C, 137.98 Mg C ha^{-1} and 21.20 Mg C ha^{-1}, respectively (Table 9). 7810 m^2 area was found in roadside plantation with continuous tree covering around the whole campus. In roadside average carbon stock was measured 159.18 Mg C ha^{-1} (Appendix VII). In SAU campus, the total carbon stock of roadside for 7810 m^2 area was 124.31Mg C.

It was observed that in woodlot the average biomass carbon per tree, above ground carbon (Mg/0.01 ha), below ground carbon (Mg/0.01 ha), total carbon (Mg/0.01 ha), above ground carbon (Mg ha^{-1}) and below ground carbon (Mg ha^{-1}) were 0.16 Mg C $tree^{-1}$, 1.77 Mg C, 0.30 Mg C, 2.06 Mg C, 176.52 Mg C ha^{-1}, 29.66 Mg C ha^{-1}, respectively (Table 9). 7307 m^2 area was found in woodlot plantation around the whole campus. In woodlot, the average carbon stock was measured 206.19 Mg C ha-1 (Appendix VII). In SAU campus woodlot of 19512 m^2 area, the recorded carbon stock was 150.66 Mg C.

In homegarden the average biomass carbon per tree, above ground carbon (Mg/0.01 ha), below ground carbon (Mg/0.01 ha), total carbon (Mg/0.01 ha), above ground carbon (Mg ha^{-1}) and below ground carbon (Mg ha^{-1}) were 0.12 Mg C $tree^{-1}$, 1.46 Mg C, 0.24 Mg C, 1.69 Mg C, 145.66 Mg C per ha^{-1}, 23.71 Mg C per ha^{-1}, respectively (Table 9). 25327.75 m^2 area was found in homegarden plantation around the whole campus. In homegarden, average carbon stock was measured 169.37 Mg C ha^{-1} (Appendix VII). In SAU campus, the total carbon stock of homegarden for 25327.75 m^2 area was 428.50 Mg C.

4.6 Relationship between stand structure and carbon stocks

Correlation analysis was used to determine the relationship between mean DBH (cm), basal area and stem density (trees $ha^{-1)}$. All the stand structures were significantly correlated with carbon stock except stem density (Appendix V).

4.6.1 Mean DBH

This study revealed that there was a moderate relation between mean DBH (cm) and total carbon stock (Mg ha^{-1}). Though the relationship was moderate but it was significant ($p < 0.01$). The value of r is 0.5641 and R^2 is 0.292 (Figure 3).

4.6.2 Basal area

It was found that the relationship between basal area (m^2 ha^{-1}) and total carbon (Mg ha^{-1}) was significant ($p < 0.01$). The following figure indicates that the value of r is 0.914 and R^2 is 0.836 (Figure 4).

4.6.3 Stem density

It was revealed from the study that there was a negative relation between stem density (tree ha^{-1}) and total carbon stock (Mg $ha^{-1)}$. The relationship was not significant ($p > 0.01$). The value of r is -.124 and R^2 is 0.015 (Figure 5).

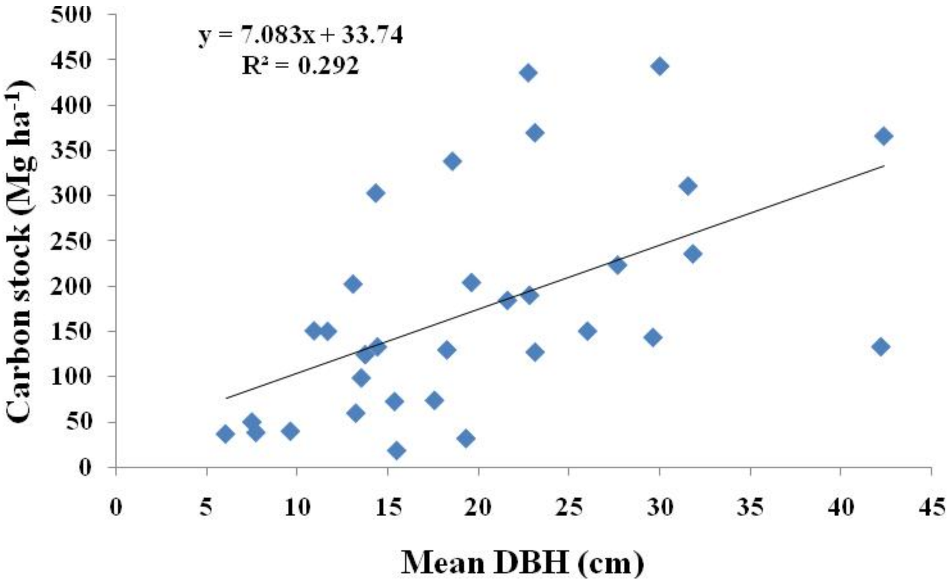

Figure 3. Relationship between mean DBH and total carbon stock Mg ha^{-1}

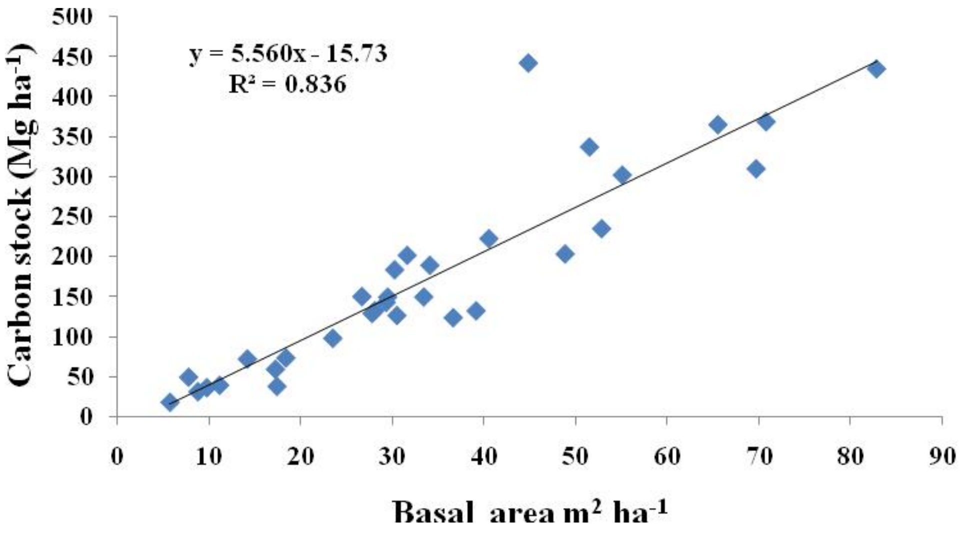

Figure 4. Relationship between basal area m^2 ha^{-1} and total carbon stock Mg ha^{-1}

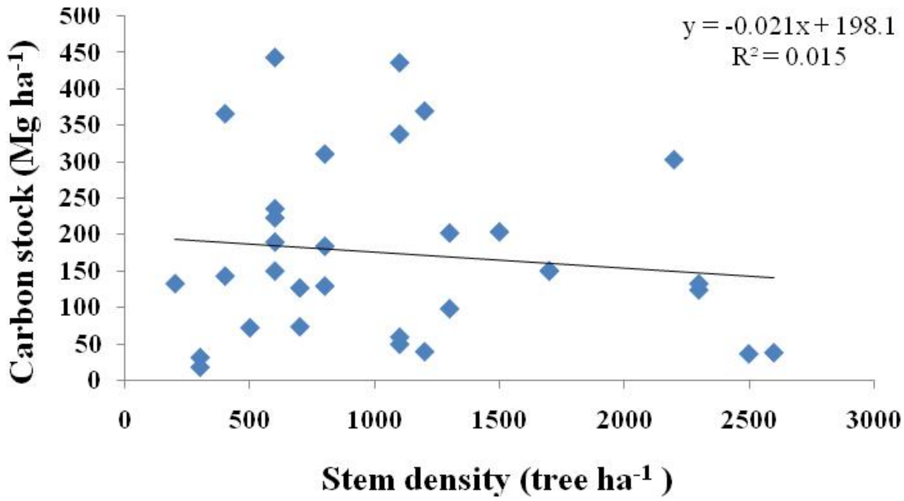

Figure 5. Relationship between stem density tree ha^{-1} and total carbon stock Mg ha^{-1}

4.7 Percent carbon contribution by tree species in roadside

The estimated average carbon stock in roadside was 159.18 Mg C per hectare. Among the 4 species, the highest carbon content was estimated in *Swietenia macrophylla* which contained 43.17% followed by *Polyalthia longifolia* (35.5%), *Mangifera indica* (20.48%) and *Roystonea regia* (0.85%) respectively at the roadside area in SAU campus (Figure 6).

