CARBON STOCK QUANTIFICATION AND TREE DIVERSITY ASSESMENT OF HOMEGARDENS IN RANGPUR DISTRICT

MD. SHAHARIAR JAMAN

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENTAL SCIENCE
SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA-1207

DECEMBER, 2014

DEDICATED

TO

MY BELOVED PARENTS

& SISTER

DEPARTMENT OF
AGROFORESTRY & ENVIRONMENTAL SCIENCE
Sher-e-Bangla Agricultural University (SAU)
Sher-e-Bangla Nagar, Dhaka-1207

CERTIFICATE

*This is to certify that the thesis entitled **"CARBON STOCK QUANTIFICATION AND TREE DIVERSITY ASSESMENT OF HOMEGARDENS IN RANGPUR DISTRICT, BANGLADESH"** 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 (MS) IN AGROFORESTRY & ENVIRONMENTAL SCIENCE**, embodies the results of a piece of bonafide research work carried out by **Md. Shahariar Jaman, Registration no. 07-02287** 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.

Dated: December, 2014
Place: Dhaka, Bangladesh

Prof. Dr. Md. Forhad Hossain
Supervisor
Department of Agroforestry
& Environmental Science
SAU, Dhaka

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ABSTRACT

Homegarden systems are suggested to hold a large potential for carbon (C) sequestration, especially for climate change mitigation and adaptation under changing environment. This is due to their multifunctional ecosystem services while decreasing pressure on natural forests and hence saving and storing carbon. In this research total above and bellow ground carbon stock, tree species diversity and soil organic carbon were quantified in homegarden around four villages of two Upazila of Rangpur district in northern part of Bangladesh. A total 64 homegardens were sampled on size, diameter at breast height of trees, tree height and tree species diversity. Using allometric equations, assuming C as 50% of biomass a total mean above and bellow ground biomass carbon stocks (AGB+BGB) was found 53.53Mg ha^{-1}. Mean carbon stock per unit area was higher in small homegarden (69.15 Mg ha^{-1}) compared to medium (47.96 Mg ha^{-1}) and large (39.93 Mg ha^{-1}) homegarden. In total 1671 trees were sampled and 32 different tree species were identified and recorded. The Shannon Wiener index was used to evaluate the tree diversity per homegarden and it ranged from 1.00 to 2.2 with a mean value of 1.64. For determination of soil organic carbon (SOC), soil sample were collected from two depths (5-10 cm and 20-25cm) at two different sampling sites of sampled homegardens. The average value of SOC was found 49.24 Mg ha^{-1} where small size homegarden had high tree density contain highest amount of SOC (63.62 Mg ha^{-1}) per unit area compared to medium (42.80 Mg ha^{-1}) and large (38.50 Mg ha^{-1}) size homegardens. These results imply that homegarden can serve as an important ecological tool in terms of carbon sequestration, conservation of tree species diversity and storage of soil organic carbon. However specific homegarden management plan for increased carbon sequestration potentiality and conservation of homegarden species diversity through scientific management should be encouraged for further investigation in this region. This result also useful for whether homegarden should be considered to be included in the UN-REDD+ National Program as an activity to enhance natural forest cover within Bangladesh.

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LIST OF ABBREVIATION AND ACRONYMS

ρ	:	**Wood specific gravity (g/cm³)**
AGB	:	Above-ground biomass
BGB	:	Below-ground biomass
C	:	Carbon
CO_2	:	Carbon dioxide
O_2	:	Oxygen
DBH	:	Stem diameter at breast height (over bark)
GBH	:	Girth breast height
e.g.	:	For example
GHG	:	Green house gas
GPS	:	Global Positioning System
ha	:	Hectare
IPCC	:	Intergovernmental Panel on Climate Change
Mg	:	Mega gram = 10^6 gram
SWI	:	Shannon-Wiener Index
et al.	:	And others
^0C	:	Degree Celsius
cm	:	Centimeter
m^2	:	Square meter
%	:	Percent
t	:	Ton
AGC	:	Above ground carbon
BGC	:	Below ground carbon
UNFCC	:	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

INTRODUCTION

A homegarden can be defined as an intensive land use system that combine diverse farming components such as annual and perennial crops, domestic animals, occasionally fish that are provide environmental services, employment opportunities and household needs (Weerahewa *et al*., 2012). Homegarden also referred as a household or homestead farm, multi strata tree garden, analogue forest, compound farm, village forest garden and household garden (Mattson *et al*., 2013). Rapid deforestration and heavy industrialization increase the amount of greenhouse gas in the atmosphere thus necessary forest management has been focused on altering deforestration and forest degradation targeting to get benefit from reducing emission from deforestration and forest degradation (REDD+) program in response to climate change. Homegarden has its immense important in climate change mitigation and green house gas minimization in the atmosphere. Multiple arrangement of plant and relatively high species diversity prevent environmental degradation (Nair, 1993), provide economic benefits and maintain a sound and sustainable ecology (Mohan, 2004). It is well established that maintenance of ecosystem and conservation of biodiversity is necessary for welfare of the human being (Beaumont *et al*., 2011). Almost 75% of terrestrial biomes have altered its characteristics due to various anthropogenic activities. Fragmentation of land, overexploitation and habitat degradation have a great contribution to the loss of biodiversity around the world. Homegarden and agroforestry practice can in general contribute to climate change mitigation through enhance carbon sequestration (Verchot *et al*., 2007). Most of the agroforestry systems (e.g. multipurpose trees, silvopasture) have a great potentiality for carbon sequestration and homegarden are unique in this respect (Kumar, 2011).

With about 158 million people on 14.7 million ha Bangladesh is a densely populated and a developing country of the world and the developing countries are mainly suffer from negative impact of global warming (ICRAF, 2000).Under UNFCCC, countries are negotiating REDD (reducing green house gases from deforestration and forest degradation) as a key that would provide incentive for land based forest mitigation practices and REDD+ which main aim is conservation of forest, sustainable management of forestland and increase forest carbon stock (FAO, 2008). In Bangladesh homegarden represent a well established land use system where natural forest cover less than 10%;

homestead garden which are maintained by at least 20 million household and represent one possible strategy for conservation of biodiversity (M.E. Kabir, 2008). Not only that homegarden also provide some potential ecosystem service such as carbon sequestration, soil conservation, preserving of water and air quality (Thevathasan and Gordon, 2004; Josh, 2009). Natural forest of Bangladesh are shrinking at an alarming rate because of unprecedented anthropogenic pressure. For this reason to meet future challenges of land and water scarcity, to ensure food security as a result to adverse effects of climate change, to conserve biodiversity and to provide daily needs of rural people homegarden could be the prime example in all this respect.

However there is still lack of quantitative data and very little informations available on homegarden in respect of their carbon content, carbon sequestration potential and species diversity specially in northern homegarden in Bangladesh. Although carbon sequestration potential in homegarden has been subject of scientific interest (Srivastava and Vellend, 2005). Therefore, this study focused on assessing the amount of biomass carbon (Above and Below ground), soil organic carbon (SOC) content and the pattern of tree diversity around the four selected village homegardens in Rangpur district.

OBJECTIVES:

1. To determine the amount of biomass carbon stock (AGB and BGB) in homegarden around four selected villages of Rangpur district, Bangladesh;
2. To asses the pattern of tree species diversity in homegarden; and
3. To explore a relationship within biomass carbon, tree species diversity and soil organic carbon (SOC) in homegarden.

CHAPTER II

REVIEW OF LITERATURE

2.1 General concept of homegarden

Nair and Sreedharan (1986) has stated that the importance of homegardens is much vital as its acts mainly subsistence level existence of the farmers in the tropics.

Fernandes and Nair (1986) stated that because of multipurpose stucture and composition of homegarden it fulfill most of the fundamental needs of the local people and their high species diversity act as a strong protector from environmental deterioration so homegardens are considered as a economically efficient, ecologically sound and biologically sustainable agroforestry systems.

Dash and Misra (2001) and Ali (2005) has stated that homegardens throughout the tropics are operational farm units that occupy a portion of homestead land on which particularly women and children engage as family labor and considered sustain and high agricultural production.

Das and Das (2005) stated that homegardens are traditional agroforestry system with complex structure and multiple functions and the homegardens are the sites of conservation of a large diversity of plant both wild and domesticated, because of their uses to the households.

2.2 Homegarden in Bangladesh

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

Millat-e-Mustafet *et al*., (2000) stated that in Bangladeshi homegardens mainly multipurpose tree species tree species are grown. The most of the tree species are grown in backyard, at the pond side and around the cow shed for the provision of fruit of food, fuel wood or timber and fodder both for domestic use as well as for cash.

Khan (2001) stated that homegardens are called a well established land use system in Bangladesh

Khan (2001) stated that most of homegardens of Bangladesh are rectangular in shape built on a raise land above the water level during the annual floods and usually fenced by trees and shrubs.

M. Skutsch and P. E.Van laake (2008) reported that Homestead gardens represent a well established land use system in Bangladesh where natural forest cover less than 10%; homegardens which are maintained by at least 20 million households, represent a possible strategy for biodiversity conservation. .

Zaman *et al.,* (2010) has stated that a homestead garden in Bangladesh is an integrated production system and a stable ecosystem that maintain the diversity of life as well as the biological wealth.

2.3 Species composition of homegarden

Fernandes and Nair (1986) stated that choice of species composition varies in different homegardens according to the choice of the homegardener but there is remarkable similarities also present with respect of species composition among different homegardens in various places of the same geographical location.

Fernandes and Nair (1986) reported that the magnitude and rate of output of products as well as the ease and rhythm of maintaince of homegarden system depend upon their species composition.

Abedin and Quddus (1990) reported that in homegardens of Rangpur district neem is most dominant species and it was about (35%) of total tree species on the other hand at Rajshahi region it was (33%)

Vankatash *et al.,* (2003) found that in tropical homegardens species diversity and density is generally very high. Homegardens of Andaman Nicobor island reached high level of development in terms of plant diversity and multistory canopy structure.

Ahmed and Rahman (2004), Kabir (2007) has stated that plant composition of homegardens is greatly influenced by the specific needs, testes, knowledge, skills, ethnicity, culture and experience of gardeners.

Kumar and Nair (2004) and Kabir (2007) studied that species composition of the traditional homegardens influenced by labour availability, access to water and nutrients, economic development, production intensity, market access, agricultural environment and traditional social organizations.

Kirbby and Potvin (2007) suggested that a complete utilization of resources takes place in a system when more tree species are include in that system the system become more productive.

Kabir and Webb (2008) has reported that homegardens are act as a complex resource with wide variation in composition and represent high plant species diversity as in other tropical and subtropical region of the world.

Shobuj *et al.,* (2010) observed that a total of 32 different tree species recorded in the homestead area of Nator district of which Jackfruit, Eucalyptus, Ipil-ipil, Mango, Neem and Mehagani were dominant species. On an average 21.25 tree species were found in homestead.

Mahmud (2010) studied on species composition and its diversity in the homestead of kolaroa and tala upazilla of Shatkhira district and found that totalof 69 different tree species was recorded in the homestead of the study area of which Akashmoni, Mahogani, Jackfruit, Coconut, and Papaya were dominant species.

Jahan (2010) identified that a total of 50 different tree spscies recorded of which Jackfruit, Betelnut, Raintree, Mango, Mahogani and Banana were dominant in homesteads of Karimgonj upazilla, Kishorgonj district.

Yasmin *et al.,* (2010) observed that a total of 68 different tree species were recorded of which Akshmoni, Jackfriut, Coconut, Eucalyptus, Mango, Neem were dominant in the homegardens, cropland, pond embankment of Madhupur Upazilla, Tangail district . On an average 22.75 and 4 tree Species were found in the homegarden and cropland respectively.

Belali (2011) studied that in homegarden of Sonargaon upazilla, Narayangonj district there are 78 different tree species, 11 crop species were found.

Chandra (2011) studied on species richness and tree diversity in the homegarden of Jamalpur district and found a total of 75 different tree species where Jackfruit, Mango, Akashmoni and Guava were dominant.

Bishwajit roy *et al.*, (2013) identified 62 plant species belongings to 36 families and 5 threatened species where majority of the species were used as a fruit and food (45%) and timber only (29%) at Kishorgonj district in northern Bangladesh.

M.A. Mannan *et al*., (2014) has studied tree diversity in haor area of Syllet division of Bangladesh and reported Higher diversity (0.967) found at Ajmirigonj union followed by sibpasha (0.961) and the lowest was found in Kakailchey union (0.952).

M. A. Mannan *et al.*, (2014) has studied that in Ajmiriganj upazila of Hobigonj district in Bangladesh coconut was found in 80.67% homesteads followed by mango (79.33%), guava (63.67%), papaya (51.67%) and the remaining fruits are present in the less than 50% homesteads.

C. R. Sarker *et al.*, (2014) has been reported that at coastal area homestead gardens of Potuakhali district of Bangladesh species diversity was higher for some major fruits: mango (0.923),banana (improved) (0.989), pineapple (0.987), coconut (0.901) and papaya (0.921). But of the minor fruits, velvet apple was highest (0.994) while wax jambu was least (0.517).

2.4 Carbon sequestration potentiality in homegarden

Houghton *et al*., (1993) has reported that in sub Saharan African homegardens C sequestration potential in aboveground biomass through agroforestry interventions of 59 Mg C ha^{-1} (henry).

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.

Dixon *et al*., (1994), Dixon (1995), Albrecht and Kandji (2003) has reported that agroecosystem play a central role in global carbon cycle and contain approximately 12% of the world terrestrial carbon.

Kumar *et al*., (1994) Homegarden size and survival strategies of the gardeners are other determinants of biomass and above ground carbon pools

Woomer *et al*., (1997) reported that in sub Saharan African homegardens C sequestration potential 66 Mg C ha^{-1} both above- and belowground through nutrient recapitalization and agroforestry practices.(henry)

UNFCCC (2001) reported that trees in the forest as well as forest products are primary carbon sequestration mechanism because of approximately 50% of wood consists of carbon.

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

J. M. Roshetko *et al*., (2002) reported that tree density varied from 13-59 trees sampled per homegardens and contained 260- 1180 Mg ha^{-1} in Indonesian homegardes.

J.M. Roshetko *et al*., (2002) has reported that in term of above ground biomass homegardens contained significantly more carbon stock and it is approximately 34.7 Mg ha^{-1} which is 58 times more than imperata- cassava agroforest system and 1.5 times greater young rubber agroforestry system.

Albrecht and Kandij (2003) has stated that plant stored carbon for long as they live in term of live biomass and once they die the biomass become a part of food chain and eventually enters in the soil as soil carbon. If the biomass is incinerated, the carbon is reemitted into the atmosphere and is free to move in the carbon cycle.

Montagnini and Nair (2004); Henry *et al.,* (2009) studied that difference in carbon stock is a result of difference in tree diversity, management practices, homegarden age, site characteristics and composition differences

According to IPCC (2005) carbon sequestration can be done by terrestrial sequestration or vegetative sequestration, geological sequestration and oceanic sequestration and the terrestrially carbon carbon is stored in vegetation and in the soil.

It has been reported by Kumar *et al*., (2005); Kumar (2008) that coconut palm constituted the predominant tree component of the homegardens and bamboos were present 2.23-7.4% of the homegardens

According to UNFCCC (2007) Carbon sequestration is a process of removing carbon from the atmosphere and depositing it in a reservoir.

Verchot *et al.,* (2007) Stated that contribution to climate change mitigation through enhance carbon sequestration is one of the major function of homegardens.

Premakanta *et al*., (2009) has been reported that homegardens in Nuwara Eliya district of Sri Lanka contain 77 Mg C ha^{-1}.

It has been reported by Dissanayake (2009) that the average aboveground carbon stocks of Sri Lankan homegarden were 90 Mg ha^{-1} and 104 Mg ha^{-1} in Kandy and Matale district respectively.

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

FAO (2010) has reported that around 13 million hectares of forest are converted to other uses or lost through natural causes each year between 2000-2010 and the world has estimated 850 million hectares of degraded forests which could potentially be restored and rehabilitated to bring back lost biodiversity and ecosystem services and at the same tome contribute to climate change mitigation and adaptation.

Kumar (2011) has found that above ground carbon stocks of kerala homegardens in India ranging from 16 to 36 Mg ha^{-1}respectively with standard error values in range of 0.74-2.18.

Mattsson *et al*., (2012) estimated that the above ground carbon(AGB) stocks in natural forests range from 22 to 181 Mg C ha^{-1}in six natural forest type and with a tree density ranging from 337-1136 trees ha^{-1} for the same types of forest.

R A Mandal *et al*., (2013) reported that the estimated carbon stocks at Banke-Maraha, Tuteshwarnath, and Gadhanta-Bardibas CFMs, are 197.10, 222.58, and 274.66 Mg ha^{-1} respectively in Terai, Nepal.

Mattsson *et al*., (2014) conducted a research in dry zone Moneragala district of Sri Lanka and it has been reported that the mean above ground biomass stock 13 mega gram (Mg C ha^{-1}) with a large range among homegardens (1-56 Mg C ha^{-1}) due to a variation of tree diversity and composition between individual homegardens.

Mattsson *et al*., (2014) has been investigated that mean above ground carbon stocks of dry zone homegardens in Sri Lanka is Higher in small homegardens (0.2 ha, 26 Mg C ha^{-1}, n=11) compared to medium (0.4-0.8 ha, 9Mg C ha^{-1}, n= 27) and Large (1.0-1.2 ha, 8Mg C ha^{-1}, n=7) size homegardens respectively.

2.5 Soil organic carbon (SOC) and tree diversity

Tilman *et al*., (1997) reported that high species assemblages of homegardens is likely to harbor species with strong resource utilization characteristics compared to less species intensive systems and promote greater net primary production which in turn contribute to higher carbon sequestration.

Cairns *et al*., (1997), reported that the average stocks of carbon in root biomass in the order of 3.6, 1.0, 1.2 Mg C ha^{-1} in homegardens, food crop fields and woodlots respectively.

Drescher (1998) and Karyono (1990) has been investigated that the Mean Shannon Wiener diversity indices in tropical homegardens vary broadly from 0.93 in rural Zambia and to almost 3.0 in weat Java, Indinesia.

Kumar *et al*., (1998) and Nair *et al*., (2009) Stated that the size of the homegardens is the major factors affecting C stocks per unit area and it decreased in order of Small > medium > large .

It has been reported by Gajaseni and Gajaseni (1999) that in Thai Homegardens Shannon diversity index value was found 1.9-2.7 which are comparable to the range of values 1.45-3.14 of the present study.

Hulscher and Durst (2000); Kumar and Nair (2004) has stated that The resemblance of homegardens to forests incur that they can store carbon and provide several benefits to people through offering economic stability by providing fuel wood, fodder, timber, food and crops.

Sampson and Scholes (2000) stated that conversion of natural forest and grasslands to permanent agriculture causes 20-50% loss of soil carbon.
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.

De Costa *et al.,* (2006); Pushpokumara *et al*., (2010).Reported that homegardens offer greater economic stability to farmers and provide significant amount (30-50%) of household income.

IPCC (2007) climate change mitigation is an anthropogenic intervention to reduce the sources or enhance the sink of green house gases and adaptation as the adjustment in natural or human system to anew or changing environment.

Tittonell (2007), reported that the estimated soil C stocks ranging between 24 and 56 Mg C $ha^{-1}$for the upper 0.3 m of the soil in western Kenya small farming system . Thus, there is much more to gain in terms of C sequestration in the belowground C components. (henry).

Saha (2008) discovered that soil carbon sequestration potential of homegardens is higher than that of agricultural systems rice-paddy and comparable to that of single species tree-crop system of rubber and coconut.

Senanayake *et al*., (2009) has reported that homegardens of Pethiyagoda village in Sri Lanka the Shannon Wiener diversity index has found (SWI: 1.99 ; n=59 in wet zone) and in the Meegahakiula area (SWI:1.55-1.77 ; intermediate zone).

Shubhrajit K. Saha *et al*.,(2009) has reported that Smaller homegardens has higher tree and plant species density contain contained higher soil organic carbon (SOC) per unit area that is 119.3 Mg $ha^{-1}$and large homegardens with lower tree species density contain contained 7-14% less soil organic carbon (SOC) in the homegardes of Kerala, India.

Shubhrajit K. Saha *et al*., (2009) studied that within one meter soil profile soil organic carbon (SOC) content ranged from 101.5-127.4 Mg ha^{-1} at homegarden of Kerala, India.

P K Nair and Vimala D. Nair (2009) has stated that homegardens with high species richness contained highest soil organic carbon (SOC) storage which 127.4 Mg ha^{-1} and medium and low species richness homegardens contained 16-17% lower soil organic carbon(SOC) respectively.

Saha *et al*., (2009) reported that soil organic carbon (SOC) stock in the homegardens of Thrissur, Kerala in small homegardens (0.4 ha) with higher species density and richness and diversity compared with large (> 0.4 ha) homegardens had higher (SOC) per unit volume of soil.

Bodansky (2010) has studied that subsistence farming is responsible for 48% of deforestration ; commercial agriculture is responsible for 32% of deforestration; logging is responsible for 14% of deforestration and fuel wood removal make up 5% of deforestration.

B. Mohan Kumar (2010) studied that Simpson's diversity index for woody taxa were highest in small homegardes (0.64) and the corresponding values for medium and large homegardens were 0.41 and 0.46 respectively in Kerala, India.

APN (2012) has found that for tree diversity determination in the homegardens of Keeriyagaswewa village, Sri Lanka Shannon Wiener diversity index (SWI) is 2.13 that higher than the mean SWI of 2.05.

APN (2012) reported that homegardens of Siwalakulama village in Sri Lanka the mean Shannon Wiener index (SWI) has found 1.77 that is slightly lower than mean Shannon Wiener index (SWI) 2.05.

Homegardes could play a vital role to reduction of pressure on natural forest stated by Weerahewa *et al.,* (2012).

R.A. Mandal *et al*., (2013) has reported that in terai area, Nepal the values of Shannon-Wiener Biodiversity Index ranged 2.21–2.33.

Bishwajit roy *et al*., (2013) reported that the Shannon -winner diversity has found (3.39) for trees and (2.36) for shrubs in the urban homestead area and highest tree and shrubs diversity observed (3.5) and (2.48) respectively in rural homestead area in kishorgonj district of Bangladesh.

2.6 Climate change, Carbon dioxide and Trees

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 forest 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.
Waston *et al*., (2000) studied that the deforestation and the burning of forests release CO_2 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.

Dash S.S and Misra M.K. (2001) Studies of hill agro-ecosystems of three tribal villages on the Eastern Ghat of Orissa, India. Agriculture, Ecosystem and Environment 86: 287-302

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.

Pandey (2002) reported that forests sequester 1Mg C ha^{-1} annually through the combined effect of reforestation, regeneration and enhanced growth of existing forests.

The UNFAO (2003) estimated that since 1980, 25% of all carbon dioxide emissions associated with human activities was a result of tropical deforestation.

S P Sing *et al*., (2005) stated that approximately 8000 tree species or 9% of the total number of tree species world wide are currently under threat or extinction because of forest decline.

Ali M.S. and Masud K.M., (2005) Stated that homestead biodiversity in the offshore island of Bangladesh. Research Journal of Agriculture and Biological Science I (3): 246-253.

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.

IPCC (2009) stated that about 18% atmospheric CO_2 emission has reduced by halting deforestration.

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

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CHAPTER III

MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

The study was conducted at four villages of two upazilas (administrative unite) in Rangpur district. Rangpur district is located in the northern part of Bangladesh. The total area of the district is 2370.45 sq km, located in between 25°18' and 25°57' N latitudes and in between 88°56' and 89°32' E longitudes. The name of four studied villages are Manoharpur, Radhakrishnopur, Basantopur and Nandanpur. Among these the villages Manoharpur, Radhakrishnopur are situated in Rangpur sadar upazila and Basantopur and Nandanpur are situated in Badargonj upazila. Rangpur sadar upazila occupies an area of 330.33 km^2 and located between 25°39' and 25°50' N latitudes and in between 89°05' and 89°20' E longitudes. On the other hand Badargonj upazila occupies an area of 301.29 km^2 and located between 25°32' and 25°46' N latitudes and 88°56' and 89°10' E longitudes.

3.1.2 Climatic and Soil

Rangpur has tropical wet and dry climate. The climate is generally marked with monsoon, high temperature, considerable humidity and heavy rainfall. The hot season commences early in April and continues till July. The maximum mean temperature observed is about 32 to 36 °C during the months of May, June, July and August and the minimum temperature recorded in January is about 7 to 16 °C (BBS, 2012). The highest rainfall observed during the months of monsoon and it is 1378.6 mm. The average annual rainfall in the district is about 1587 mm (BMD, 2014). Soil composition of the study area mainly alluvial soil (80%) and the remaining 20% is barind soil (SRDI, 2014).