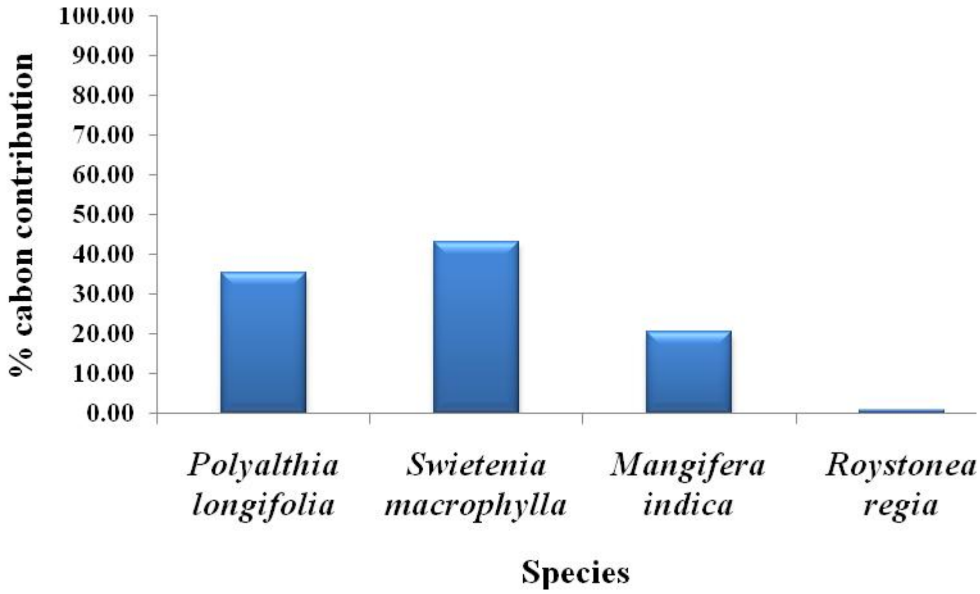

Figure 6. Percent carbon contribution by tree species in roadside

4.7.1 Percent carbon contribution by tree species in woodlot

The estimated average carbon stock in woodlot was 206.19 Mg C per hectare. Among the 7 species, the highest carbon content was estimated in *Swietenia macrophylla* which contained 32.22% followed by *Litchi chinensis* (30.70%), *Mangifera indica* (15.49%), *Tectona grandis* (12.79%), *Samanea samane* (5.56%), *Carpinus caroliniana* (1.72%), *Azadirachta indica* (0.79%), and *Albizzia lebbeck* (0.74%), respectively in woodlot of SAU campus (Figure 7).

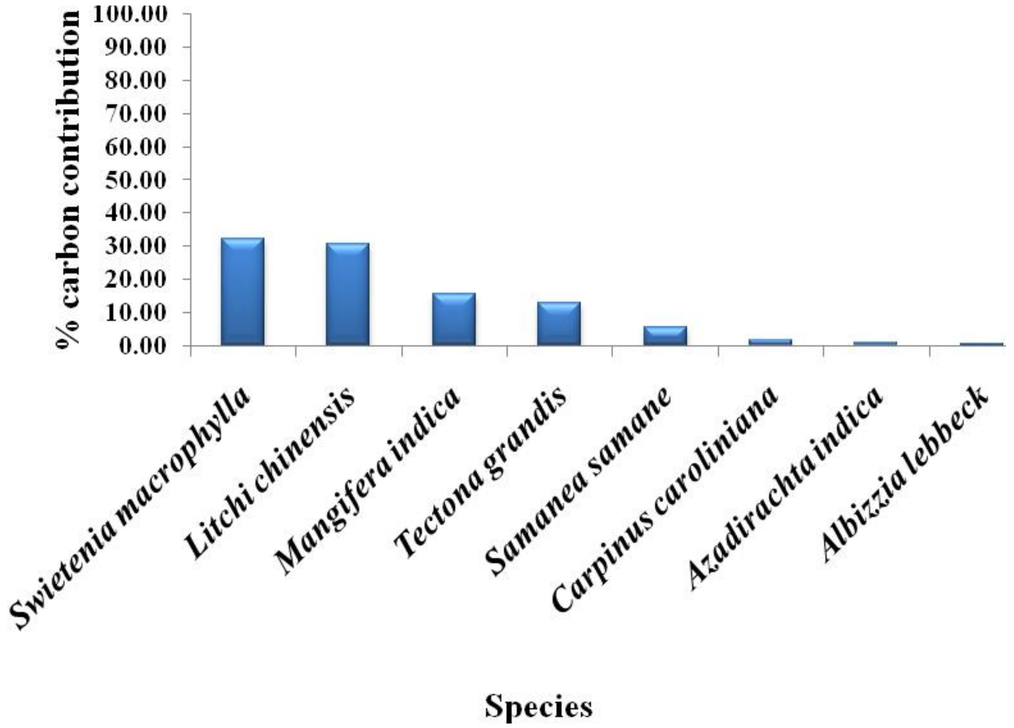

Figure 7. Percent carbon contribution by tree species in woodlot

4.7.2 Percent carbon contribution by tree species in homegarden

Carbon storage estimated in homegarden area was on an average about 169.37 Mg carbon per hectare. Among 36 species, only 10 species were considered as the most significant, in terms of percent carbon contribution in homegarden area. It was found that the highest carbon contribution was estimated in *Mangifera indica* covering 34.35% of the homegarden area in SAU campus. Other species carbon storage contribution were *Artocarpus heterophyllus* (16.91%), *Salmalia malabarica* (22.69%), *Moringa oleifera* (3.25%), *Garuga pinnata* (2.08%), *Psidium guajava* (0.85%), *Syzygium samarangense* (1.48%), *Annona reticulate* (0.88%) , *Citrus grandis* (0.45%) and *Zizyphus jujuba* (1.01%) respectively in homegarden area of SAU campus(Figure 8).