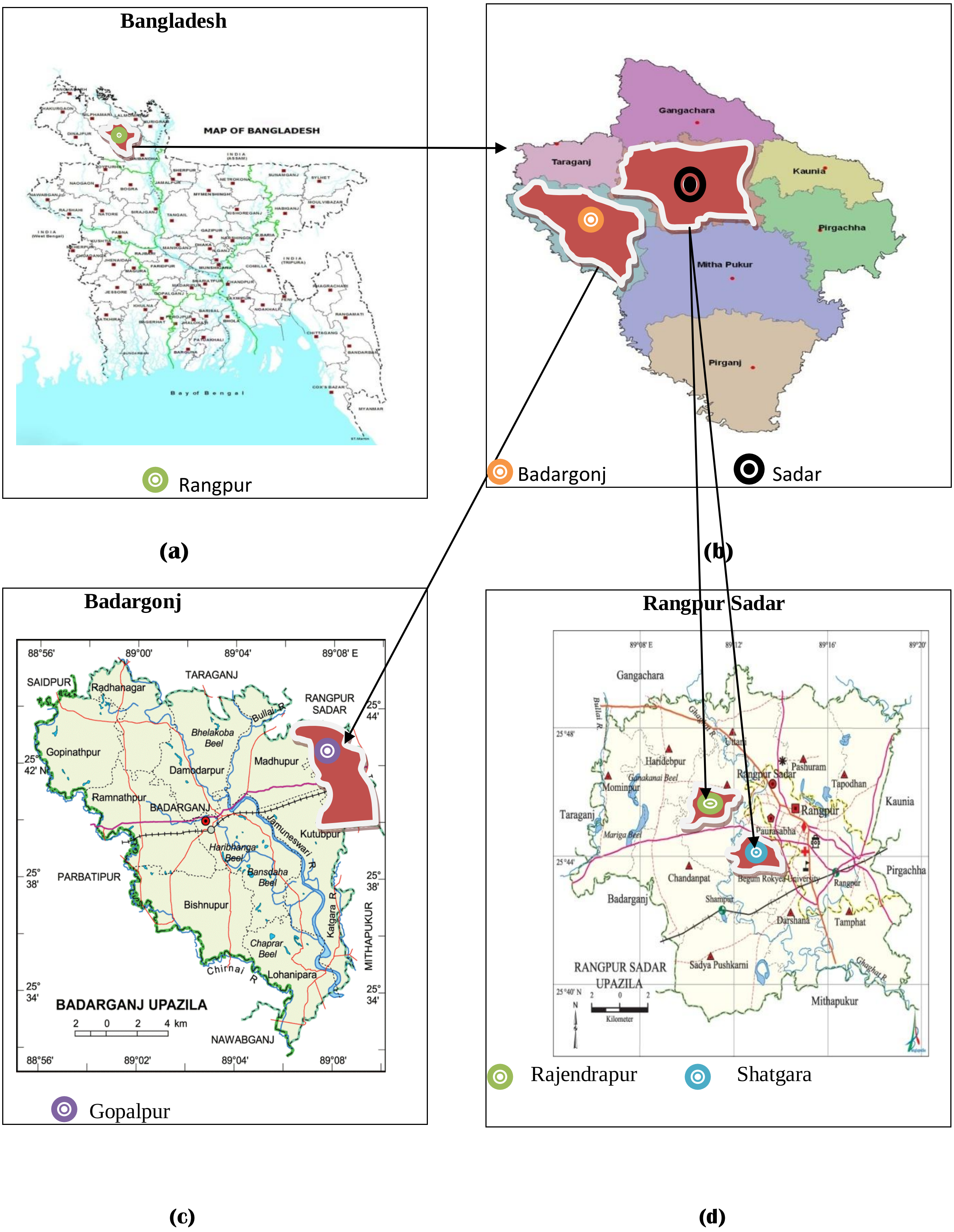

Plate 1: Stepwise location of the study area where (a) Bangladesh (b) Rangpur district (c) Badargonj Upazila (d) Rangpur Sadar Upazila.

3.1.3 Demography

Rangpur sadar upazila has a total population of about 7,18,209 of which 3,66,768 male and 3,51,415 are females. The annual population growth rate is 1.78% and literacy rate is about 61% (Male 43.9% and Female 30.1%) (Banglapedia, 2015). The highest literacy rate is 81.7% in word number 5 (Town area) of Rangpur Sadar upazila where nine residential communities are occupied and lowest in Mominpur union 39.3% (BBS, 2011). Badargonj upazila has a total population of 2,87,746 of which 1,44,254 males and 1,43,492 females. The annual population growth rate is 1.09%, and literacy rate is 43% (Male 31.1% and Female 16.2%) (Banglapedia, 2015). The highest literacy rate is 67.2% in word number 2 of Badargonj bazaar community and lowest in Damudarpur union 35.3% (BBS, 2011).

3.1.4 Socioeconomic feature

The number of households enumerated in the census for Rangpur sadar upazila is 1,65,017. The average household size (General) for the upazila is 4.2 persons. For the rural area the size is slightly lower i.e., 4.1 persons and for urban area the size is slightly higher i.e., 4.3 persons. In the Sadar upazila there are only 10.1% general household live in pucca (Brick constructed) house, 21.5% in semi-pucca house and 66.0% in kancha house (Made by bamboo and wood only) (Population and Housing census, 2011; BBS, 2011). All the 11 unions of the upazila have brought under the Rural Electrification Program. Communication facilities are more or less well developed where brick constructed roads are 191 km, semi pucca are 15 km and mud road are 580 km (Questionnaire survey, 2015) (Roads & Highway Dept, 2014). In the Sadar upazila 24.71% people depends on Agriculture as their main source of household income, while the agricultural labourer is 19.39%, wage labourer is 4.81%, commerce is 17.91%, service is 14.94%, transport is 5.93% and others are 12.31% (Bnaglapedia, 2015).

There are 71,982 households in Badargonj upazila. The average household size (General) is 4.0 persons, for both rural and urban area the size is the same i.e. 4.0. In this upazila 2.5% general household live in pucca house, (Brick constructed), 17.4% in semi-pucca house, 76.4% in kancha (Made by bamboo and wood only) houses (Population and Housing census, 2011; BBS, 2011). All the 10 unions of this upazila have brought under the Rural Electrification Program. There are 13 km roads are brick constructed , semi pucca are 21 km and mud road are 866 km; waterways are 16 nautical miles and Railways are 16.6 km (Questionnaire survey, 2015) (Roads & Highway Dept, 2014). Almost 43.49% people depends on agriculture, while 32.42% is agricultural labourer, 2.16% is wage labourer, 10.02% is commerce, 3.76% is service, and others are 8.15% (Bnaglapedia , 2015).

3.2 Sampling Procedure

This study was conducted in Rangpur district that was purposively selected. Rangpur district is consisting of 8 upazilas. Out of 8 upazilas, 2 upazilas namely Rangpur Sadar and Badargonj was randomly selected. Rangpur Sadar and Badargonj Upazila has 12 unions (Lowest unit of local government) and 10 unions respectively. Among 12 unions of Sadar Upazila, 2 unions namely Satgara and Rajendropur were randomely selected and out of 10 unions of Badargonj Upazila, one union named Gopalpur was randomly selected. Again from Satgara union of sadar upazila, one village named Manoharpur and from Rajendropur union, one village named Radhakrisnopur was randomly selected. In the Gopalpur union of Badargonj upazila two villages named Basantopur and Nandanpur were randomly selected. There are total 1244 of different farm families in these selected villages. Out of 1244 farm families, a sample of 15%, i.e., 186 household were selected by stratified random sampling method. Then finally 64 representative farm families were selected for questionnaire survey, carbon stocks measurement and tree diversity assessment from each species rich homegardens. Final selection of homegarden has been done by using (Yamane, 1967) formula:

$$n = N / \{1 + N (e)^2\}$$

Where,

n= Sampling size

N= Population

e= Error of precision.

Table 1: Distribution of population and sample size in four selected villages

Upazila	Union	Village	No. of total households	No. of households primary selected	No. of households finally selected for data collection
Rangpur Sadar	Satgara	Manoharpur	120	18	6
	Rajendrapur	Radhakrishnopur	231	34	12
Badargonj	Gopalpur	Basantopur	405	61	21
		Nandanpur	488	73	25
Total	3	4	1244	186	64

3.2.1 Household characteristics data

Initially, a questionnaire survey was conducted in 64 households in each villages. Field data collection was made by physical measurement directly from the study sites. Household biophysical data (distance in kilometer from the household to the nearest market and urban center) and demographic data (household age, head age, education, family size) were recorded with the help of family members. Household socioeconomic data such as homestead size (dwelling + homegarden), and agricultural land holding, annual income from homegarden, income from agricultural land were also recorded. Homegarden and agricultural land holdings size were recorded in decimal which further subsequently converted into hectare.

3.2.2 Homegarden plot survey

All perennial trees and palms with a diameter at breast height of ≥ 2 cm were identified and recorded to species level or by local name and botanical name. For individual tree species DBH were measured by using DBH tape and height of palm species were measured by 50 meter long measuring tape. For comparison the homegardens were categorized into three size group namely small (0.01-0.03 ha), medium (0.03-0.05 ha) and large (> 0.05 ha). The allometric equation developed by Chave *et al*., (2005) was applied for individual trees for determining the tree biomass. Wood density for every species was collected from secondary data such as FAO list of wood densities for tree species from Tropical Asia and Zanne *et al*., 2009, global wood density database. No climbers were counted due to difficulty in differentiating stems.

3.3 Ecological indices

Tree species diversity of the homegarden was estimated by the Shannon Wiener diversity Index (SWI). Species density (number of species per unit area) was measured by dividing the total number of plant species of an homegarden by the total area of that homegarden.

3.3.1 Tree diversity measurement

Tree species diversity was assessed within the fixed boundaries of the sample homegardens acquiring common names that subsequently translated into botanical names. An index was setup based on the number of species and their frequency in homegardens. For this study Shannon-Wiener diversity index (SWI) was used due to its suitability for evaluating diversity of tree species. The Shannon–Wiener diversity characterizes the proportion of species abundance in the population being at maximum when all species are equally abundant and the lowest when the sample contained one species. The proportion of species (i) relative to total number of species (Pi) was calculated and then multiplied by the natural logarithm of the same proportion (Ln Pi). The resulting product is summed across species, and multiplied by -1.

$$\mathbf{H} = \sum_{i=1}^{n} Pi \text{ Ln } Pi$$

Where,
∑=
Summation.
$\mathbf{p}_i$ = Proportion of total sample represented by species *i*. Total no. of individual species *i* , divided by total no. of plant species found in a sample community.
H = Shannon index
n = No. of species

Plate 2 : Photograph showing (a) homegarden of Radhakrisnopur village (b) homegarden Basantopur village (c) homegarden of Manahorpur village and (d) homegarden of Nandanpur village.

3.4 Soil sampling and analysis

Soil samples were collected from 64 homegardens of the 4 selected villages. In each homegarden (plot), two sampling sites were selected randomly and from each sites soil were collected at two depths 5-10 and 20-25 cm. A composite sample for each depth interval was prepared by mixing soil from two sampling sites resulting one sample per depth level from each study plots. There were total 128 soil samples (4villages × 16 replication × 2 depths) from 4 villages. Bulk density of sampled soil was measured. Carbon content in the soil was analyzed by Walkley-Black method. Soil analysis has been done in Soil Resource Development Institute (SRDI), Bangladesh.

Bulk density (BD g/cc) = (Oven dry weight of soil)/ (volume of soil in the core)

Organic carbon content percentages were calculated by using following formula:

$$\% \text{ OC} = \frac{(B-T) \times N \times 0.003 \times 1.3 \times 100}{ODW}$$

Where,

B = $FeS0_4 .7H_2O$ Solution required for blank titration

T = Volume of $FeS0_4 .7H_2O$ solution required for actual titration

N = Strength of $FeS0_4 .7H_2O$ or Normality

1.3 = Convention recovery fraction

Soil organic carbon (SOC) was measured by Walkly - Black (1934) formula:

SOC = Depth (cm) × Bulk density (g/cc) × Organic carbon (%)

Plate 3: Photograph shows (e) measurement of GBH (f) inserting auger into the soil and (g) Carefully taken the soil sample.

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3.5 Allometric equation for above and bellow ground biomass:

3.5.1 Tree biomass

Biomass equations relate to diameter at breast height (dbh) of tree biomass and biomass may differ among species. It is because trees in similar functional group can differ greatly in their growth forms between different geographical areas (Pearson *et al.*, 2007). Considering these factors Chave *et al.*, 2005 developed allometric equations for tropical trees that can be used for wide graphical and diameter range.

3.5.2 Above ground biomass:

To measure the above ground biomass, following equation has been used:

$$AGB = \rho\times \exp(-1.499+2.148\times\ln(DBH) + 0.207\times(\ln(DBH))^2 - 0.0281(\ln(DBH))^3$$

(Chave *et al.*, 2005)

ρ = Wood density (g cm^{-3}): - 1.499, 2.148……………………………………0.207 and 0.0281= Constant.

3.5.3 Bellow ground biomass:

To determine the below ground biomass and carbon, the model equation 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 = Aboveground biomass, -1.0587 and 0.8836 are constant.

3.5.3 Palm biomass

Palm species such as *Cocos nucifera, Areca catechu, Phoenix silvestris* are most common species found in the selected homegardens in Rangpur distict. These are the vital homegarden species in the homegardens. The following equation for palms was used for above ground biomass calculation.

Above ground biomass calculation for palm:

$AGB = 6.666 + 12.826 \times (HT^{0.5}) \times \ln (HT)$. (Brown *et al*., 2001), (Delaney *et al.*, 1999).

Where,

HT = Height of the trunk in meters (for palms this is the main stem, excluding the fronds)

ln = Natural logarithm.

3.5.4 Conversion of biomass to carbon

After estimating the biomass from allometric relationship, it was multiplied by wood carbon content (50%). Almost all carbon measurement projects in the tropical forest assume all tissues (i.e. wood, leaves and roots) consist of 50% carbon on a dry mass basis (Chave *et al*., 2005; Pricard 2000; Smith and Heath, 2002).

Carbon (Mg) = Biomass estimated by allometric equation × Wood carbon content % = Biomass estimated by allometric equation × 0.5

3.6 Data Analysis

Data collected from questionnaire survey were analysed by SPSS-20 software and other field data were processed and analysed using MS excel 2007 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 different variables.

CHAPTER IV

RESULTS

4.1 Above ground and bellow ground biomass carbon (AGB and BGB)

Tree species of the selected households were measured based on dbh, height etc and computed in the selected equations and found significant differences. The above and bellow ground biomass (AGB+ BGB) carbon for the 64 sampled homegarden ranged from 6.25 to 193.83 Mg C ha^{-1}. Mean carbon stocks per unit area was higher in small homegarden (69.15 Mg C ha^{-1}) where area of the small homegarden was (0.02-0.03 ha.) and total number of small homegarden was n=24 compared to medium (47.96 Mg C ha^{-1} ., 0.03-0.05 ha., n=21) and large (39.93 Mg C ha^{-1}., >0.05 ha., n=19) size homegarden (**Table 2)**. The variation in carbon content of individual homegarden may be because of differences in garden composition, site characteristics, and holding sizes in different physiographic zones such as midlands, highlands and river basin area of Rangpur district. Size of gardens was a major factor affecting C stocks per unit area and it decreased in the order of small > medium > large (**Figure 1)**.

Table 2. Carbon stocks at various homegardens in Rangpur district

Home garden category	Number of homegarden	Carbon Stock Range (Mg ha^{-1})		Mean ± CI
		Highest	Lowest	
Small	24	193.83	15.48	69.15 ± 21.3
Medium	21	143.97	6.58	47.96 ± 15.8
Large	19	84.11	6.25	39.93 ± 11.2

* CI = 95% confidence interval

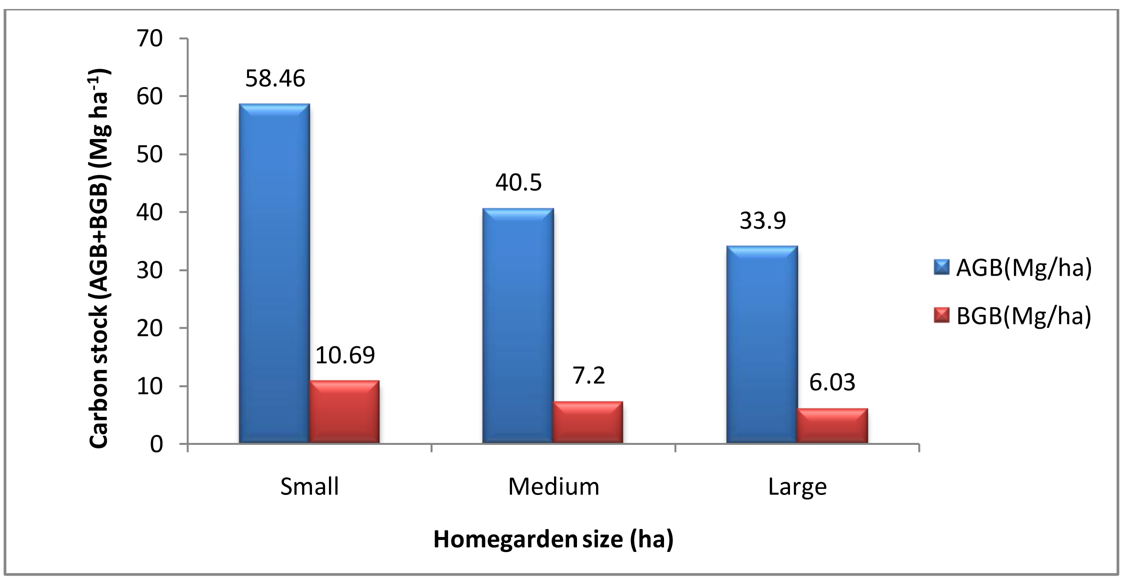

Figure 1. Above and bellow ground carbon stocks at various homegarden in Rangpur district

4.2 Relationship between stand structure of trees and carbon stocks

A regression analysis was used to determine the relationship between mean DBH, basal area and stem density with biomass carbon.

4.2.1 Mean DBH

The relationship between mean DBH and carbon stock were estimated and presented in **Figure 2**. The estimated relationships were: Y=4.400x + 7.196 (R^2 = 0.182), where R^2 value was positive. This figure also indicates that mean DBH of tree species are not significantly correlated with carbon stock.

4.2.2 Basal area

The relationship between mean basal area and carbon stock were estimated and presented in **Figure 3**. The figure indicates a linear equation as: Y= 5.574x – 4.170 (R^2 = 0.917), where R^2 value was positive. This figure also indicates that basal area of tree species are significantly correlated with carbon stock.

4.2.3 Stem density

The relationship between stem density and carbon stock were estimated and presented in **Figure 4**. The estimated relationships were: Y= 0.055x + 12.58 (R^2 = 0.258), where R^2 value was positive. This figure also indicates that stem density of tree species are less significantly correlated with carbon stock.

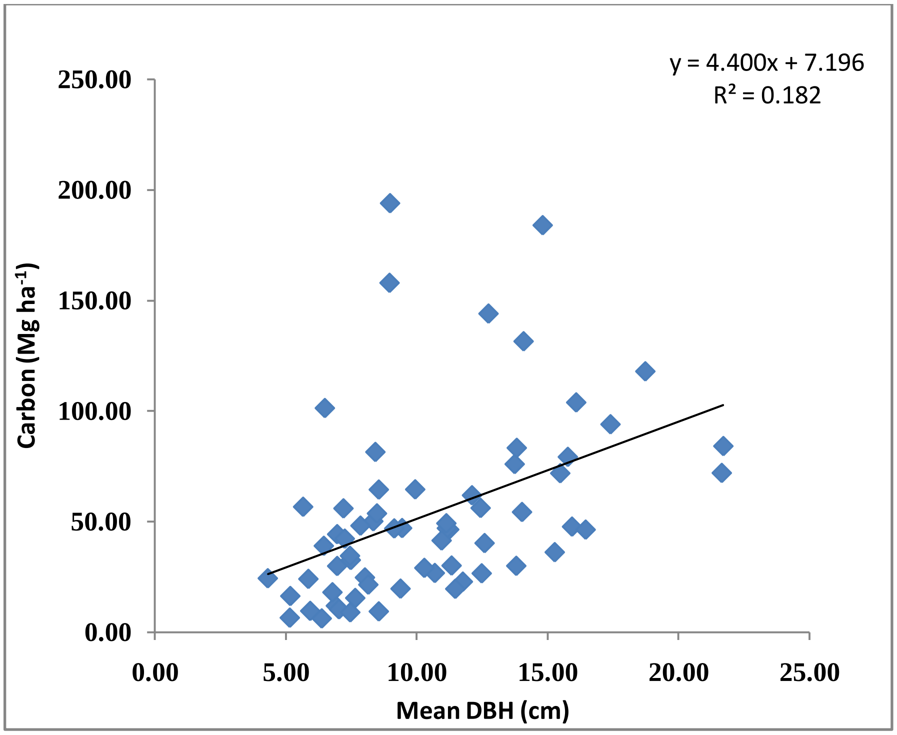

Figure 2. The relationship between mean DBH and total carbon stock (Mg ha^{-1}) per unit area

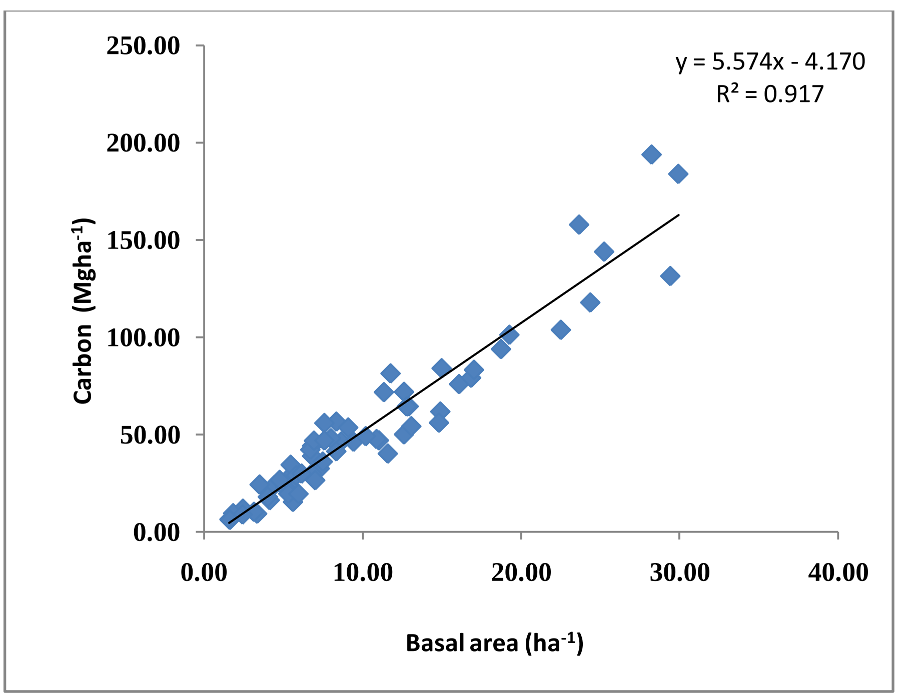

Figure 3. The relationship between Basal area and total carbon stock (Mg ha^{-1})

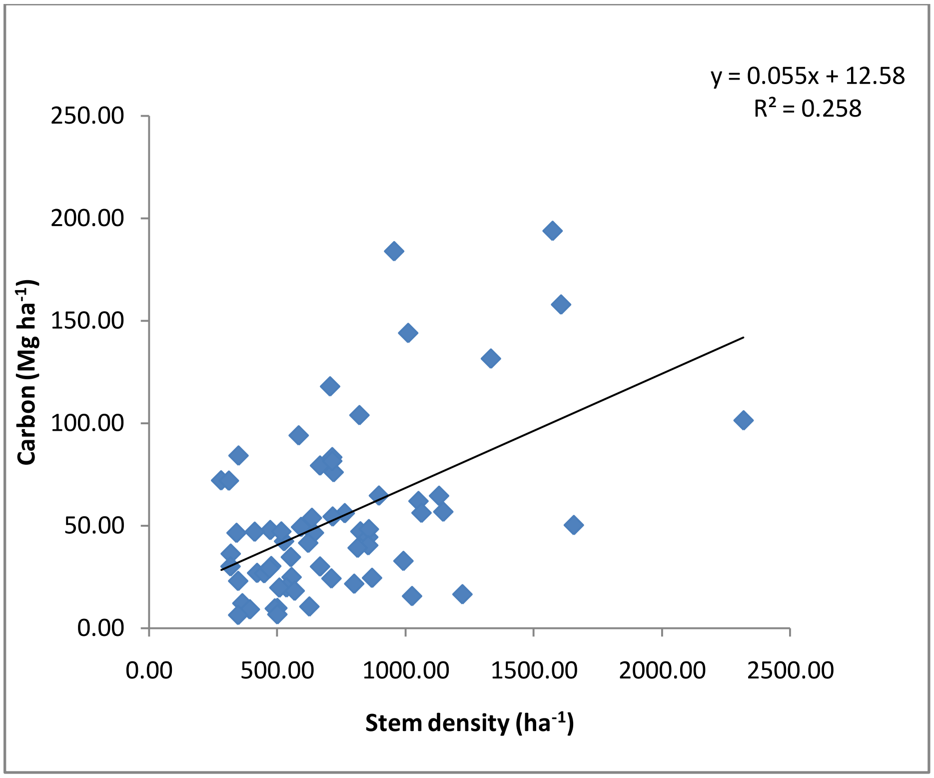

Figure 4.The relationship between stem density (ha $^{-1}$) and total carbon stock (Mg ha^{-1})

4.3 Vegetation characteristics

Vegetation characteristics like number of trees per hectare, basal area, mean DBH of 64 sampled homegarden with their standard error showed in **Table 2**. From this findings is estimated that average number of tree (40 nos. ha^{-1}) and basal area of (13.56 m^2 ha^{-1}) were higher in small homegarden rather than medium (33 nos. ha^{-1}, basal area of 9.28 m^2 ha^{-1}) and large (24 nos. ha^{-1}, basal area of 7.48 m^2 ha^{-1}) homegardens, respectively. But only differences is that the mean DBH of large homegardens (11.23 cm) is comparatively higher than small (10.30 cm) and medium (10.16 cm) homegardens because GBH of palm species like *Areca catechu* and *Cocos nucifera* were not measured except height.

4.4 Tree diversity

In total, 32 different plant species were found from 21 families in the selected households and total 1671 trees were measured (**Figure 5)**. The most common plant species was found betel nut which was 453 nos. (n=453) and 27.10 % of the total plant population followed by Mango (n =362, 21.66%), Jackfruit (n =178, 10.65%), Mahagani (n= 146, 8.73%), Gora neem (n=128, 7.66%) and Eucalypyus (n=98, 5.86%). Tree diversity described by the Shanon-Wiener diversity index (SWI) showed a variation between 1 and 2.2 with a mean value of (1.64±0.03) where small size homegardens had the highest mean diversity of trees (1.66±0.05) followed by medium (1.65±0.05) and large (1.60±0.06) homegardens, respectively (**Table 3)**. Mean number of tree species per hectare were 40, 33 and 24, respectively for small, medium and large homegardens.

Table 3. Average number of trees (ha), basal area (ha) and mean DBH (cm) of various homegardens in Rangpur district

Parameters	Homegardens		
	Small	Medium	Large
Mean Trees(ha)	40 (1.44)	33.37 (3.31)	24.28 (1.66)
Basal area (ha)	13.56 (1.7)	9.28 (1.4)	7.48 (0.74)
Mean DBH(cm)	10.30 (0.7)	10.16 (0.97)	11.23 (0.90)

*Parenthesis are the standard errors.