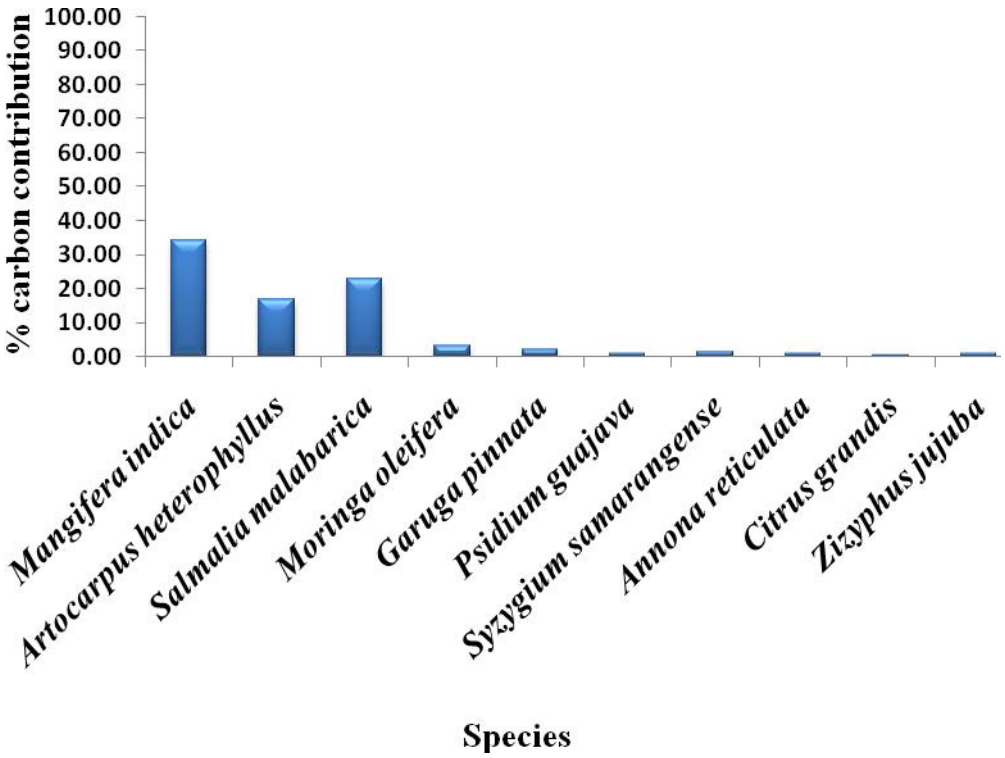

Figure 8. Percent carbon contribution by tree species in homegarden

4.8 Species wise carbon composition

Among 38 tree species, only 15 species were considered as the most significant in terms of total carbon storage. It was observed from the study that these 15 species accumulated 96% of carbon stock and the rest 23 species contributed only 4% to store carbon in the study area. Out of 15 species, *Mangifera indica* accumulated the highest percentage of carbon (26%), followed by *swietenia macrophylla*, *Polyalthia longifolia*, *Salmalia malabarica*, *Litchi chinensis*, *Artocarpus heterophyllus* and *Tectona grandis* with carbon storage percentage of 21, 11, 11, 9, 8 and 3 respectively (Figure 9).

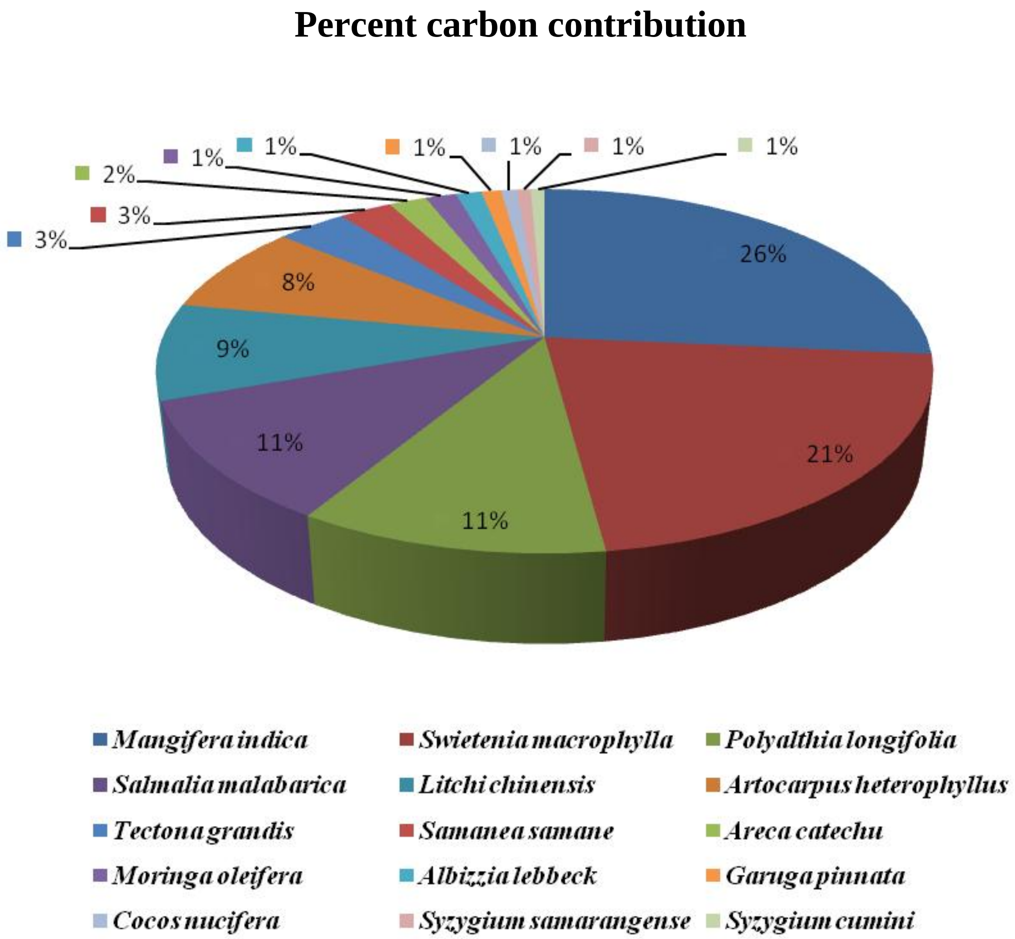

Figure 9. Percent carbon contribution by fifteen species from total of thirty eight species

4.9 Family composition and family carbon composition

There were 25 families at the three plantation sites. Among them 10 families showed the highest carbon composition (Figure 10). From the perspective of carbon composition, Anacardiaceae family occupied the highest carbon from the others and it was approximately 25% but their species composition under this family was lower i.e. only 16.80%. On the other hand, Meliaceae encompasses the highest number of species composition that was almost 23% but their contribution on carbon composition was lower i.e., 21%. The other two families (Annonaceae and Bombaceae) covered almost the same portion of carbon composition and it was approximately 10% but in terms of species composition under the family Annonaceae and Bombaceae were 10.25% and

1.14% respectively (Figure 10). The number of family and carbon composition were shown in Appendix VI.

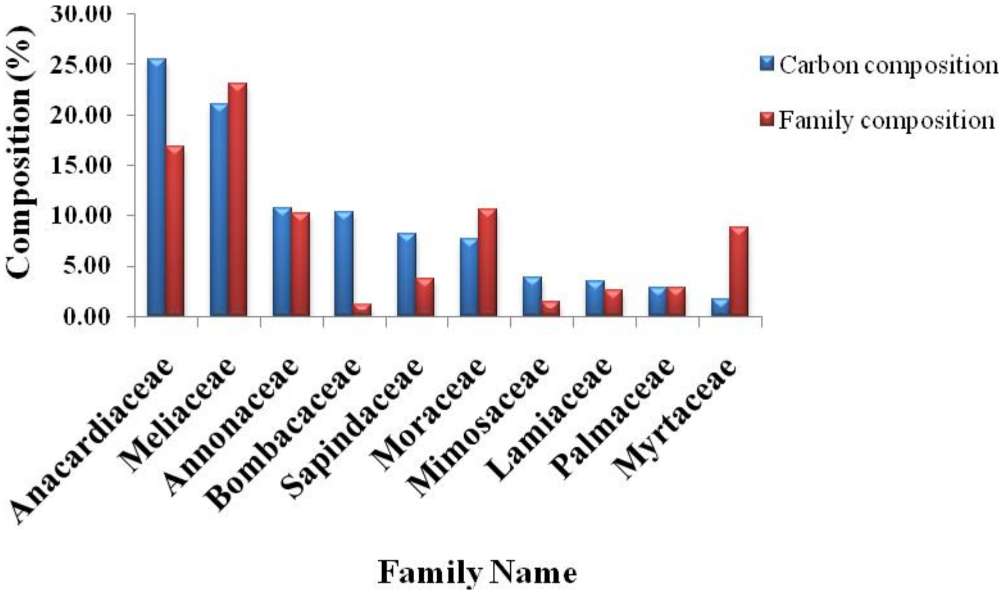

Figure 10. Carbon composition in respect to family in the plantation sites

CHAPTER V

DISSCUSSION

Carbon is stored in different pools like vegetation, soil, dead wood etc. especially trees store and sequester large amounts of carbon, providing an important service to society: carbon dioxide uptake. The total number of woody species in the study area is slightly varied from other studies because this study was conducted within the sample plot area and counted all woody species within this demarcated plot area but was not considered the whole area of roadside, woodlot and homegarden. In this study the tree species in roadside comprised of four species while in woodlot area seven species was found, that is comparatively lower than the tree species found in homegarden area which comprised of 34 species. The tree species in homegarden of SAU campus was slightly higher (34 spp) than those found in homestesd of Jessore (28 spp), Patuakhali (20 spp), Rajshahi (28 spp), and Rangpur (21 spp) district respectively (Abedin and Quddus, 1990) but was slightly smaller than those found in homesteads of Sandwip upazila (76 spp) of Chittagong and the homesteads of Tangail (52 spp) (Mohammed and Kazi, 2005).