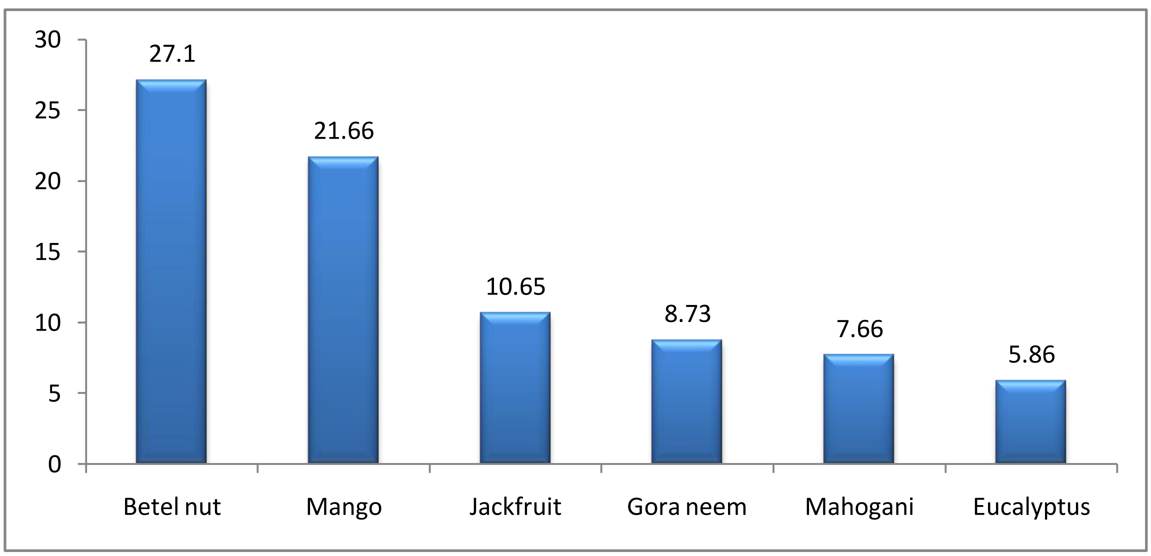

Figure 5. Occurrence of major tree species (%) of various homegardens in Rangpur district

Table 4. Tree diversity of various homegardens in Rangpur district

Homegarden size	Mean number of trees per hectare	Species recorded in homegardens		Shannon Wiener Index (SWI)	
		Total	Mean	Mean ± SE	Range
Small	40	29	19.34	1.66 ± 0.051	1.27 –2.20
Medium	33	25	22.16	1.65 ± 0.055	1.22 – 2.1
Large	24	26	21.38	1.60 ± 0.068	1.04 – 2.2

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4.4.1 Relationship between tree diversity and biomass carbon

The relationship between diversity of trees and carbon stocks in small, medium and large homegardens showed in **Figure 6**. The figure indicates a linear equation as: Y=0.001x + 1.546 (R^2 = 0.66), where R^2 value was positive and significant. This figure also indicate that small size homegarden had high tree diversity (H=1.66) contained higher amount of carbon (69.15 Mg ha^{-1}) per unit area compared to medium (H=1.65, 47.96 Mg ha^{-1}) and large (H=1.60, 39.93Mg ha^{-1}) homegardenand the values are gradually decreased in the order of small > medium > large homegarden.

4.4.2 Relationship between tree diversity and soil organic carbon

The relationship between tree diversity and soil organic carbon was shown in **Figure 7.** It is shown a linear equation as: Y= 0.001x+1.552 (R^2 = 0.54) where R^2 value is positive and significant. This figure also indicate that small homegarden had relatively high tree diversity (H=1.66) contain higher amount of SOC (63.62 Mg ha^{-1}) per unit area rather than medium (H=1.65, 42.80 Mg ha^{-1}) and large (H=1.60, 38.50 Mg ha^{-1}) and the values are gradually decreased in the order of small > medium > large homegarden.

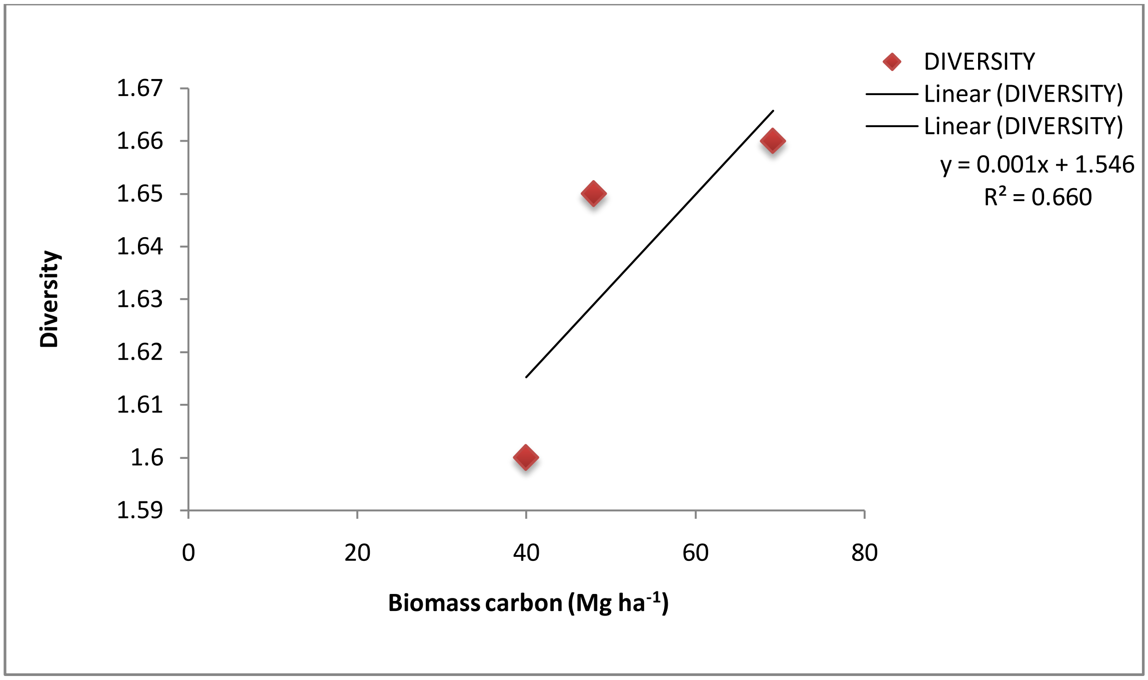

Figure 6. The relationship between diversity of trees and carbon stocks of various Homegardens in Rangpur district

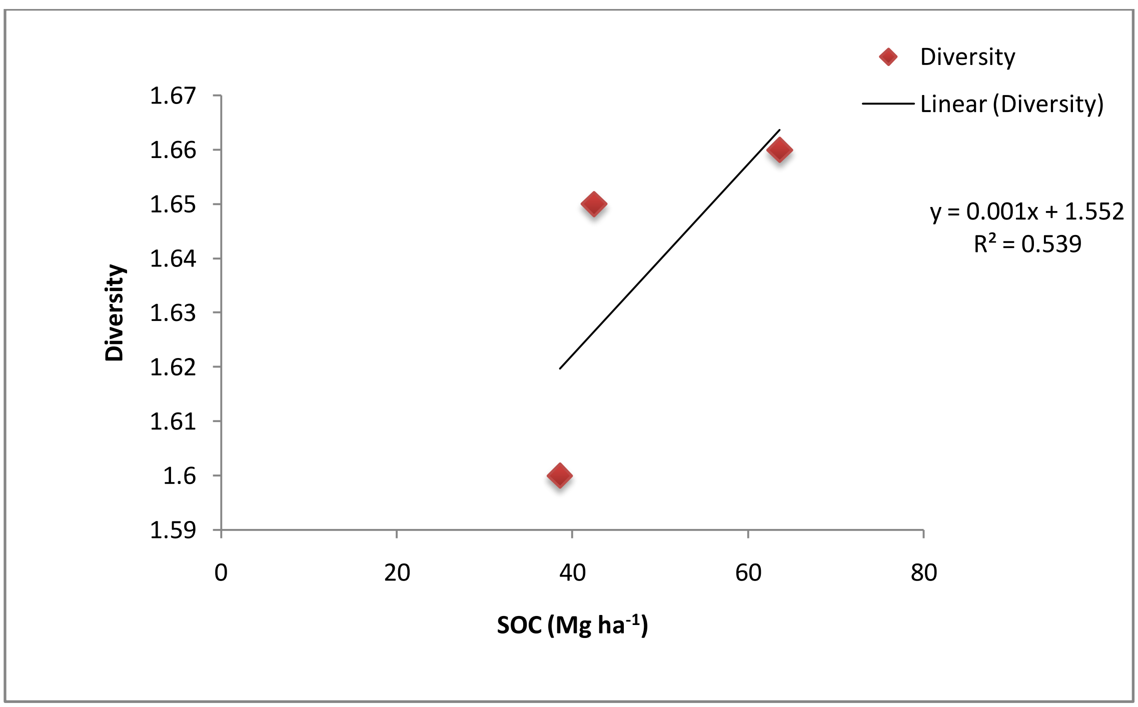

Figure 7. The relationship between diversity of trees and soil organic carbon (SOC) of various homegardens in Rangpur district

4.4.3 Tree density characteristics

The tree density varied from 280.61 to 2319.28 trees ha^{-1} in small, medium and large homegardens, respectively where small homegardens showed the highest level of tree density (1630 nos. ha^{-1}) followed by medium (878 nos. ha^{-1}) and large (358 nos. ha^{-1}) homegardens, respectively (**Table 4)**.

4.5 Major tree species and their contribution to carbon

Among 32 species from 21 different families, it is clearly mentioned that six major tree species like Betel nut, Mango, Jackfruit, Mahagani, Gora neem and Eucalyptus are the most common and dominant tree species found in the sampled homegarden of Rangpur district. Their carbon content also higher than other tree species. In this study betel nut was found the most dominant species (453 nos.) contain carbon (15.59 Mg) followed by Mango (362 nos., 26.7 Mg) Jackfruit (178 nos., 29.71 Mg), Mahagani (146 nos., 17.24 Mg), Gora neem (128 nos., 5.65 Mg) and Eucalyptus (98 nos., 6.4 Mg) at various homegardens (**Figure 8)**. In this study it is also observe that 6 species contained 78% carbon while other 28 species contained only 22% carbon.

Table 5. Tree density of various homegardens in Rangpur district

Homegarden categories (HG no.)	Lower tree density value (LTDV)Per hectare	Higher tree density value (HTDV)Per hectare	Total tree density (ha^{-1})	Mean ± SE
Small (24)	555.55	1333.33	1629.5	971.14 ± 64.02
Medium (21)	280.61	2319.28	877.5	706.94 ± 94.44
Large (19)	317.46	714.29	385.3	469.54 ± 28.25

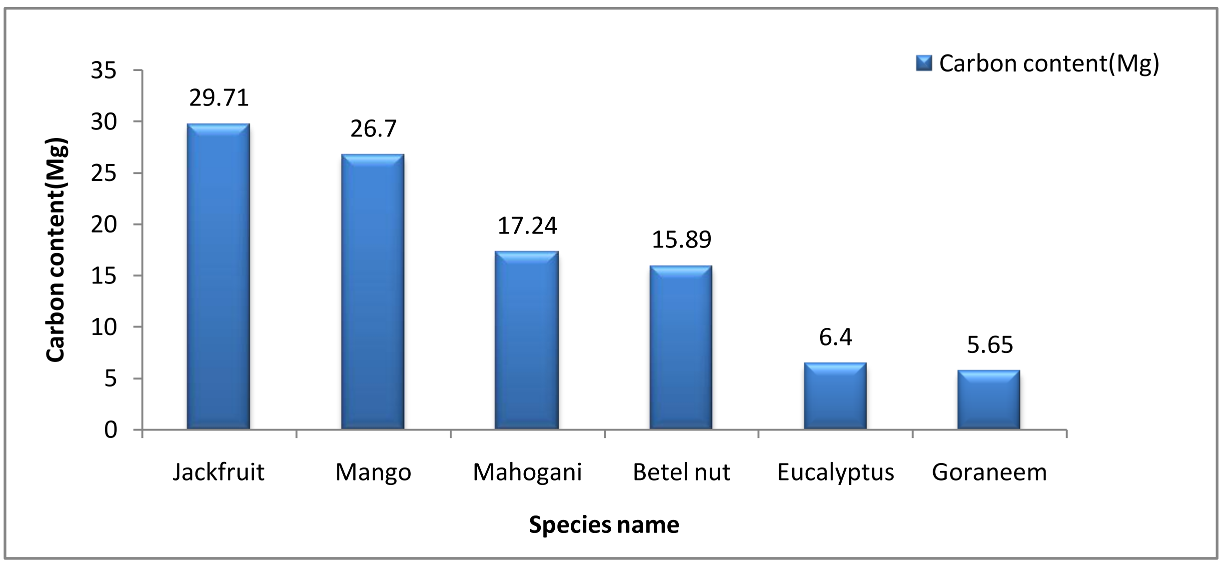

Figure 8. Major six tree species and their carbon content of various homegardens in Rangpur district

4.5.1 Dominancy of tree species and their uses

Homegardens of selected study area composed with multiple tree species. The species, their predominance in homegardens and primary uses are given in **Table 6**. Tree species in the homegardens are used for mainly fruit, fuel, and timber purposes. Non wood products and services such as vegetables, oil, medicines, resins etc. are provided by different tree species. Among 32 plant species major six species found in dominancy than others and the highest percent of occurrence was found *Areca catechu* (27.10%) followed by *Mangifera indica* (21.66%), *Artocarpus heterophyllus* (10.65%), *Swietenia mahogany* (8.73%), *Melia azedirach* (7.66%), and *Eucalyptus camaldulensis* (5.86%) respectively **(Table 7).**