This variation may be because of differences in geographic and physiographic coverage, environmental gradient and purpose of plantation. For example in roadside plantation ornamental species are planted mainly with an objective of beautification and aesthetic value, while in homegarden, multipurpose tree species including fruit, timber, palm and medicinal species are planted. On the other hand, in woodlot, mainly timber species are usually planted with an objective of sustainable land management issues. Hence, the homegarden of Sher-e-Bangla Agricultural University campus represent a pretty enriched in tree species composition.

In order to characterize stand structure, the importance value index (IVI) was computed using the derivatives of density, basal area and frequency of each recorded species. The importance Value Index (IVI) indicates a complete picture of phytosociological character of a species in the community (Hossain *et al.,* 2004). In the present study it was observed that the dominant tree species of roadside, woodlot and homegardens were *Polyalthia longifolia* (43.94%), *Swietenia macrophylla* (51.31%) and *Mangifera indica* (22.46%), respectively which showed the maximum IVI (Table 3, 4 & 5). As a whole in three plantation area, it was observed that dominant tree species was *Mangifera indica* which showed the maximum IVI (17.25%) followed by *Swietenia macrophylla* (17.20%), *Artocarpus heterophyllus* (9.76%), and *Polyalthia longifolia* (8.42%), respectively (Table 2). The maximum value of IVI was found in *Mangifera indica* due to the highest plantation at three plantation sites (Table 2).

Determination of the relative density of different species of the three plantation sites revealed that *Swietenia macrophylla* (22.22%) are the most important species of the three vegetation area followed by *Mangifera indica* (16.52%), *Artocarpus heterophyllus* (10.26%) and *Polyalthia longifolia* (8.26%) (Table 2). The study disclosed that the species of *Mangifera indica* (12.90%) and *Artocarpus heterophyllus* (10.48%) are the most frequently occurring species, followed by the *Swietenia macrophylla* (5.65%) *and Polyalthia longifolia* (5.65%) both showed the similar values (Table 2). Basal area represents the real extent of domination of a species in the community. Determination of relative dominance based on basal area revealed that *Swietenia macrophylla* (23.73%) was the most dominant, which was followed by *Mangifera indica* (22.33%), *Polyalthia longifolia* (11.35%) and *Artocarpus heterophyllus* (8.53%), respectively (Table 2). The maximum relative dominance of *Swietenia macrophylla* is due to the average amount of an *area* occupied by Swietenia species was higher.

The study showed that the average stem density (1096.88 tree ha^{-1}) was higher than recorded stem density (705 tree ha^{-1}) from Taiwanese highway plantation (Wang 2011), 279 tree ha^{-1} from urban roadside forest in Shenyang, China (Liu and Li, 2012), 381 tree ha^{-1} in Chittagong Hill Tracts (South) Forest Division (Nath *et al.,* 1998), 459 tree ha^{-1} in Chunati Wildlife Sanctuary, Cox's Bazar

(Rahman and Hossain, 2003) and 464 tree ha^{-1} in Dudpukuria-Dhopachori Wildlife Sanctuaries of Chittagong South Forest Division (Hossain *et al.,* 2013). The findings of very high density trees in three plantation sites compared to other study due to maintaining a closer tree spacing in roadside and woodlot while in homegarden, this site contained diverse tree species (juvenile and adult) due to different multipurpose uses.

On the other hand the average basal area (34.16 m^2 ha^{-1}) of present study was higher than basal area (16.88 m^2 ha^{-1}) in Chunati Wildlife Sanctuary, Cox's Bazar (Rahman and Hossain, 2003) and 27.07 m^2 ha^{-1} in Dudpukuria-Dhopachori Wildlife Sanctuaries of Chittagong South Forest Division (Hossain *et al.*, 2013) but lower than the basal area (53.5 m^2 ha^{-1}) in Chittagong Hill Tracts (South) Forest Division (Nath *et al.,* 1998).

The present study was covered only tree biomass carbon (above and belowground tree biomass carbon) because of limited logistic support. The present study revealed that per hectare average carbon stock at roadside, woodlot and homegarden areas in SAU campus were 159.18 Mg C ha^{-1}, 206.19 Mg C ha^{-1} and 169.37 Mg C ha^{-1} respectively (Figure 2). In SAU campus, the total biomas carbon stock of roadside woodlot and homegarden for 7810 m^2, 7308 m^2 and 25327.75 m^2 area were 124.31(Mg C), 150.66 (Mg C) and 428.50 (Mg C), respectively.

ANOVA was used to test the differences between and within the group of Above-and below ground carbon, basal area, mean DBH (Diameter at breast height) and stem density at three plantation sites in SAU campus. However, no significant difference ($p > 0.05$) was found in Above-and below ground biomass carbon and basal area while stem density and mean DBH showed significant differences ($p < 0.05$) between and within the group of three plantion sites in 32 sample plots. The cause behind the non significance difference ($p > 0.05$) in Above-and below ground biomass carbon and basal area could be due to the difference in replication at three plantation sites.

The results of this study showed that the average total biomass carbon stock (above and below ground) of three plantation sites were 174.24 Mg C ha^{-1} (Figure 2). The mean biomass carbon (174 Mg ha^{-1}) of present study was higher than mean biomass carbon (65-158 Mg ha^{-1}) in Bangladesh (Gibbs *et al.*, 2007), 83.72 Mg ha^{-1} in Hill Forest of Bangladesh (Shin *et al*., 2007) and 110.94 Mg ha^{-1} in Hill Forest of Bangladesh (Ullah and Al-Amin, 2012) but lower than the mean biomass carbon 192.80 Mg ha^{-1} in roadside plantation (Rahman *et al.,* 2015). In a study it was found that biomass tree organic carbon was 110.94 Mg C ha^{-1} in a purely natural forest where no plantation were ever held, which shows less than the University plantation (Ullah and Al-Amin, 2012). It was found that the per tree carbon storage potential was higher in comparisan to natural stands. Thus, plantation tree species gather higher organic carbon than pure natural stand.

Similar research was carried out at Gujarat university campus, Ahmedabad where the total carbon stock in the trees of Gujarat university campus was found to be 661.30 Mg C ha^{-1} (Rathore and Jasrai, 2013). The result of the present study was also consistent with other relevant findings, on a per unit tree cover basis, C storage by urban trees and gross sequestration may be greater than in forest stand due to a greater proportion of large trees in urban environments, and relatively fast growth rates because of the more open urban forest structure (Nowak, 1994). The current study is in accordance with the findings of Nowak and Crane (2002) the individual urban trees on an average contain approximately four times more C than individual trees in forest stands. The another cause for being higher carbon stock of the present study area is due to differences in stem density, wood density, age structure, species composition, storage potential, stage of development and site characteristics between urban and natural stands.

The roadside plantation was stored a significant amount of carbon per hectare. In this study, mean biomass carbon stocks of roadside (159.18±36 Mg C ha^{-1}) was exceptionally higher than that of roadside carbon stocks of Eastern

Australia roadside (11.71±3.57 Mg C ha^{-1}), (Eldridge and Wilson, 2002) of Buter street (45.49 Mg C ha^{-1}), Penn street (22.29 Mg C ha^{-1}) USA (Keating *et al.,* 2005).

The mean biomass carbon stock of woodlot (206.19±42 Mg C ha^{-1}) was exceptionally higher than that of Eucalyptus plantation (EP) and mixed species plantation (MP) in Bharathiar University campus at Coimbatore, India. They observed that the total carbon stock by the two plantations were 27.72 and 22.25 t ha^{-1} respectively (Pragas and Karthick, 2013).

The present study showed that the mean biomass carbon stocks of homegaden (169.37±34 Mg C ha^{-1}) was higher than that of Indonesian homegarden with an average of 107 Mg C ha^{-1} (Roshetko *et al.*, 2002). The present average homegarden aboveground carbon stock reported at SAU campus (145.66 Mg C ha^{-1}, Table 9) was higher than that of Javanese and Sumatran homegardens which was aboveground carbon stock values 58.6 Mg ha^{-1} and 35.3 Mg ha^{-1} respectively (Jensen, 1993 and Roshetko *et al.,* 2002). The carbon stock at present study could be varried from others because of different basal area and stem density per ha and it was found that basal area per ha had strong correlation with carbon stock (Figure 4). Furthermore, the rate of carbon sequestration depends on the growth characteristics of the tree species, the conditions of growth and the density of the tree wood where the trees are planted (i.e., the local climate).

In the present study, the average biomass carbon captured by single tree was maximum in roadside (0.42 Mg C tree^{-1}) which followed by woodlot (0.16 Mg C tree^{-1}) and homegarden (0.12 Mg C tree^{-1}) (Table 9) because of in roadside plantation, tree species found with more or less similar diameter class but in case of homegarden and woodlot plantations they exhibited with diverse diameter class as for per tree average biomass carbon stock was higher in roadside species. The individual tree species at three plantation sites capturing the higher average carbon stock (0.17 Mg C tree^{-1}) (Table 9) than average carbon capture by single tree for site of Eucalyptus plantation (0.09 Mg C tree^{-}

^{1}) and it was 0.05 Mg C tree^{-1} for site of mixed species plantation, University campus at Coimbatore, India (Pragas and Karthick, 2013).

The above ground carbon that is derived from AGB by multiplying 0.5 and this AGB is closely linked to wide wood density, tree-stem density and basal area (Saatchi *et al.*, 2007). In this study the basal area and mean DBH varied from 5.76 to 82.78 m^2 ha^{-1} and 6.05 to 42.33 cm ha^{-1}, respectively of the three plantation area in SAU campus (Appendix VIII). It was found from the present study that basal area had a strong relationship with carbon stock (Figure 4) while the mean DBH have a moderate relationship with carbon stock, (Figure 3) but both the relationship showed significant relation in Pearson's correlation analysis ($p < 0.01$) (Appendix V).

The result indicates that tree carbon content increase with the increase in basal area. So, sites with higher basal area tend to store more carbon. The present study followed the relationship of basal area and carbon stock. In woodlot plantation site, the average carbon stock (206.19 Mg C ha^{-1}) was higher than the carbon stock of roadside (159.18 Mg C ha^{-1}) and homegarden (169.37 Mg C ha^{-1}) due to higher basal area in woodlot (38.28 m^2 ha^{-1}) compared to roadside (33.80 m^2 ha^{-1}) and homegarden (32.42 m^2 ha^{-1}) basal area. Though the homegarden was showed less basal area (32.42 m^2 ha^{-1}) than the roadside (33.80 m^2 ha^{-1}) it produced more biomass carbon compared to roadside because of while the homegarden basal area was measured, the palm species DBH was not recorded (Table 1). In a study it was reported that a significant positive correlation found between mean DBH and Carbon stock as well as between basal area and total woody C have also showed a high correlation of biomass with diameter at breast height (Mani and Parthasarathy, 2007). Similar trend has been observed by several workers in tropical forests (Murali *et al.*, 2005). In another study conducted in Borneo, Southeast Asia, showed the relationship between basal area and AGB, where the value of R^2 was 0.44 (Slik, 2010).

The present study showed that there was a negative correlation between stem density and total carbon stock (Figure 5). In this study area (three plantation sites) tree density ranged from 200 to 2600 stem ha^{-1} (Appendix VIII). The present study revealed that there was no positive correlation ($p > 0.01$) between biomass total carbon stock and stem density at three plantation sites. (Appendix V). In one study that was carried out in an old growth forest of Costa Rica, Central America, found two plots with a stem density 462 to 504 per ha where the AGB was 139 to 138 Mg ha^{-1} respectively (Clark, 2000). It indicates that the stem density is not a determinant factor of aboveground carbon stocks. AGB was only correlated with basal area, but not with stem density (Slik, 2010). It was observed from a study that tree density had a negative relationship with tree basal area, total woody biomass (aboveground + belowground), woody biomass accumulated carbon, SOC and total carbon (woody biomass carbon + SOC) (Sundarapandian *et al.,* 2013). Another study showed that tree density is important to store carbon as it directly relates to the carbon sequestration (Roshetko *et al.,* 2007).

The present study also indicates that in roadside *Swietenia macrophylla* comprised 43.17% (68.26 Mg C ha^{-1}) of carbon where *Polyalthia longifolia* comprised 35.50 % (56.13 Mg C ha^{-1}) (Figure 6). As carbon percentage depend on basal area of species which increases it's biomass and carbon storage. Similarly carbon percentage obtained in *Swietenia macrophylla* was 32.22 (66.43 Mg C ha^{-1}) (Figure 7) and in *Mangifera indica* was 34.35 (58.18 Mg C ha^{-1}) (Figure 8) in woodlot and home garden respectively.

The average carbon stock of various tree species at three plantation sites showed that the maximum percentage of carbon stock in trees was found with *Mangifera indica* 26 (44.38 Mg C ha^{-1}) followed by *Swietenia macrophylla* 21 (35.86 Mg C ha^{-1}), *Polyalthia longiafolia* 11 (18.13 Mg C ha^{-1}) *Salmalia malabarica* 11 (18.01 Mg C ha^{-1}), *Litchi chinensis* 9 (14.36 Mg C ha^{-1}), *Artocarpus heterophyllus* 8 (13.42 Mg C ha^{-1}) and *Tectona grandis* 3 (5.82 Mg C ha^{-1}) respectively (Figure 9 & Appendix X). This study also observed that meliaceae family covered the heigest value in species number (23%) but their contribution on carbon storage was lower (21%). On the other hand, Anacardiaceae family occupied the highest carbon from the others and it was approximately 25% but their species composition under this family was lower i.e. only 16.80%, because of, the wood density of anacardiaceae family 0.53 gm cm^{-3} which was higher than the wood density of meliaceae family composed only 0.53 gm cm^{-3} (Figure 10).

Through policies and management practices, Sher-e-Bangla Agricultural University campus will be able to maximize the sequestration of its plantation sites (roadside, woodlot and homegarden) and ensure that it continues to sequester as much as possible.

CHAPTER VI

SUMMARY AND CONCLUSION

Higher educational institutions are well suited to being leaders in environmental protection, because universities have a profound influence on the whole of society based on their research, teaching and policy development expertise (Dahle and Neumayer, 2001).

It was found that the study area contained much tree species (38 species) with greater potential of carbon stock and at the same time these tree species serving multipurpose function and aesthetic value at three plantation sites in SAU (Table 6,7 and 8). As a whole at three plantation sites in SAU campus, the dominant tree species was *Mangifera indica* (IVI = 17.25 %). On the other hand, the dominant tree species of roadside, woodlot and homegardens were *Polyalthia longifolia* (43.94%), *Swietenia macrophylla* (51.31%) and *Mangifera indica* (22.46%) respectively.