Table 6. Tree species identified in the 64 homegardens in Rangpur district

S.l no	Botanical name	Local name	Family	primary uses	Total no	% of total
1	*Areca catechu*	Shupari	Arecaceae	fr, st, fl, md,	453	27.1
2	*Mangifera indica*	Aam	Anacardiaceae	fr, wd, fl,	362	22.6
3	*Artocarpus heterophyllus*	Kathal	Moraceae	Fr, tm, vg, md, dy	178	10.6
4	*Swietenia mahogani*	Mahagoni	Meliaceae	Tm	146	8.7
5	*Melia azedarach*	Gora neem	Meliaceae	Tm, md, rs, ol	128	7.6
6	*Eucalyptus camaldulensis*	Eucalyptus	Myrtaceae	tm, fl	98	6.1
7	*Citrus maxima*	Jambura	Rutaceae	Fr	44	2.6
8	*Syzygium cumuni*	Jam	Myrtaceae	Fr, wd, fl	32	1.9
9	*Cocos nucifera*	Narikel	Palmaceae	Su, md, fr,ol	29	1.73
10	*Neolamarckia cadamba*	Kadam	Rubiaceae	Wd, fr, fl	28	1.67
11	*Olea europaea*	Jolpai	Oliaceae	Fr, ol, fl	16	0.95
12	*Annona squamosa*	Ata	Annonaceae	Fr	16	0.95
13	*Samanea saman*	Randi koroi	Mimosaceae	Tm, fl	14	0.83
14	*Moringa oleifera*	Shojna	Moringaceae	Vg, fl	14	0.83
15	*Ziziphus jujuba*	Boroi	Rahmnaceae	Fr, fl	12	0.71
16	*Litchi sinensis*	Litchu	Sapindaceae	Fr, wd	12	0.71
17	*Dalbergia sissoo*	Sissoo	Papilionaceae	Tm, fr, fl	11	0.65
18	*Azadirachta indica*	Deshi neem	Meliaceae	Tm, md, rs, ol	9	0.53
19	*Leucaena leucocephala*	Ipil-ipil	Mimosaceae	Fl, fr, si	8	0.47
20	*Psidium guajava*	Peyara	Myrtaceae	Fr, fl	7	0.41
21	*Dillenia indica*	Chalta	Dilleniaceae	Fr, fl	7	0.41
22	*Phoenix sylvestris*	Khejur	Palmaceae	Fr, fl, md, fd	7	0.41
23	*Bombax ceiba*	Shimul	Malvaceae	Co, wd, fl	6	0.37
24	*Terminalia orjuna*	Arjun	Combretacea	ol, fr, md, wd	5	0.30
25	*Aegle marmelos*	Bel	Rutaceae	Fr, md,	5	0.30
26	*Punica granatum*	Dalim	Punucaceae	Fr,fl	5	0.30
27	*Erythrina indica*	Mander	Papilionaceae	Or, fl	4	0.23
28	*Artocarpus lakoocha*	Dewa	Moraceae	Fr, wd, fl	3	0.17
29	*Averrhoa carambola*	Kamranga	Averhoacea	Fr, fl	3	0.17
30	*Spondias pinnata*	Amra	Anacardiaceae	Fr, fl	2	0.11
31	*Annona reticulata*	Shorifa	Annonaceae	Fr	2	0.11
32	*Thespesia populnea*	Bot	Moraceae	Wd, fl, rs	1	0.05

Table 7. Percent of occurrence six major species present in study areas and their carbon contribution

Sl No.	Species Name	Scientific Name	% of occurrence
1	Jackfruit	*Artocarpus heterophyllus*	10.65
2	Mango	*Mangifera indica*	21.66
3	Mahogani	*Swietenia mahogani*	8.73
4	Betel nut	*Areca catechu*	27.10
5	Bead tree	*Melia azedarach*	7.66
6	Eucalyptus	*Eucalyptus camaldulensis*	5.86

4.6 Soil Organic Carbon (SOC)

Among the other land use system homegardens is one of the major source of soil organic carbon. In the study area SOC range varied from 2.95 to 70.19 Mg ha^{-1} with mean value range varied from 10.42 to 44.15 in small, medium and large homegarden respectively within 5-10 cm and 20-25 cm soil profile (**Table 8)**. Considering the total SOC (Mg ha^{-1}) medium and large homegarden has found 33% and 39% less SOC than small homegarden in the particular study area.

4.6.1 Soil organic carbon and homegarden size

Size of the homegarden is one of the major factor affecting soil organic carbon per unit area and it is decrease in the order of small > medium > large (**Figure 9).**

Table 8. Soil organic carbon at various homegardens in Rangpur district

Homegardns (HG no.)	Depth (cm)	Range SOC (Mg ha^{-1})		Mean ± CI
		Highest	Lowest	
Small (24)	5-10	70.19	11.26	44.15 ± 5.22
	20-25	35.92	10.10	19.46 ± 2.94
Medium (21)	5-10	60.83	12.90	32.37 ± 6.26
	20-25	20.12	2.95	10.42 ± 2.96
Large (19)	5-10	60.38	8.90	26.28 ± 7.02
	20-25	32.01	3.32	12.29 ± 2.96

* CI = 95% confidence interval

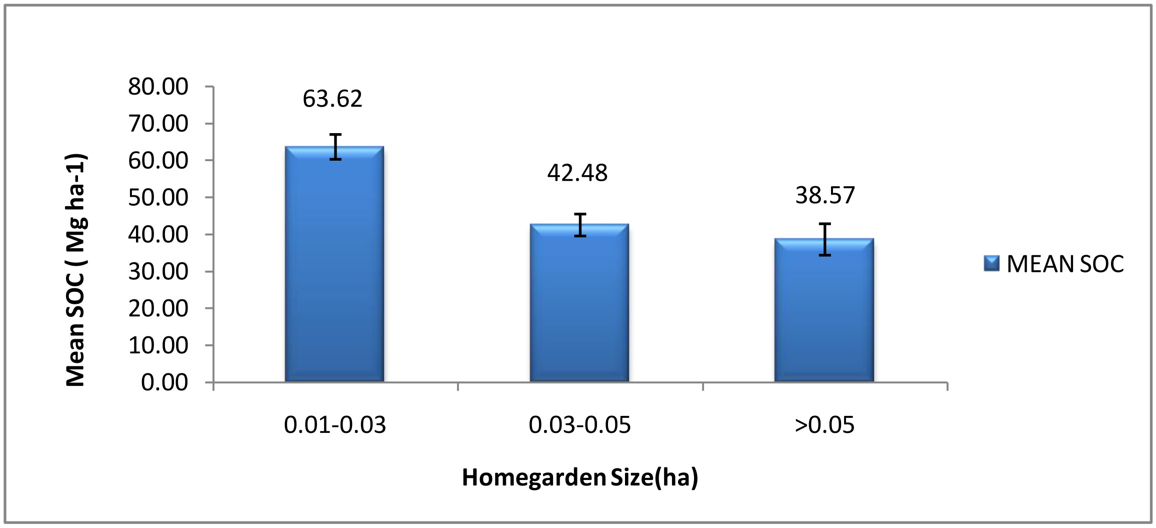

Figure 9. Soil organic carbon (SOC) and homegardens size at various homegardens in Rangpur district. Error bar shows the standard error

4.6.2 Soil organic carbon in relation to tree density

The relationship between tree density and soil organic carbon stocks in small, medium and large homegardens showed in (**Figure 10)**. The figure indicate a linear equation as: Y=44.95x - 1203 (R^2 = 0.934), where R^2 value was positive and highly significant. This figure also indicate that small size homegarden had high tree density (1630 nos. ha^{-1}) contained higher amount of SOC (63.62 Mg ha^{-1}) per unit area compared to medium (878 nos. ha^{-1}, 42.48 Mg ha^{-1}) and large (385 nos. ha^{-1}, 38.57 Mg ha^{-1}) size homegardens. The values are gradually decreased in the order of small > medium > large homegarden.

4.6.3 Soil organic carbon in different soil profile

Soil samples were collected in two different soil profile i.e. 5-10 cm and 20-25 cm. Soil organic carbon (SOC) has found always higher within 5-10 cm than 20-25 cm soil depth in the three different categories of homegardens (**Figure 11).**

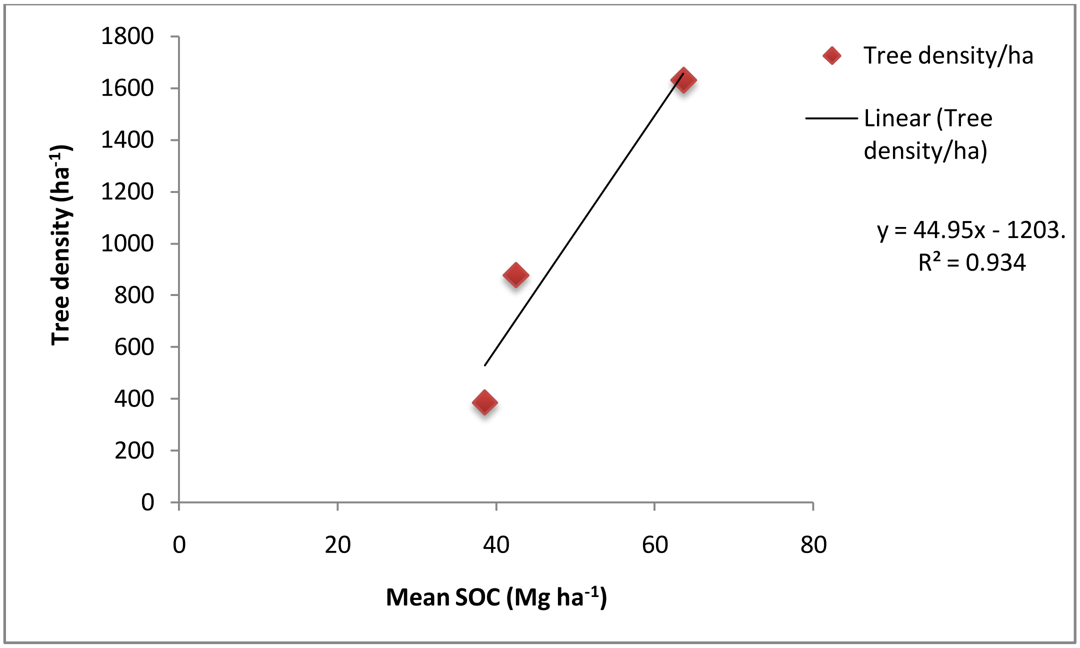

Figure 10. The relationship between tree density (ha^{-1}) and soil organic carbon (SOC) (Mg ha^{-1}) at various homegardens in Rangpur district

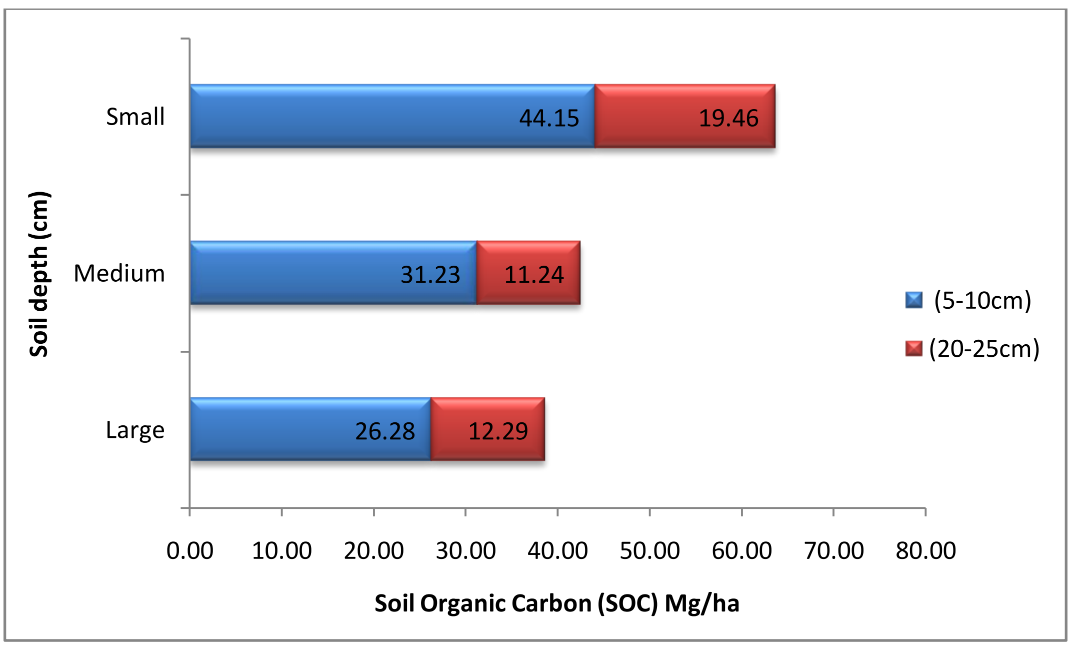

Figure 11. Soil organic carbon (SOC) (Mg ha^{-1}) at various homegardens in Rangpur district

CHAPTER IV
DISCUSSION

Controlling the present level of atmospheric carbon dioxide through reducing deforestation, increasing afforestation or reforestation, and preventing biodiversity loss is a significant concern among scientists and policy makers (Kanowski *et al*., 2011; Pandey *et al*., 2014). The importance of engaging in meaningful action to combat deforestation is recognized in the United Nations Framework Convention on Climate Change (UNFCCC) and parties are discussing policies and approaches to reduce CO_2 emissions from deforestation in a post-2012 international agreement on climate change. The UNFCCC recognizes various mitigation and adaptation options: firstly, the Clean Development Mechanism (CDM); secondly, Reduced Emissions from Deforestation and Forest Degradation (REDD); and most recently the new strategy—reducing emissions from deforestation and forest degradation, and enhancing forest carbon stocks in developing countries (REDD+). These are intended to engage multi-scale stakeholders in conservation and sustainable management of forest resources for enhancing carbon sequestration in developing countries with incentives as a reward for mitigating global climate change (Gardner *et al*., 2012). There are two integral parts of REDD+ used as an effective mechanism for reducing global climate change one is afforestration and second is reforestration (Bonan, 2008; Wang *et al*., 2011; Pandey *et al*., 2014). In this case an well-adapted agroforestry system of homegardens could have a potential for achieving multiple goals of climate change adaptation and mitigation as well as poverty reduction and sustainable development for a third world country like Bangladesh. So that the parties involved need accurate information on carbon stocks, biodiversity and the socioeconomic status of the communities in developing countries participating in the REDD+ financial mechanism (Pandey *et al*., 2014).