As an institutional area, plantation sites (roadside, woodlot and homegarden) of Sher-e-Bangla Agricultural University campus was stored on an average 174.24 Mg C ha^{-1}(Figure 2). The study showed that per hectare average carbon stock at roadside, woodlot and homegarden area in SAU campus were 159.18 Mg C ha^{-1}, 206.19 Mg C ha^{-1} and 169.37 Mg C ha^{-1} respectively (Figure 2).

In this study it was also found that individual plots of the study area contain higher carbon stocks (range from 18.82 – 443.08 Mg C ha^{-1}, Appendix VII) with higher basal area (range from 5.77-82.78 m^2 ha^{-1}) and stem density (range from 200-2600 trees ha^{-1}) (Appendix VII). It was found that the average carbon storage potential was higher at SAU campus in comparison to natural stands which was resembled by the findings of Ullah and Al-Amin, 2012. As plantation site basis, it can be summerized that the average carbon stock value was higher in woodlot (206.19 Mg C ha^{-1}) compared to homegarden (169.37 Mg C ha^{-1}) and roadside area (159.18 Mg C ha^{-1}) because of carbon content in tree biomass depend on growth rate, wood density, establishment, stem density and basal area. In SAU campus, the total carbon stock of roadside, woodlot and homegarden for 7810 m^2, 7308 m^2 and 25327.75 m^2 area were 124.31(Mg C), 150.68 (Mg C) and 428.50 (Mg C), respectively . So, in woodlot plantation sites there is an ample scope to increase the carbon stock by extending the woodlot area through plantation activity. On the other hand, more plantations in the existing area can also enriched the level of carbon stock at roadside and homegarden in Sher-e-Bangla Agricultural University.

In order to maximize the amount of carbon stock on Sher-e-Bangla Agricultural University campus, as a means of offsetting Co_2 from atmosphere, policies and planting programme should focus on the tree species that sequester the most carbon in their biomass. As a sustainable land management option in an urban institutional area, Sher-e-Bangla Agricultural University campus can serves as a model because of carbon stock at three plantation sites (roadside, woodlot and homegarden) act as a tools for making policies in future plantation protocol in this university as well as other institutional areas.

The summery that can be drawn from this findings is that, as an institutional plantation sites (roadside, woodlot and homegarden) in urban area, Sher-e-Bangla Agricultural university campus can store a significant amount of biomass carbon (174.24 Mg C ha^{-1}) as well as contributing in greening the campus area. As a result, besides carbon sequestration “green” campus could potentially attract better staff and students with sound healthy enviornment which also provides supportive role for biodiversity conservation in urban area. The greening of campus could also improve the reputation and image of university. The results of the present study prove that plantations acting as storehouse of carbon by stocking C in their tissues, thereby lowering the levels of atmospheric greenhouse gases as stated by Brown *et al*., 1989 .

The findings of the present study imply that University plantations have a great potential to store C in their biomass and it could be suggested that increase in their number and maintenance over a long time period will mitigate the atmospheric CO_2 concentrations, apart from the standpoint of conservation. Therefore, plantations in an institutional area can play important role to atmospheric carbon sequestration in addressing the global climate change issue.

The future study will be helpful, moreover, to obtain a clear picture about the change in tree biomass as well as in change in carbon stock, biodiversity conservation and carbon sequestration rate which will contribute in the planning sustainable land management issues.

Conclusions:

From the result of this study, it can be concluded that management of existing vegetation, and increasing in vegetation cover at the studied area, are likely to be more effective strategies for retaining carbon in the landscape and potentially increasing carbon sequestration. Present study will facilitate to get more complete understanding of the organic carbon sequestration potential of different types of plantations in urban institutional areas.

Recommendation:

This study has profound influence in terms of climate change mitigation strategy in urban areas as for similar research works need to be carried out in other institutional areas of urban green patches to find out the status of carbon stock as well as enlarging the knowledge of global issues of carbon sequestration in terrestrial area. The allometric equation applied in the present study is not free of errors in calculating carbon levels in different trees. Such errors are caused by approximation of wood densities of trees, slight deviations of biological make up of species in different sites that are not equal to where the allometric equation was developed, and site specific environmental conditions. As a solution, the allometric equation formulated for other countries should be calibrated to suit local situations through field research, and then use them to determine the carbon levels in different trees exactly.

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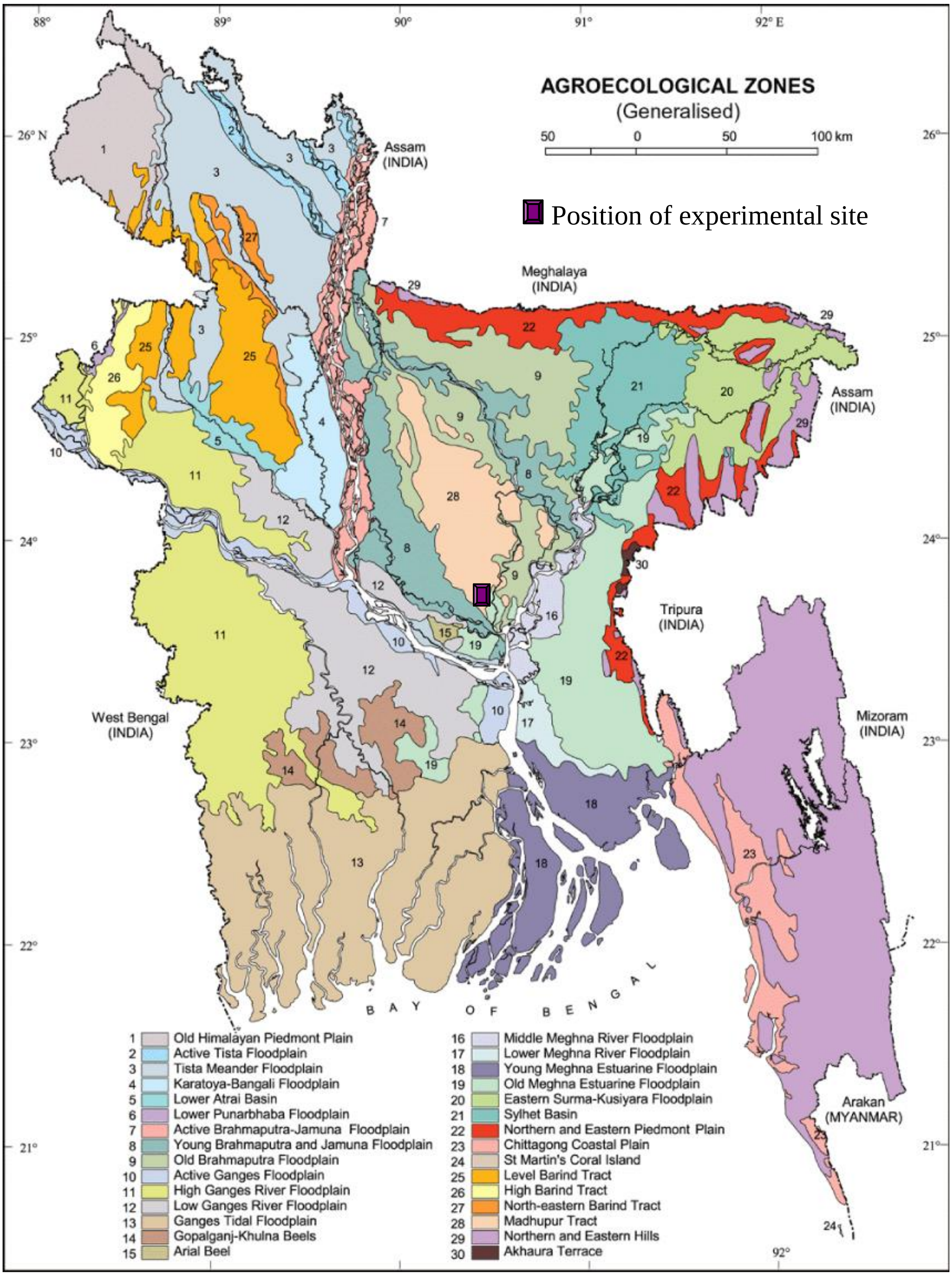
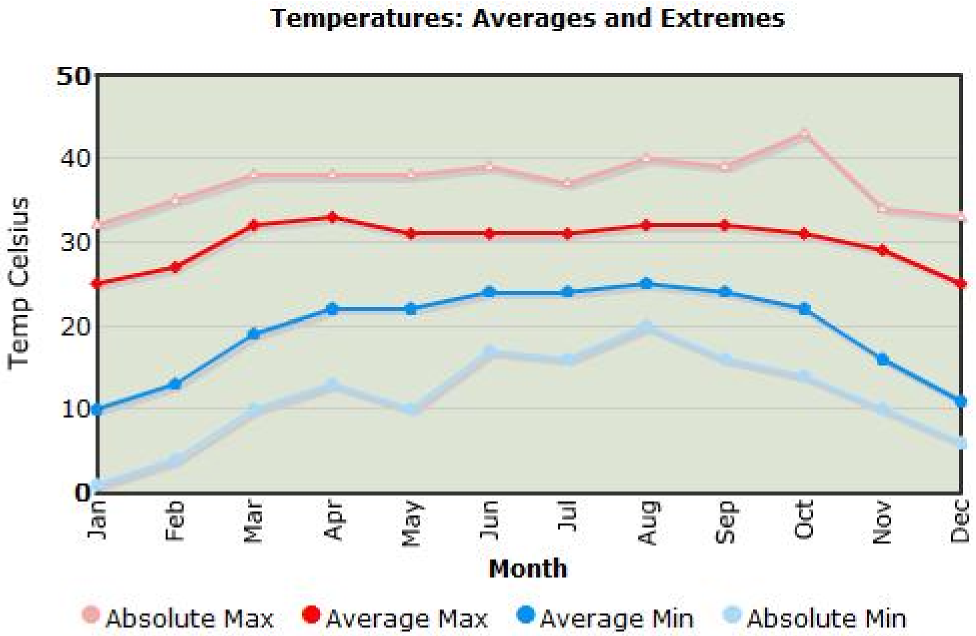
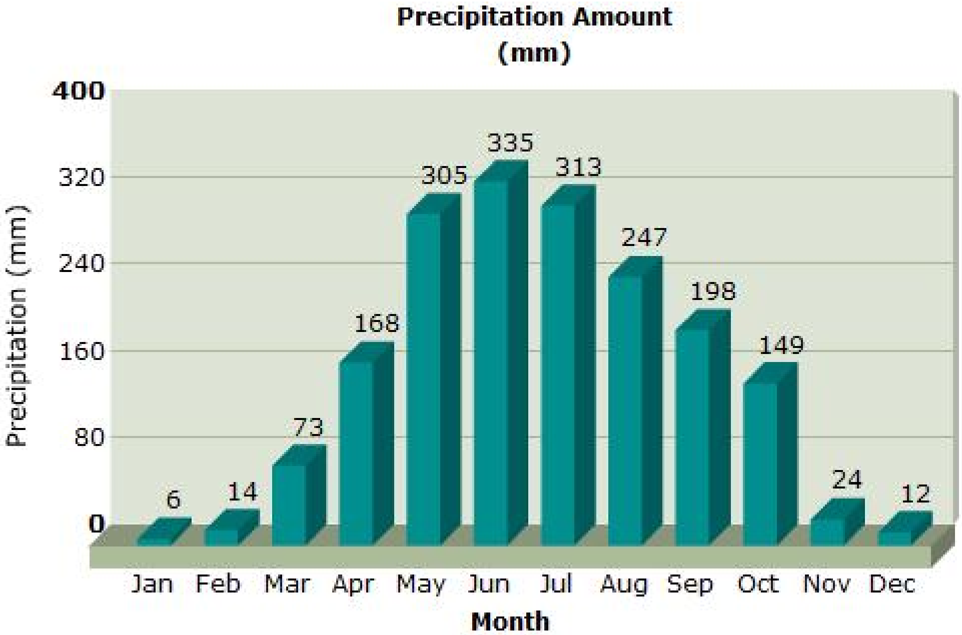
APPENDICES

Appendix I. Experimental location on the map of Agro-ecological Zones of Bangladesh



Appendix II. Yearly Trends: Weather Averages & Extremes, Dhaka





Source:http://www.myweather2.com/HolidayDestinations/Bangladesh/Dhaka/climate-profile.aspx?month=10

Appendix III. Physiochemical properties of the initial soil

Characteristics	**Value**
Partical size analysis.	
% Sand	26
% Silt	45
% Clay	29
Textural class	silty-loam
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Source: Soil Resources Development Institute (SRDI), Dhaka-1207

Appendix IV. Analysis of variance of the data for above ground carbon, below ground carbon, mean DBH and basal area

Source of variation	Variation	Sum of Squares	df	Mean Square	F	Sig.
AGC (Mg ha^{-1})	Between Groups	6652.60	2	3326.30 ^{NS}	.283	.756
	Within Groups	341338	29	11770.29 ^{NS}		
	Total	347991	31			
BGC (Mg ha^{-1})	Between Groups	302.234	2	151.117 ^{NS}	.659	.525
	Within Groups	6653.947	29	229.446 ^{NS}		
	Total	6956.181	31			
Mean DBH (cm)	Between Groups	1102.956	2	551.478 *	10.415	.000
	Within Groups	1535.545	29	52.950 *		
	Total	2638.501	31			
Basal area (m^{-2} ha^{-1})	Between Groups	7705.459	2	3852.730 ^{NS}	.826	.448
	Within Groups	135310	29	4665.872 ^{NS}		
	Total	143015	31			
Stem density (Trees ha^{-1})	Between Groups	5548687	2	2774343*	8.939	.001
	Within Groups	9001000	29	310379*		
	Total	14549687	31			

* = Significant at 5% level

NS = Not significant

Appendix V. Pearson Correlation analysis between Mean DBH, Stand basal area, stem density and total carbon. *P –value* is given in parenthesis.

Variables	**Total Carbon (Mg ha^{-1})**
Mean DBH	0.541**(0.000)
Stand basal area	0.914**(0.000)
Stem density	-.124^{NS}

**Correlation is significant at the 0.01 level (2-tailed).

NS=Non Significant

Appendix VI. Composition of family and carbon (%)

Sl No.	**Family Name**	**No of trees**	**Carbon composition**	**Family composition**
1	Anacardiaceae	59	25.56	16.81
2	Meliaceae	81	21.08	23.08
3	Annonaceae	36	10.79	10.26
4	Bombacaceae	4	10.32	1.14
5	Sapindaceae	13	8.23	3.70
6	Moraceae	37	7.71	10.54
7	Mimosaceae	5	3.86	1.42
8	Lamiaceae	9	3.40	2.56
9	Palmaceae	10	2.86	2.85
10	Myrtaceae	31	1.72	8.83
11	Moringaceae	9	1.48	2.56
12	Burseraceae	10	0.95	2.85
13	Rhamnaceae	9	0.46	2.56
14	Betulaceae	4	0.45	1.14
15	Arecaceae	2	0.37	0.57
16	Oxalidaceae	2	0.30	0.57
17	Rutaceae	9	0.25	2.56
18	Dilleniaceae	1	0.08	0.28
19	Apocynaceae	11	0.06	3.13
20	Combretaceae	3	0.05	0.85
21	Lythraceae	2	0.02	0.57
22	Piperaceae	1	0.01	0.28
23	Ebenaceae	1	0.01	0.28
24	Punicaceae	1	0.00	0.28
25	Oleaceae	1	0.00	0.28