5.1 Above and Bellow ground carbon stock (AGB and BGB)

The findings of this study is that the average carbon stock (AGB + BGB) of standing homegarden trees (DBH > 2cm) was 53.53 Mg ha^{-1}; n=64 which ranging from 6.25 to 193.83 Mg ha^{-1} and it is expressed earlier that small homegarden had higher amount of carbon (69.15 Mg ha^{-1}) than medium (47.96 Mg ha^{-1}) and large (39.93 Mg ha^{-1}) homegardens respectively. The average carbon stocks presently reported are lower than that of Javanese homegarden (58.6 Mg ha^{-1}) as well as mature (>35-year old) agroforests (101 Mg ha^{-1}) and secondary forests of Sumatra (86 Mg ha^{-1}), Indonesia but higher than that of AGB (13 Mg ha^{-1}) ranged from 1 to 56 Mg ha^{-1}; (n=45) in the homegarden of Moneragala district, Sri Lanka (Mattsson *et al*., 2014) and Sumatran homegarden (35.3 Mg ha^{-1}) (Jensen, 1993 and Roshetko, 2002). Woodlots in Palakkad district, Kerala, India, also showed C stocks in the range of 7.8 to 163.2 Mg ha^{-1}, implying that profound species-related variations are possible in this respect (Kumar *et al*., 1998; Nair *et al*., 2009). The variability among the homegardens in this respect may be because of differences in garden composition, site characteristics, management practices, and holding sizes in different physiographic zones such as midlands, highlands of Rangpur district. Size of the homegardens was a major factor affecting carbon stock per unit area ($p<0.001$) and it is gradually decreased in the order of small > medium > large homegarden. This result is also similar that was reported by Saha *et al*., (2009) in the homegarden of Thrissur, Kerala, India. Another study was accomplished in central Kerala, India where the average standing carbon stocks of homegarden ranged from 16 to 36 Mg ha^{-1} (Kumar 2011). Dissanayake *et al*., (2009) estimated the AGB carbon stock in homegardens in Kandy 90 Mg C ha^{-1} and Matale districts 104 Mg C ha^{-1} Premakantha *et al*., (2014) reported that homegardens in Nuwara Eliya district of Sri Lanka contain 77 Mg C ha^{-1}, E. Rana (2011) reported that in Kathmandu, Nepal the community forest contain 240 Mg ha^{-1} and Michael Kessler *et al*., (2012) in Sulawesi, Indonesia in Cacao agroforest contain carbon stocks ranged from 82 to 211 Mg C ha^{-1} which is comparatively higher than the homegarden of Rangpur district of Bangladesh.

The resultant variation due environmental, geo-morphological factors and management practices of individual homegarden.

5.2 Tree diversity and density

Tree diversity maintenance and its conservation practices are the major issue of biodiversity conservation is now become a growing concern for all over the world specially the third world country like Bangladesh because it has a potential role of maintaining healthy environment, vigor of the biosphere, minimize the earth temperature rising and regulate a balance ecosystem functioning. For exploring the tree diversity, Shannon Wiener diversity index (SWI) was used. The mean value has found SWI: 1.64; n=64 ranged from 1.04 to 2.20 is lower than the SWI found by APN (2012) in the homegardens of the Keeriyagaswewa village (SWI: 2.13; n = 59) located in the Sri Lankan dry zone and in Siwalakulama village (SWI: 1.77; n = 30); intermediate zone Pethiyagoda village (SWI: 1.99; n = 59), wet zone and the homegarden of Chao Pharaya basin, Thailand ranged (1.9-2.7) (Gajaseni and Gajaseni,1999) but higher than that of Meegahakiula area SWI: 1.55–1.77; intermediate zone; Senanayake *et al.*, (2009) and Vihiga (0.74) and Siaya (0.86) district in western Kenya (M. Henry *et al.*, 2008). The estimated SWI is also higher than the mean SWI found in homegardens from two villages in West Bengal, India and six villages in Dhaka Division, Bangladesh (APN 2012), but lower (1.45-3.14) than in Thrissur, Kerala homegardens in India (Saha *et al*., 2009). Mean Shannon-Wiener diversity indices in tropical homegardens have been reported to vary broadly from 0.93 in rural Zambia (Drescher 1998) to almost 3.0 in West Java, Indonesia (Karyono, 1990). The Shannon Wiener diversity index (SWI) value of the present study is higher than that of fruit species diversity (0.99) found in coastal homestead Bangladesh (C. R. Sarker *et al*., 2014) and fruit (0.799) and timber (0.798) species diversity in haor homestead (M.A. Mannan *et al*., 2014). In the present study of Rangpur district small homegarden has found the highest tree diversity (1.66) followed by medium (1.65) and large (1.60) which are comparatively higher than that of found in small (0.64), medium (0.41) and large (0.46) homegarden in central kerala state, India (Kumar, 2011). In a previous study covering 252 homegardens throughout the state of Kerala, (Kumar *et al*., 1994) also reported similar diversity values (0.606, 0.441, and 0.459 respectively, for small, medium, and large holdings) which are also lower than that of present study value. This study found a little standard deviation (0.26) that indicates the mean value of tree diversity is an equal representation of all homegarden. This study also only considers trees, and the overall SWI would have been higher if all plants were included. In this study regression analysis has found a positive relationship between tree diversity with above and bellow ground carbon stock and tree diversity with homegarden size which are similar with the result of (Kumar, 2011) and (Pushpakumara *et al*., 2012) but only different is that they found slightly negative relationship between tree diversity and above ground carbon stock.

Tree density is an important factor to store carbon as it directly relates to the carbon sequestration (Roshetko *et al*., 2007).Tree density of the study area varied from 385.3 to 1629.5 per hectare (11-77 trees per homegarden). Regression analysis showed a positive but moderately significant relationship between tree density and biomass carbon stock where R^2=0.508 (fig 4.) but strongly significant relationship between tree density and soil organic carbon stock (SOC) where R^2=0.904 (fig 10). In one study conducted in Borneo, Southern Asia shown very weak relationship between tree density and aboveground carbon stock where the value of R^2 was 0.049 (Silk, 2010). Another study that was carried out in an old aged forest of Costarica and Central America found tree density 462 to 504 per hectare where above ground carbon stock (AGB) was 139 to 138 Mg ha^{-1} respectively (Clark, 2000) that are comparatively lower than the present study result. Considering the relationship between tree density and biomass carbon stock it is indicated that tree density is not a strong determinant factor of aboveground carbon stock. Above ground carbon stock correlated with basal area.

5.3 Soil Organic Carbon (SOC)

Homegarden are comprised of trees, shrubs, and herbs and these plant classes have different belowground growth patterns. The majority of root growth and activity of shrubs and herbs are expected to be restricted within the upper soil (Waisel *et al.*, 1991). In general, the SOC stock decreased with soil depth across all treatments of the present study area and increased with the increase in plant species density. Due to accumulation of higher quantity of litters and other organic materials on the surface and their rapid decomposition, homegarden act as a vital source of storing organic carbon in the soil. The SOC stocks in homegarden in relation to both tree species density and richness were also higher in the upper, than in the lower, soil layer. In the selected study area average soil organic carbon in two different layer (5-10 and 20-25 cm) was found 49.24 Mg ha^{-1} with the range from 2.95 to 70.19 Mg ha^{-1} is lower than the homegarden of Kerala, India ranged 101.5 to 127.4 Mg ha^{-1} (Saha *et al.*, 2009) in four different soil layer, coastal land area of Ireland (383 Mg ha^{-1}) in (0-10 cm) soil depth (X. Xu *et al.*, 2011) but higher than the homegarden of Golestan province, Iran (0.49 to 16.64 Mg ha^{-1}) (M. Zeraatpishe and F. Khormali 2012) and Brazilian savanna soils (22.98 Mg ha^{-1}) (Juliana Hiromi Sato *et al.*, 2014). On the other hand soil organic carbon content within 1 m soil depth under moist deciduous forests in the district of Kerala were 176.6 Mg ha^{-1} (Saha, 2008) that is much higher than the present homegarden SOC because forests characterized by high rates of litterfall, very low soil disturbance and high plant species diversity. A positive relationship was found between tree density and SOC as well as between homegarden size and SOC with significant R value.

5.5 Species composition

The most important attribute of homegarden is species composition. Species composition is closely related to tree density of individual homegarden. This study found 32 different tree species within 21 different families. The number of tree species in this study area was slightly smaller than those found in homestead of Sandwip upazilla (76 spp.) of Chittagong (Mohhammed and

Kazi, 2005), coastal area homestead of Potuakhali (57 spp.) (C. R. Sarker *et al*., 2014), Tangail (52 spp.) and Ishurdi (34 spp.) but higher than that of Bhola (31 spp.), Borguna (30 spp.) (Miah *et al*., 2013), Patuakhali (20 spp), Rajshahi (28 spp.), and the other part of Rangpur district (21spp) respectively (Abedin and Quddus, 1990). Millat-e-Mustafa identified 92 perinnial plant species in one study conducted in different part of the country (Millat-e-Mustafa, 1997). This study was conducted considering whole homegarden area in one plot so uniform counting of tree species was possible but little variation also occurred from one homegarden to another because homestead need and choice of the family influenced the distribution of tree species. This study also explored that *Areca catechu* (27.10%), *Mangifera indica* (21.66%) and *Artocarpus heterophyllus* (10.65%) are the most important and common fruit species followed by the timber yielding species *Swietenia mahogany* (8.73%) and *Melia azedirach* (7.66%) that are also found in Sylhet Sadar (Rahman *et al*., 2005), Patuakhali (C. R. Sarker *et al*., 2014), Azmirigonj upazilla of Habigonj district (33.33% fruit and 28.57% timber) (M.A. Mannan *et al*., 2014) and Char Gobadia of Mymenshing district (10 fruits and 6 timber) (A. Zico *et al*., 2011). The homegarden owner are specially concentrate on fruit and rapidly growing timber species because of their subsistence and cash need.

CHAPTER VI

SUMMERY, CONCLUSION AND RECOMMENDATION

SUMMERY

Many tropical plant species are threatened day by day due to reduction, fragmentation and degradation of forest land area. Revival of traditional land use systems such as tropical and subtropical homegardens has the highest potentiality to maintain improved socio-economic condition, agrobiodiversity conservation and climate change mitigation. Homegardens of four different villages in Sadar and Badargonj upazilla of Rangpur district hold a good range of carbon and it is 6 to 193.83 Mg ha^{-1} with mean value of 53.53 Mg ha^{-1}. Structural characteristics of homegardens such as size of the garden is one of the major determinant of carbon sequestration potential, species richness, tree diversity and these parameter values are decreased in the order of small > medium > large homegardens. The present study revealed that tree diversity is one of the most important structural attribute of homegardens which may be a consequence of the interplay of several socioeconomic and biophysical processes. Overall, this study showed that tree diversity value of homegardens is quite substantial (H=1.64) with the range of 1.04 to 2.20. On the other hand tree density value range from 385.3 to 1625.9 (nos. ha^{-1}). The result also explored that higher the species composition and species diversity ensure greater amount of soil organic carbon in the individual homegarden. Soil organic carbon (SOC) found in this study was quite satisfactory and the value of SOC range from 2.95 to 70.19 Mg ha^{-1} with mean value of 49.24 Mg ha^{-1}. Furthermore, regression analysis (R^2) between tree diversity and biomass carbon, tree diversity and SOC and finally tree density and SOC showed positive and significant result where strongly significant relationship is found between tree density and SOC.

CONCLUSION

The present studied homegardens of Rangpur district represent a wide range of biomass carbon, tree species diversity, species composition and soil organic carbon. There were differences between small, medium and large homegardens in terms of their plant-stand characteristics such as trees and tree-species density, and overall tree species diversity. However, the following conclusion can be drawn based on the present study:

1. Homegardens with higher number of species retained more carbon both in tree biomass and in the soil compared to those with lower number.
2. Tree density, tree diversity and species composition were found higher in small homegardens.
3. Plant species influence on SOC was prominent at the top 10 cm of soil and It was decreased with increasing soil depth.

The carbon estimates found here are reflecting the differences in tree density, tree diversity and management practices between individual homegardens. Smaller homegardens hold a higher carbon content and tree diversity than medium and large homegardens. The finding of present study revealed that homegardens should be established in a small area with diverse tree species so that it sequester substantial amount of carbon and contribute to the global climate change.