Appendix VII. Tabulated data view for carbon estimation at three plantation sites in SAU campus

Plots	Sectors	AGC Mg ha^{-1}	BGC Mg ha^{-1}	Total C Mg ha^{-1}	Average C Mg ha^{-1}	Standard deviation	Standard error
1	**Roadside**	**116.16**	**17.24**	**133.39**	**159.18**	**113.98**	**36.04**
2	Roadside	204.74	31.23	235.97			
3	Roadside	124.17	19.46	143.64			
4	Roadside	108.78	18.66	127.45			
5	Roadside	129.35	21.28	150.63			
6	Roadside	321.59	44.38	365.97			
7	Roadside	62.43	10.50	72.94			
8	Roadside	27.14	5.01	32.15			
9	Roadside	269.68	41.18	310.86			
10	Roadside	15.74	3.08	18.82			
11	**Wood lot**	**192.95**	**30.58**	**223.53**	**206.19**	**111.56**	**42.16**
12	Wood lot	111.36	18.58	129.94			
13	Wood lot	103.83	20.83	124.65			
14	Wood lot	385.86	57.22	443.08			
15	Wood lot	157.60	26.97	184.57			
16	Wood lot	110.94	22.27	133.21			
17	Wood lot	173.12	31.19	204.31			
18	**Homegarden**	**295.69**	**42.45**	**338.14**	**169.37**	**133.92**	**34.57**
19	Homegarden	83.36	15.58	98.93			
20	Homegarden	258.32	44.70	303.02			
21	Homegarden	381.62	54.25	435.87			
22	Homegarden	321.40	48.23	369.63			
23	Homegarden	33.34	6.81	40.15			
24	Homegarden	41.91	8.36	50.27			
25	Homegarden	172.66	29.96	202.61			
26	Homegarden	62.64	11.62	74.26			
27	Homegarden	128.30	22.73	151.02			
28	Homegarden	50.14	9.95	60.09			
29	Homegarden	164.95	25.26	190.22			
30	Homegarden	128.35	22.06	150.41			
31	Homegarden	31.65	7.08	38.73			
32	Homegarden	30.52	6.64	37.16			
	Combined		**Average**	**174.24** (Mg C ha^{-1})			
			Standard deviation	120.81			
			Standard error	21.36			

Appendix VIII. Descriptive statistics of (minimum, maximum, mean and standard error) of basal area, mean DBH, and stem

Plot No.	Plantation sites	No. of Individual	Stem density tree ha^{-1}	Basal m^2 ha^{-1}	mean DBH cm

density of 32 plots at three plantation site in SAU Campus.

Stand characteristics	Minimum	Maximum	Mean	Std. Error
Basal area	5.76	82.78	34.16	3.51
Mean DBH	6.05	42.33	19.83	1.63
Stem density	200	2600	1096.87	121.10

1	Roadside	2	200.00	28.09	42.18
2	Roadside	6	600.00	52.82	31.82
3	Roadside	4	400.00	29.33	29.62
4	Roadside	7	700.00	30.50	23.12
5	Roadside	6	600.00	33.43	26.01
6	Roadside	4	400.00	65.48	42.34
7	Roadside	5	500.00	14.19	15.37
8	Roadside	3	300.00	8.80	19.31
9	Roadside	8	800.00	69.65	31.55
10	Roadside	3	300.00	5.77	15.49
11	Wood lot	6	600.00	40.52	27.68
12	Wood lot	8	800.00	27.78	18.26
13	Wood lot	23	2300.00	36.63	13.75
14	Wood lot	6	600.00	44.82	30.00
15	Wood lot	8	800.00	30.24	21.60
16	Wood lot	23	2300.00	39.13	14.43
17	Wood lot	15	1500.00	48.83	19.61
18	Homegarden	11	1100.00	51.48	18.56
19	Homegarden	13	1300.00	23.51	13.55
20	Homegarden	22	2200.00	55.07	14.34
21	Homegarden	11	1100.00	82.78	22.74
22	Homegarden	12	1200.00	70.74	23.11
23	Homegarden	12	1200.00	11.17	9.63
24	Homegarden	11	1100.00	7.79	7.51
25	Homegarden	13	1300.00	31.61	13.08
26	Homegarden	7	700.00	18.39	17.58
27	Homegarden	17	1700.00	26.68	10.93
28	Homegarden	11	1100.00	17.25	13.24
29	Homegarden	6	600.00	34.08	22.81
30	Homegarden	17	1700.00	29.48	11.69
31	Homegarden	26	2600.00	17.42	7.73
32	Homegarden	25	2500.00	9.78	6.05

Appendix IX. The number of individual, stem density, basal area and mean DBH in 32 plots of 100 m^2 area

Appendix X: Average carbon stock at three plantation sites in SAU campus

Scientific Name	Family	No. of trees	AGC (Mg ha^{-1})	BGC (Mg ha^{-1})	Total carbon (Mg ha^{-1})
Mangifera indica	Anacardiace	58	38.46	5.92	44.38
Swietenia	Meliaceae	78	30.65	5.21	35.86
Polyalthia	Annonaceae	29	15.48	2.65	18.13
Salmalia	Bombacacea	4	15.89	2.12	18.01
Litchi chinensis	Sapindaceae	13	12.48	1.88	14.36
Artocarpus	Moraceae	36	11.40	2.02	13.42
Tectona grandis	Lamiaceae	8	4.96	0.85	5.82
Samanea samane	Mimosaceae	2	3.82	0.58	4.40
Areca catechu	Palmaceae	6	2.67	0.48	3.15
Moringa oleifera	Moringaceae	9	2.19	0.39	2.58
Albizzia lebbeck	Mimosaceae	2	1.84	0.30	2.14
Garuga pinnata	Burseraceae	10	1.38	0.27	1.65
Cocos nucifera	Palmaceae	3	1.09	0.20	1.29
Syzygium	Myrtaceae	10	0.97	0.20	1.18
Syzygium cumini	Myrtaceae	4	0.99	0.17	1.16
Azadirachta indica	Meliaceae	3	0.78	0.15	0.93
Zizyphus jujuba	Rhamnaceae	9	0.66	0.14	0.80
Carpinus	Betulaceae	4	0.65	0.13	0.78
Annona reticulata	Annonaceae	7	0.58	0.12	0.70
Psidium guajava	Myrtaceae	17	0.55	0.12	0.68
Phoenix sylvestris	Palmaceae	1	0.47	0.08	0.55
Averrhoa	Oxalidaceae	2	0.44	0.08	0.52
Roystonea regia	Arecaceae	1	0.35	0.07	0.42
Citrus grandis	Rutaceae	6	0.29	0.06	0.35
Spondias mangifera	Anacardiace	1	0.20	0.04	0.24
Areca triandra	Arecaceae	1	0.20	0.04	0.23
Albizzia procera	Mimosaceae	1	0.17	0.03	0.21
Dillenia indica	Dilleniaceae	1	0.12	0.03	0.15
Vitex negundo	Lamiaceae	1	0.09	0.02	0.11
Carissa carandas	Apocynaceae	11	0.08	0.02	0.10
Feronia limonia	Rutaceae	1	0.05	0.01	0.06
Terminalia chebula	Combretacea	1	0.03	0.01	0.04
Ficus religiosa	Moraceae	1	0.03	0.01	0.03
Terminalia belerica	Combretacea	1	0.02	0.01	0.03
Lawsonia inermis	Lythraceae	2	0.02	0.01	0.03
Terminalia arjuna	Combretacea	1	0.02	0.00	0.02
Citrus limon	Rutaceae	2	0.01	0.00	0.02
Piper cubeba	Piperaceae	1	0.01	0.00	0.01
Diospyros	Ebenaceae	1	0.01	0.00	0.01
Punica granatum	Punicaceae	1	0.01	0.00	0.01
Nyctanthes arbor-	Oleaceae	1	0.00	0.00	0.00
Total					174.24