RECOMMENDATION

Homegarden is a well adapted agroforestry system and it has a potential role for achieving multiple goals of climate change mitigation and adaptation as well as poverty alleviation. Moreover, homegarden have a good capacity for carbon storage and carbon sequestration potential which provide useful information for the national process of whether homegarden could be consider to be included as an activity within commenced national programme on REDD+. Another option which is very crucial for rapidly rising populated and developing country like Bangladesh that, homegardens should be established by intensification or extensification on marginal and degraded lands that serve as important buffer zone for the remaining natural forests in areas that are experiencing pressure from increasing populations. As the tree rich homegardens have a potentiality to enhanced carbon sequestration and green house gas mitigation, it could be useful for the emerging scientific interest on understanding the relationship between tree diversity, tree density and tree biomass carbon. More elaborate studies are needed including larger number of homegardens and all categories of plant species with varying soil, environment and different agroclimatic conditions to explore these relationship. Furthermore, different patterns of plant species compositions should be compared for their carbon sequestration characteristics to develop carbon sequestration friendly species composition models for different situations.

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APPENDICES

Appendix I: Above and bellow ground biomass carbon stock in 64 individual homegarden of Rangpur district.

H.G no.	H.G Categories	AGC (Mg ha^{-1})	BGC (Mg ha^{-1})	Total C (Mg ha^{-1})	Average C (Mg ha^{-1})	Standard deviation	Standard error
1	Small	65.09	10.88	75.98	69.15	52.19	10.64
2	Small	39.55	7.51	47.07			
3	Small	20.61	4.12	24.75			
4	Small	24.83	5.09	29.93			
5	Small	47.81	8.86	56.68			
6	Small	41.45	8.70	50.16			
7	Small	19.95	4.14	24.10			
8	Small	12.64	2.83	15.48			
9	Small	36.94	7.35	44.30			
10	Small	39.06	7.35	46.42			
11	Small	40.21	7.94	48.16			
12	Small	13.24	3.12	16.37			
13	Small	165.51	28.30	193.83			
14	Small	100.37	17.49	117.87			
15	Small	88.62	15.20	103.84			
16	Small	51.81	10.06	61.88			
17	Small	33.46	6.82	40.28			
18	Small	46.75	9.38	56.15			
19	Small	26.95	5.68	32.64			
20	Small	112.19	19.25	131.45			
21	Small	133.35	24.49	157.85			
22	Small	67.66	11.56	79.22			
23	Small	157.19	26.68	183.89			
24	Small	17.71	3.80	21.51			

H.G no.	H.G Categories	AGC (Mg ha^{-1})	BGC (Mg ha^{-1})	Total C (Mg ha^{-1})	Average C (Mg ha^{-1})	Standard deviation	Standad error
25	Medium	84.75	16.53	101.29	47.96	34.62	7.54
26	Medium	47.02	8.94	55.97			
27	Medium	40.39	7.32	47.72			
28	Medium	25.21	4.91	30.13			
29	Medium	19.38	3.48	22.87			
30	Medium	20.08	4.30	24.39			
31	Medium	9.94	2.02	11.97			
32	Medium	22.40	4.37	26.78			
33	Medium	29.00	5.53	34.54			
34	Medium	7.87	1.77	9.65			
35	Medium	61.92	10.05	71.98			
36	Medium	54.29	10.25	64.55			
37	Medium	80.24	13.71	93.96			
38	Medium	7.72	1.70	9.43			
39	Medium	32.68	6.35	39.05			
40	Medium	70.77	12.53	83.30			
41	Medium	54.27	10.18	64.46			
42	Medium	123.11	20.85	143.97			
43	Medium	45.79	8.52	54.32			
44	Medium	5.30	1.26	6.58			
45	Medium	8.42	1.95	10.38			

H.G no.	H.G Categories	AGC (Mg ha^{-1})	BGC (Mg ha^{-1})	Total C (Mg ha^{-1})	Average C (Mg ha^{-1})	Standard deviation	Standard error
46	Large	22.35	4.27	26.63	39.93	22.26	5.1
47	Large	35.77	6.50	42.28			
48	Large	39.90	6.99	46.90			
49	Large	16.34	3.35	19.70			
50	Large	7.39	1.61	9.01			
51	Large	39.91	7.10	47.02			
52	Large	24.49	4.59	29.08			
53	Large	45.83	7.84	53.68			
54	Large	15.04	3.02	18.07			
55	Large	16.26	3.35	19.62			
56	Large	5.08	1.16	6.25			
57	Large	69.43	12.01	81.45			
58	Large	39.53	6.82	46.36			
59	Large	41.47	7.75	49.23			
60	Large	72.44	11.66	84.11			
61	Large	62.01	9.83	71.85			
62	Large	34.78	6.67	41.46			
63	Large	30.74	5.43	36.17			
64	Large	25.31	4.69	30.01			

APENDIX II. Tree diversity characteristics in 64 individual homegarden of Rangpur district.

H.G no.	H.G Categories	Tree diversity value	Mean	Standard deviation	Standard error
1	Small	2.17	1.66	0.25	0.05
2	Small	1.61			
3	Small	1.92			
4	Small	1.31			
5	Small	1.48			
6	Small	1.66			
7	Small	1.62			
8	Small	1.13			
9	Small	1.56			
10	Small	2.02			
11	Small	1.67			
12	Small	1.43			
13	Small	1.70			
14	Small	1.66			
15	Small	1.97			
16	Small	1.69			
17	Small	1.60			
18	Small	1.47			
19	Small	1.69			
20	Small	1.27			
21	Small	1.93			
22	Small	1.76			
23	Small	1.58			
24	Small	2.01			

H.G no.	H.G Categories	Tree diversity value	Mean	Standard deviation	Standard error
25	Medium	1.46	1.65	0.26	0.05
26	Medium	1.66			
27	Medium	2.06			
28	Medium	1.99			
29	Medium	1.33			
30	Medium	1.49			
31	Medium	1.78			
32	Medium	1.72			
33	Medium	1.72			
34	Medium	1.78			
35	Medium	1.29			
36	Medium	1.31			
37	Medium	1.58			
38	Medium	1.89			
39	Medium	1.37			
40	Medium	1.94			
41	Medium	1.47			
42	Medium	1.75			
43	Medium	1.22			
44	Medium	1.79			
45	Medium	2.02			

H.G no.	H.G Categories	Tree diversity value	Mean	Standard deviation	Standard error
46	Large	1.04	1.60	0.29	0.06
47	Large	1.16			
48	Large	1.39			
49	Large	1.85			
50	Large	1.92			
51	Large	1.85			
52	Large	1.91			
53	Large	1.58			
54	Large	1.54			
55	Large	1.12			
56	Large	1.50			
57	Large	1.64			
58	Large	1.63			
59	Large	1.45			
60	Large	2.17			
61	Large	1.71			
62	Large	1.89			
63	Large	1.46			
64	Large	1.56			

APPENDIX III. Soil organic carbon stock (SOC) at two different depth classes of sixty four individual homegarden.

H.G no.	H.G Categories	SOC (Mg ha^{-1}) (5-10cm)	SOC (Mg ha^{-1}) (20-25cm)	Total SOC (Mg ha^{-1})	Mean	Std. deviation	Standard error
	Small	45.23	15.94	61.17	63.62	16.47	3.36
2	Small	51.38	26.08	77.46			
3	Small	51.38	16.88	68.27			
4	Small	57.97	29.32	87.29			
5	Small	49.44	35.92	85.37			
6	Small	38.61	24.43	63.04			
7	Small	36.80	18.42	55.22			
8	Small	54.72	23.54	78.26			
9	Small	53.12	19.32	72.45			
10	Small	62.60	33.95	96.56			
11	Small	52.54	25.72	78.26			
12	Small	22.35	21.76	44.11			
13	Small	47.82	15.28	63.10			
14	Small	47.97	17.51	65.48			
15	Small	25.69	10.72	36.41			
16	Small	39.53	10.85	50.39			
17	Small	39.13	16.18	55.31			
18	Small	43.47	15.70	59.17			
19	Small	42.74	11.66	54.40			
20	Small	70.19	16.96	87.16			
21	Small	11.26	24.81	36.07			
22	Small	38.76	14.79	53.56			
23	Small	42.16	10.10	52.26			
24	Small	34.79	11.25	46.04			

H.G no.	H.G Categories	SOC (Mg ha^{-1}) (5-10cm)	SOC (Mg ha^{-1}) (20-25cm)	Total SOC (Mg ha^{-1})	Mean	Standard deviation	Standard error
25	Medium	12.90	20.12	33.02	42.80	13.64	2.97
26	Medium	27.88	17.96	45.84			
27	Medium	17.36	9.93	27.29			
28	Medium	27.53	16.57	44.11			
29	Medium	42.16	4.40	46.56			
30	Medium	55.85	4.56	60.42			
31	Medium	8.66	18.60	27.27			
32	Medium	26.02	2.95	28.98			
33	Medium	42.25	3.62	45.87			
34	Medium	28.12	17.51	45.64			
35	Medium	45	6.95	51.95			
36	Medium	41.82	6.03	47.85			
37	Medium	40.72	17.86	58.58			
38	Medium	60.83	6.90	67.74			
39	Medium	20.83	19.29	40.13			
40	Medium	22.37	8.32	30.69			
41	Medium	15.16	4.15	19.32			
42	Medium	30.65	15.39	46.05			
43	Medium	34.89	16.34	51.24			
44	Medium	13.01	4.16	17.18			
45	Medium	41.84	14.41	56.26			

H.G no.	H.G Categories	SOC (Mg ha^{-1}) (5-10cm)	SOC (Mg ha^{-1}) (20-25cm)	Total SOC (Mg ha^{-1})	Mean	Standard deviation	Standard error
46	Large	35.41	15.61	51.02	38.57	18.56	4.25
47	Large	8.90	5.61	14.52			
48	Large	14.58	8.72	23.30			
49	Large	25.81	15.65	41.47			
50	Large	14.53	13.54	28.07			
51	Large	12.90	7.54	20.45			
52	Large	13.13	18.88	32.02			
53	Large	31.55	3.32	34.87			
54	Large	30.53	15.07	45.60			
55	Large	28.32	13.61	41.94			
56	Large	18.76	11.01	29.78			
57	Large	31.88	14.5	46.38			
58	Large	10.56	6.34	16.90			
59	Large	9.11	5.70	14.82			
60	Large	17.80	11.68	29.49			
61	Large	32.86	16.42	49.29			
62	Large	54.72	7.29	62.01			
63	Large	60.38	11.02	71.41			
64	Large	47.5	32.01	79.51			

APPENDIX IV. Stem density, Basal area and Mean DBH of sixty four individual homegarden in Rangpur.

H.G no.	H.G Categories	Stem density (trees ha^{-1})	Basal area (m^2 ha^{-1})	Mean DBH (cm)
1	Small	719.70	16.09	13.74
2	Small	824.18	11.03	9.44
3	Small	555.56	4.85	8.02
4	Small	666.67	5.59	6.96
5	Small	1147.54	8.34	5.66
6	Small	1656.80	12.61	8.34
7	Small	711.11	4.43	5.86
8	Small	1025.64	5.60	7.65
9	Small	854.70	6.81	6.96
10	Small	642.86	8.64	11.24
11	Small	857.14	8.00	7.85
12	Small	1222.22	4.13	5.17
13	Small	1574.07	28.25	8.98
14	Small	705.88	24.38	18.73
15	Small	820.31	22.52	16.09
16	Small	1050.72	14.91	12.11
17	Small	854.70	11.59	12.59
18	Small	1062.50	14.82	12.44
19	Small	992.06	7.29	7.48
20	Small	1333.33	29.43	14.08
21	Small	1607.14	23.67	8.96
22	Small	666.67	16.85	15.77
23	Small	955.88	29.94	14.81
24	Small	800.00	16.09	8.15

H.G no.	H.G Categories	Stem density (trees ha^{-1})	Basal area (m^2 ha^{-1})	Mean DBH (cm)
25	Medium	2319.28	19.27	6.49
26	Medium	763.16	7.59	7.20
27	Medium	472.22	10.88	15.93
28	Medium	476.19	6.80	11.33
29	Medium	347.22	5.11	11.76
30	Medium	869.57	3.50	4.31
31	Medium	363.64	2.44	6.91
32	Medium	421.05	4.76	10.69
33	Medium	552.88	5.46	7.45
34	Medium	500.00	1.83	5.93
35	Medium	280.61	12.62	21.65
36	Medium	896.36	12.91	9.94
37	Medium	583.33	18.74	17.40
38	Medium	490.20	3.34	8.55
39	Medium	813.40	6.81	6.45
40	Medium	714.29	17.03	13.82
41	Medium	1130.95	12.79	8.55
42	Medium	1010.53	25.25	12.74
43	Medium	715.79	13.08	14.02
44	Medium	500.00	1.60	5.15
45	Medium	625.00	3.14	7.03

H.G no.	H.G Categories	Stem density (trees ha^{-1})	Basal area (m^2 ha^{-1})	Mean DBH (cm)
46	Large	448.72	7.01	12.48
47	Large	526.32	6.70	7.25
48	Large	411.76	6.93	9.14
49	Large	535.71	5.31	9.38
50	Large	392.86	2.42	7.46
51	Large	515.63	7.59	11.15
52	Large	469.14	5.80	10.29
53	Large	634.92	9.09	8.48
54	Large	567.77	4.02	6.78
55	Large	507.94	5.95	11.47
56	Large	347.22	1.62	6.37
57	Large	714.29	11.77	8.42
58	Large	340.91	9.43	16.45
59	Large	592.59	10.20	11.13
60	Large	348.48	14.99	21.71
61	Large	310.93	11.35	15.48
62	Large	620.49	8.34	10.95
63	Large	318.18	7.48	15.27
64	Large	317.46	6.15	13.80